DISKO WEST

A strategic environmental impact assessment of hydrocarbon activities

Scientific Report from DCE – Danish Centre for Environment and Energy No. 71 2013

AARHUS UNIVERSITY
DCE – DANISH CENTRE FOR ENVIRONMENT AND ENERGY

DISKO WEST

A strategic environmental impact assessment of hydrocarbon activities

Scientific Report from Danish Centre for Environment and Energy No. 71 2013

Editors
David Boertmann
Anders Mosbech
Doris Schiedek
Michael Dünweber

Aarhus University, Department of Bioscience

AARHUS UNIVERSITY
DCE – DANISH CENTRE FOR ENVIRONMENT AND ENERGY

Data sheet

Series title and no.:	Scientific Report from DCE - Danish Centre for Environment and Energy, No. 71
Title:	Disko West
Subtitle:	A strategic environmental impact assessment of hydrocarbon activities
Institution:	Aarhus University, Department of Bioscience
Contributing authors:	P. Batty[2], D. Boertmann[1], E. W. Born[2], T. K. Boye[2], A. Bruhn[1], A. Burmeister[2], Daniel S. Clausen[1], P.B. Christensen[1], R. Dietz[1], M. Dünweber[1], J.L.S. Hansen[1], M.P. Heide-Jørgensen[2], M. Hjorth[1], K.L. Johansen[1], A.B. Josefson[1], O.A. Jørgensen[4], S. Kjellerup[1], K.L. Laidre[2], F. Merkel[2], A. Mosbech[1], P.M. Pedersen[5], L.M. Rasmussen[2], M.B. Rasmussen[1], A. Retzel[2], A. Rosing-Asvid[2], S. Rysgaard[2], D. Schiedek[1], M. Sejr[1], H. Siegstad[2], M. Simon[2], C. Sonne[1], K. Sünksen[2], F. Ugarte[2], S. Wegeberg[1] and Ø. Wiig[3].
Institutions:	[1]AarhusUniversity, depertment of Bioscience [2]Greenland Institute of Natural Resources [3]Natural History Museum, Oslo [4]DTU Aqua [5]University of Copenhagen
Publisher:	Aarhus University, DCE – Danish Centre for Environment and Energy©
URL:	http://dce.au.dk/en
Year of publication:	2013
Editing completed:	May 2013
Referees:	Frank Riget & Vibeke Vestergaard Nielsen
Greenland summary:	Bjørn Rosing
Financial support:	Bureau of Minerals and Petroleum, Greenland Government
Please cite as:	Boertmann, D., Mosbech, A., Schiedek, D. & Dünweber, M. (Eds.) 2013. Disko West. A strategic environmental impact assessment of hydrocarbon activities. Aarhus University, DCE – Danish Centre for Environment and Energy, 306 pp. Scientific Report from DCE – Danish Centre for Environment and Energy No. 71.
	Reproduction permitted provided the source is explicitly acknowledged
Abstract:	This report is a preliminary strategic environmental impact assessment of activities related to exploration, development and exploitation of oil in the waters of central West Greenland (67°-71° N), the Disko West area.
Keywords:	Strategic environmental impact assessment, SEIA, oil exploration, oil exploitation, oil spill, Baffin Bay, Davis Strait, Disko West, Greenland
Layout:	Tinna Christensen, AU Graphics Group, Silkeborg
ISBN:	978-87-7156-029-9
ISSN (electronic):	2245-0203
Number of pages:	306
Internet version:	The report is available in electronic format (pdf) at http://www.dmu.dk/Pub/SR71.pdf

Contents

Preface

In 2006 the Government of Greenland (Landsstyret) and the Danish Government initiated a decision process for a hydrocarbon licensing round covering an area offshore West Greenland between 67° and 71° N (= the Disko West Area, Figure 1). A preliminary strategic environmental impact assessment (SEIA) was carried out to be included into the decision process (Mosbech et al. 2007a). When preparing this SEIA, knowledge gaps were identified concerning biological background data. Therefore, supplementary studies were initiated to fill some of these information gaps, including projects on benthic fauna and flora, seabirds and marine mammals to be performed in 2009-2011. The results of these studies are included in this updated SEIA.

Summary and conclusions

This document is a Strategic Environmental Impact Assessment (SEIA) of activities related to exploration, development and exploitation of hydrocarbons offshore West Greenland between 67° and 71° N (= the Disko West area, Figure 1). The area was opened for licence applications in 2006 and seven licenses were granted by the Bureau of Minerals and Petroleum (BMP), in 2007 and 2008.

The SEIA has been carried out by DCE - Danish Centre for Environment and Energy- formerly known as National Environmental Research Institute (NERI) - 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 licence areas; although the oil could drift beyond the borders of this area. The area to the north of the assessment area is covered by another SEIA of hydrocarbon activities in the Baffin Bay (Boertmann & Mosbech 2011).

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.

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 three *Calanus*-species which represent 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 ecosystems. They consume a significant fraction of the available production and are in turn an important food source for fish, seabirds and mammals. The benthic community has been studied in the coastal areas and offshore. Areas with high abundance and biomass of benthic species, e.g. bivalves have been identified (e.g. Store Hellefiskebanke).

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 higher trophic levels of the food web. Studies concerning macroalgal diversity in the assessment area have been carried out, documenting the importance of this group in coastal waters.

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

Sandeel occur also in dense schools on the banks (e.g. Store Hellefiskebanke) and are important prey for some species of fish, seabirds and baleen whales.

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, seaducks assemble in certain fjords and bays to moult, and millions of seabirds migrate through the area on their passage between breeding sites in Northwest Greenland and Arctic Canada and winter grounds off Southwest Greenland and Newfoundland. Some of the most important species are northern fulmar, common eider, thick-billed murre and little auk. During their migration they depend on zooplankton and smaller fish, such as polar cod.

Thick-billed murre, common eider, black-legged kittiwake and ivory gull are all red-listed in Greenland due to declining, or in case of the common eider, previously declining populations. 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), e.g. the little auk.

Marine mammals are significant components of the ecosystem. Four species of seal, walrus, 14 species of whale, and polar bear occur in the assessment area. The assessment area is particularly important to 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 red-listed because their populations have been reduced by present or past hunting or are expected to decline because of climate change (especially polar bear).

Important areas and biological hotspots have so far been identified on Store Hellefiskebanke, particularly the shallow part with a high diversity of benthic animals, high densities of sandeels, very high concentrations of wintering king eiders, high numbers of wintering bearded seals and white whales and the most important winter site for walrus in West Greenland.

The Disko Bay area is another biological hotspot, very importnat for breeding seabirds (several significant breeding colonies), for wintering and migrating marine mammals (narwhal, bowhead whale) and for northern shrimp and Greenland halibut (extensive fisheries).

A third important area, at least during winter, is the winter habitat for narwhals in central Baffin Bay.

These three areas are designated by IUCN as 'Ecologically and culturally Biologically Significant Areas' and is by Greenland proposed to PAME as ‘Arctic marine areas of heightened ecological and cultural significance’ (Christensen et al. 2013).

The natural resources of the assessment area is utilised by the local human population, by subsistence and small-scale hunting (marine mammals and seabirds) and fishery in the coastal areas, and by a substantial commercial fishery in Disko Bay and on the banks.

Commercial fisheries represent the most important export industry in Greenland, and the main commercially exploited species within the assessment area are Greenland halibut, deep-sea shrimp and snow crab.

Tourism is a growing industry in Greenland and now counts as the third largest economic activity in the country. The number of guests staying in the Disko area, e.g. in Ilulissat is increasing a trend also seen in the numbers of tourists brought in by cruise ships. The coastal marine areas are an important asset for the tourist activities

For the assessment of the sensitivity and environmental impacts from petroleum activities, knowledge on background levels of contaminants such as hydrocarbons and heavy metals is important. Owing to long-range transport into the Arctic, the levels of certain contaminants, i.e. organochlorines, are high in Greenland, particular in the higher trophic level (e.g. whales, polar bears). In addition, new persistent pollutants, such as brominated flame retardants and perflouronated 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 relation 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. Changes in the distribution of species are to be expected, e.g. northward move of true Arctic species and more temperate species become more abundant, also in the assessment area. Alterations in the distribution and abundance of keystone species at various trophic levels could have significant and rapid consequences for the structure of the ecosystems 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.

Assessment

The assessment presented here is based on our present knowledge concerning 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, involving different license areas. They will take place during the ice free seasons, i.e. summer and autumn. Seismic and site surveys have in recent years been conducted as late as November. Exploration drillings have to be terminated in the Disko West area 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 economically feasible to exploit, activities will proceed for up to 50 years under a license.

During exploration activities, the main environmental impacts derive from 1) noise generated either by seismic surveys or the drilling platforms or 2) from cuttings and drilling mud if these are released to the sea during the drilling process.

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 seismic survey, time period depending on fish species.

The fishery at risk of impact from noise from seismic surveys in the assessment area is the Greenland halibut fishery. There is a risk of temporary (days or weeks) displacement of fish which may cause reduced catches in that period.

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

The species most sensitive to noise from seismic surveys in the assessment area are the baleen whales (minke, fin and humpback whales) and toothed whales such as sperm and bottlenose whales. These may be in risk of being displaced from parts of their critical summer habitats. A displacement would also impact the availability of whales to hunters if the habitats include traditionally hunting grounds. Narwhals, white whales, bowhead whales and walruses are also sensitive to seismic noise, but their occurrence in the assessment area only overlaps briefly with the time in which seismic surveys would take place.

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

Noise from drilling rigs will also be temporary but locally more permanent than seismic surveys. The most vulnerable species in the assessment area are the whales and the walrus. If alternative habitats are available to the whales no effects are expected, but if several rigs operate in the same region there is a risk of cumulative effects and displacement even from alternative habitats.

Release of drilling mud

During drilling operations, drilling mud (if water based) and cuttings will be released to the seabed, resulting in local impacts on the benthic fauna. Mitigating such impacts include release of chemicals with low or no harm to the environment, as defined by OSPAR (HOCNF) standards. However, the knowledge on degradation and toxicity of even the environmentally safe chemicals under Arctic conditions is very limited, why use and discharge should be thoroughly monitored and evaluated, including further testing of degradation and toxicity.

The use of oil based mud have untill now been prohibited, but may in the future be allowed under strict regulation in order to prevent any release to the environment.

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 gasses. The drilling of three wells in West Greenland in 2010 increased the Greenland contribution 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 durability. In this context cumulative impacts will be important to consider. The activities during development, production and transport are long-lasting, and there are several activities which have the potential to cause severe environmental impacts.

Emissions and discharges

The largest contribution to pollution from an oil field is expected to be the discharge of produced water (if not re-injected or transported to treatment facilities on land). Besides oil residues, produced water contains small amounts of acute toxic substances, radioactive substances, heavy metals, substances with hormone-disruptive capacity and plant nutrients. Some of these substances have the potential to bio-accumulate, but in general knowledge on long-term effects of release of produced water are limited.

There is concern regarding the environmental impacts of produced water, particularly if it is released under ice. In combination with limited turbulence in the surface layer, increased impacts could occur on ice communities or fish eggs, e.g. from polar cod which accumulate here. The most obvious way to mitigate effects of produced water is an effective cleaning before discharge or preferable re-inject it into the well.

Drilling activities also occur during most of the production period, why large amounts of muds and cuttings need to be disposed of. If released to the seabed more severe impacts on the bottom fauna are to be expected than during exploration because of the larger quantities released.

Development of an oil field and production of oil are energy-consuming activities which will contribute significantly to the Greenland emission of greenhouse gases. For example were the annual emissions from a single large Norwegian production field more than twice the current total Greenland CO_2 emission. Several other environmentally harmfull substances will be emitted to the atmosphere, including NO_x and VOC's.

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

Noise

Similar to exploration activities there will be a risk of displacement of marine mammals from critical habitats during development and production. However, in this case the effects are long term or even permanent. Walrus and whales, particularly narwhal, white whale and bowhead whale are sensitive in this respect and may be permanently scared away from specific habitats with consequences for the populations. This could also impact hunters if quarry species are scared away from traditional hunting grounds.

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

Placement of structures

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

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

A specific impact on fisheries is the exclusion/safety zones (typically 500 m) which will be established around both temporary and permanent offshore installations. These will hamper fishery for Greenland halibut and northern shrimp.

Another effect of exclusion zones is that they act as sanctuaries, and in combination with the artificial reefs created by the subsea structures (Kaiser & Pulsipher 2005), attract fish and even seals.

Illuminated structures and the flame from flaring may attract seabirds during the dark hours with the risk of mass mortality on especially eiders and perhaps little auks.

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

Cumulative impacts

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

Mitigation of environmental impacts

Careful planning concerning the placement of structures and establishment of transport corridors based on detailed background studies to localize sensitive ecosystem components will reduce inevitable impacts. Strict Health, Safety and Environment (HSE) procedures, application of the Precautionary Principle in combination with Best Environmental Practice (BEP), Best Available Technique (BAT) and international standards (OSPAR) will further contribute to reduce environmental impacts of both exploration and exploitation activities.

Accidents

The accident due to the activities described above with most severe environmental consequences is a large oil spill. Such oil spills may occur either during drilling (blowouts) or from accidents during storing or transportation of oil. Nowadays, large oil spills are rare events 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 Disko West, the probability of an accident is elevated.

Oil spill trajectory modelling carried out by DMI as a part of this SEIA showed that spills far from the coast (> 100 km) oil did not reach the coasts, while spills originating closer (< 48 km) had the potential to foul extensive stretches of the coast. This means that oil spills from activities in the three eastern blocks Puilasoq, Orsivik and Naternaq have a high probability of hitting sensitive coastlines throughout the assesment area.

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 and even species level (AMAP 2010) and the impacts may last for decades as documented in Prince William Sound in Alaska. The lack of adequate response methods in ice-covered waters and the remoteness and lack of infrastructure in larger parts of the assessment area will add to the severity of an oil spill.

Oil in ice

In general, oil slicks occurring in the coastal zone are more harmful and cause longer-lasting effects than oil spills staying in the open sea. This applies also to the assessment area. 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, e.g. 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 'Valued Ecosystem Components' (VECs) aggregate, such as primary production, zooplankton, polar cod, seabirds and marine mammals. Particular concern has been expressed about polar cod stocks. This fish spawns in late winter, and the eggs accumulate just below the ice where spilled oil will also accumulate.

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

Oil spills on sea surface

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

Subsea oil spills

If subsea plumes of dispersed oil are generated in the Disko West area, impacts in the water column are to be expected for example on primary production, zooplankton and fish/shrimp larvae.

Impacts in the coastal zone

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

Impacts on the seabed

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

Impacts on fish

Impacts from a surface spill on adult fish stocks in the open sea are not expected. But if an oil spill occurs in ice-covered waters there is a risk to polar cod populations. This is an ecological key species and significant impacts on polar cod stocks may be transferred up in the food web (to other fish, seabirds and marine mammals). Another exception is a subsea spill. This could impact both the fish directly or through the food. Greenland halibut will also be exposed in both ways because they move up in the pelagic waters to feed.

Impacts on seabirds

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

Impacts on marine mammals

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

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

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

Recent studies indicate that whales and seals are very sensitive to inhaling oil vapours, and particularly narwhals, white whales and bowhead whales could be vulnerable during an oil spill in winter when the availability of open waters is limited by the sea-ice. Walruses and other seals living in the ice may also be vulnerable in this respect. There is also a risk of indirect impacts on walrus and bearded seal populations through contamination of benthic fauna, especially at shallow (<10-15 m) feeding grounds where oil may reach the seafloor. For some animal populations oil spill mortality can to some extent be compensatory, while for others it will be largely additive to natural mortality. Some populations may recover quickly while others will recover very slowly to pre-spill conditions, depending on their life strategies. A general decline in a population may be enhanced by oil spill induced mortality. For species which are vulnerable to oil spills and are also harvested, oil spill impacts could be mitigated by managing the harvest wisely and sustainably.

Impacts on fisheries and hunting

An oil spill in the open sea will affect fisheries mainly by means of temporary closure in order to avoid contamination of catches. Closure time will depend on the duration of the oil spill, weather, etc. Even though the offshore fisheries for Greenland halibut within the assessment area is small (compared to other Greenland fisheries for this species), a closure zone probably will extend further south and cover a much larger area, including both Greenland and Canadian fishing grounds. In this combined fishing ground approx. 13,000 t are taken annually.

The northern shrimp fishery in the assessment area is on a national scale very important and economic consequences can be significant in case of closure.

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

Long term impacts

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

Mitigation

Oil spills shall be prevented and avoided. This is done primarily by high HSE levels, knowledge on the risks and by applying the Best Available Technique (BAT) and Best Environmental Practice (BEP) principles. If a spill occurs, efficient contingency plans shall be in place including access to adequate equipment and oil spill sensitivity maps where the most sensitive areas have been identified.

Information needs

Since the first edition of this SEIA a number of studies have been carried out to provide biological data which can be used in an operational context, i.e. for NEBAs, EIAs, sensitivity mapping and regulation of activities. These studies are listed in Section 12. However, many more biological topics have to be covered to provide adequate data for operational purposes, and a number of studies – both of local character, but also some which have a more general arctic outreach – are proposed in Section 12.

Sammenfatning

Indledning

Denne rapport er en strategisk miljøvurdering af aktiviteter forbundet med olieefterforskning og -udvinding i Disko Vest-området, som nærmere bestemt er farvandet ud for Vestgrønland mellem 67 og 71° N (Figur 1).

Der er tale om en revideret og opdateret version af en tidligere og tilsvarende strategisk miljøvurdering udgivet i 2007. Opdateringen er primært baseret på ny viden indsamlet gennem en række studier gennemført i årene 2009 til 2011 (se sektion 12), men for eksempel også på viden indsamlet, som en del af myndighedernes miljøkrav, af olieselskabernes observatører (MMSO) på de skibe, der har udført seismiske undersøgelser.

I 2007/8 blev der gennemført en udbudsrunde for et antal licensblokke i Disko Vest-området, og 7 blokke blev udliciteret, efterfulgt af yderligere én blok i 2011. Der har siden været udført seismiske undersøgelser i hele området, og i 2010 og 2011 gennemførte selskabet Capricorn Greenland Exploration (selskab under det skotske Cairn Energy) i alt 5 efterforskningboringer.

Miljøvurderingen er udarbejdet af DCE – Nationalt Center for Miljø og Energi og Grønlands Naturinstitut for Råstofstyrelsen i Grønland. Formålet med en strategisk miljøvurdering er dels at danne grundlag for politiske beslutninger, dels at gøre rede for det vidensgrundlag, som benyttes ved myndighedsbehandlingen og -reguleringen af olieselskabernes aktiviteter. Desuden skal den bidrage med opdateret viden til selskaberne, når de skal udarbejde miljøvurderinger af deres specifikke aktiviteter eller miljøafvejninger (*Net Environmental Benefit Analysis – NEBA)* når de skal afveje løsninger, der på forskellig vis påvirker miljøet.

Området som rapporten dækker kaldes generelt for vurderingsområdet (the assessment area eller Disko West assessment area), og med det er hele det vestgrønlandske havområde mod nord til 78° N nu (2012 og 2013) omfattet af opdaterede strategiske miljøvurderinger.

Rapporten beskriver det fysiske og biologiske miljø, inklusiv beskyttede områder, truede arter, niveauer af forurenende stoffer samt udnyttelse af de biologiske ressourcer. Baseret på denne beskrivelse af den nuværende situation, vurderes de potentielle miljømæssige konsekvenser af olieaktiviteter (herunder oliespild) i området. 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.

Aktiviteterne fra en komplet livscyklus for et oliefelt er kort beskrevet og så vidt muligt vurderet, med vægt på de aktiviteter og hændelser, som erfaringsmæssigt giver de væsentligste miljøpåvirkninger. Men da der ikke er erfaringer med udvinding af olie i Grønland, kan vurderinger af aktiviteter i denne forbindelse 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). Endvidere er der inddraget viden fra det i 2010 store undersøiske olieudslip i den Mexicanske Golf, omend erfaringerne herfra endnu er begrænsede.

På grund af vejrforholdene og udbredt is om vinteren og foråret forventes efterforskningsaktiviteterne at foregå i perioden maj til december. Hvis egentlig olieproduktion påbegyndes, forventes der aktiviteter året rundt.

Miljøet

Disko Vest-området er beliggende i den arktiske zone og har de for denne klimatiske zone karakteristiske biologiske træk. Dvs. forholdsvis lav biodiversitet (undtagen bunddyr), 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 det økologieks system. Dvs. at de økologiske systemer og sammenhænge er afhængige af disse arters forekomst. Endelig er det karakteristisk at mange organismer har høje 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 lokalt meget rigt i biologisk/økologisk forstand. Primærproduktionen om foråret er høj, der er rige dyresamfund på havbunden ligesom der er store og meget vigtige forekomster af både fugle og havpattedyr.

De fysiske forhold i vurderingsområdet er kort beskrevet med fokus på oceanografi og isforhold. Området er normalt mere eller mindre isdækket om vinteren og om foråret. Isfjelde forekommer talrigt, især i Disko Bugt.

Langs kysten syd for Disko Bugt er der områder, hvor der er isfrit også om vinteren (polynyer), på grund af stærk tidevandsstrøm, og disse polynyer er af særlig høj biologisk betydning og har høj følsomhed overfor olieaktiviteter.

Plankton

Den mest markante økologiske begivenhed i det marine miljø er forårsopblomstringen af planteplankton, som udgør primærproducenterne i fødekæden. Disse græsses af zooplankton, inklusiv de vigtige *Calanus*-vandlopper, som udgør nøglearter i det marine økosystem.

Plante- og dyreliv på havbunden

Bunddyrene konsumerer en betydelig del af den tilgængelige primærproduktion og udgør til gengæld vigtige fødeemner for fisk, havfugle og havpattedyr. Artsantallet er meget højt og tætheden af dyr på bunden kan også være meget høj, ligesom der er stor variation i sammensætningen af arter. Der mangler stadig viden om den rumlige og tidsmæssige variation i de forskellige bunddyrssamfund og fra områderne langt til havs.

Makroalgerne (tang) findes langs kystlinjen tilknyttet hård bund og de forekommer ud til ca. 50 m's dybde. Biomassen og produktionen af makroalger kan være betydelig, og de er på mange måder vigtige for de højere led i fødekæden. Tang er substrat for fastsiddende organismer og de store tangskove er vigtige områder for fiskeyngel, som her er beskyttet mod prædation, udtørring, strøm og bølgeslag, og endelig udnyttes tang også direkte som fødeemne. Der er stadig mange uafklarede spørgsmål om algerne i vurderingsområdet.

Både bunddyr og tang indgik i de undersøgelser, der ligger til grund for opdateringen af denne rapport. Box 2 fortæller om resultaterne af algestudierne og Box 3 om bunddyrsstudierne.

Fisk

Fiskefaunaen i offshore områderne, inklusiv fiskebankerne (de lavvandede områder – ud til 200 m's dybde - på kontinentalsoklen), er domineret af bundlevende arter, som hellefisk, helleflynder, rødfisk, havkat, grønlandshaj samt andre ikke-kommercielle arter. Den vigtigste fiskeart hellefisk, som lever på store dybder både på kontinentalskrænterne og i fjordene. Hellefisken gyder ikke i vurderingsområdet, men bestanden fornys ved at larver fra gydeområder længere mod syd i Davisstræde driver ind og slår sig ned. Tobis forekommer i tætte stimer på fiskebankerne og udgør et vigtigt fødemene for visse fisk, havfugle og bardehvaler (se Box 4 om studier af denne fiskeart). Tobisen er den eneste fisk der gyder om sommeren.

I det kystnære område gyder to vigtige arter om foråret: lodde og stenbider. Lodde er vigtig som fødeemne for større fisk, havfugle, havpattedyr. Fjeldørred findes også i de kystnære farvande, og vandrer op i elve for at gyde og overvintre.

Havfugle

I alt 16 arter af havfugle yngler i området (Tabel 5). De 15 yngler normalt i kolonier på stejlsider (fuglefjelde) eller på lave øer (fugleøer). Der er flere meget vigtige havfuglekolonier i området, heriblandt det store fuglefjeld ved Ritenbenk med rider og polarlomvier, øgruppen Grønne Ejland med landets største koloni af havterne, samt sjældne arter som thorshane og rosenmåge og endelig de små øer Rotten og Brændevinskær med lunder. Flere af de i kolonierne ynglende arter, er på den grønlandske rødliste over truede arter (Tabel 11).

Den sydlige del af vurderingsområdet er et vigtigt overvintringsområde for ederfugl, kongeederfugl og polarlomvie. Særlig er de lavvandede områder på Store Hellefiskebanke af meget stor betydning for kongederfuglen, idet op til en halv million fugle kan forekommer her samtidigt.

Både forår og efterår trækker meget store antal havfugle igennem vurderingsområdet mellem ynglekolonier i Nordvestgrønland og arktisk Canada og overvintringsområder i Sydvestgrønland og Newfoundland.

Der var flere fugleundersøgelser i blandt de studier, som har leveret ny viden til denne rapport: Box 1 fortæller om forekomsten af plankton, fisk og fugle på det åbne hav i september 2009. Box 5 fortæller om resultaterne af satellitsporing af kongeederfugle, Box 6 om tilsvarende studier af polarlomvierne fra fuglefjeldet ved Ritenbenk og Box 7 om havfuglenes fordeling på det åbne hav.

Havpattedyr

Havpattedyr er et vigtigt element i det marine økosystem. Fem arter af sæler forekommer i vurderingsområdet, hvoraf ring-, remme- og spættet sæl yngler og klapmyds og grønlandssæl er gæster fra yngleområder der ligger udenfor (Tabel 8). Hvalros har et meget vigtigt overvintringsområde på Store Hellefiskebanke, hvor bestanden er opgjort til mellem 2300 og 3000 dyr. Disse dyr tilbringer sommeren på den canadiske side af Davis Stræde.

Blandt hvalerne er der en gruppe som er vintergæster i vurderingsområdet – narhval, hvidhval og grønlandshval, mens et større antal arter optræder som sommergæster. Blandt disse er vågehval, finhval og pukkelhval de talrigeste. Isbjørn forekommer vinter og forår i forbindelse med havisen.

Flere af de i vurderingsområdet forekommende havpattedyr er medtaget på både den grønlandske og den internationale rødliste over truede atter (Tabel 11 og 13).

Blandt de baggrundsstudier, der blev gennemført i perioden 2009-2011 var der to som omhandlede havpattedyr. Begge var sporingsstudier udført med satellitsendere: Et om isbjørne (Box 8) og et om grønlandshval (Box 9).

Særligt vigtige biologiske områder

Særligt vigtige biologiske områder, ofte betegnet *hot-spots,* er lokaliserede til Store Hellefiskebanke, særligt de lavvandede dele (indenfor 50 m dybdekurven) og til Disko Bugt.

Store Hellefiskebanke er om vinteren særligt vigtig for hvalrosser, hvidhvaler, remmesæler og kongeederfugle. Bunddyrsfaunaen er meget rig med høje artsantal og tætte bestande af tobis.

Disko Bugt er vigtig for ynglende havfugle, idet her er mange store og/eller artsrige fuglefjelde og -øer. Om vinteren og foråret er Disko Bugt et meget vigtigt område for grønlandshvaler, og også narhvaler er i perioder talrige her. Endelig er der vigtige fiskerier efter hellefisk og rejer.

Den centrale del af Baffin Bugt (i nordøsthjørnet af det område rapporten her dækker) er endvidere et vigtigt område for overvintrende narhvaler.

Disse tre områder er af IUCN udpeget som EBSA'er ("økologisk betydningsfulde og sårbare marine områder”), og er overfor PAME (arbejdsgruppe under Arktisk Råd) foreslået af Grønland som sårbare marine områder til udpegning som "Arctic marine areas of heightened ecological and cultural significance" (Christensen et al. 2013). Områderne er ligeledes listet som ”højest prioriterede sårbare marine områder” af Kongeriget Danmarks Strategi for Arktis 2011-2020.

Erhverv

Fangst og fiskeri

Menneskelig udnyttelse af de naturlige resurser er udbredt i hele området. Fangst og fiskeri på fritids og mindre kommerciel basis er udbredt i det kystnære område, mens et betydeligt kommercielt fiskeri foregår udenskærs og i Disko Bugt. Det kommercielle fiskeri omfatter primært dybhavsreje og hellefisk.

I kystnære fravande fanges om foråret især lodde (til husholdningsbrug) og stenbider, hvis rogn indhandles. Fjeldørred er også en vigtig ressource i de kystnære farvande. Flere andre fiskearter som for eksempel havkat og helleflynder udnyttes i mindre skala, både på husholdningsniveau og kommercielt.

Fangsten i vurderingsområdet omfatter primært sæler, hvaler og havfugle, men også enkelte isbjørne tages i området.

Turisme

Turisme er en voksende industri i Grønland og udgør nu det tredjestørste erhverv på landsbasis. Erhvervet benytter især de kystnære områder og indenfor vurderingsområdet findes Grønlands vigtigste turistområde: Ilulissat med UNESCO-verdensarv-området Isfjorden. Området besøges både af turister der overnatter og opholder sig i Grønland og turister der stiger i land fra krydstogtskibe.

Klimaændringer

Klimaændringerne vil påvirke det marine økosystem markant, specielt i de arktiske egne. I vurderingsområdet må det derfor forventes, at der vil ske ændringer i økosystemet, som for eksempel i fordeling og tæthed af nøglearter og ændret sammensætning af arter, idet nogle vil forsvinde og andre kommer til.

Fangst og fiskeri vil højst sandsynligt blive påvirket. Klimaændringer vil virke som en ekstra stressfaktor for nogle havpattedyr og fugle, på linje med f.eks. jagt og vil medføre en højere følsomhed overfor for eksempel oliespild. Andre arter kan blive hyppigere og deres bestande mere robuste overfor oliespild.

Forurenende stoffer

Viden om baggrundsniveauer for forurenende stoffer, som for eksempel POP'er, PAH'er og tungmetaller, er væsentlig for at kunne vurdere sårbarheden og de miljømæssige konsekvenser af olieaktiviteter.

Visse forurenende stoffer har i Grønland høje niveauer, herunder POP'er, på grund af langtransport af stofferne fra industrialiserede områder. Niveauet er særlig højt i de øverste trofiske niveauer; hvaler og isbjørne. Desuden er nye forurenende stoffer – bromerede flammehæmmere og perflurerede forbindelser – blevet påvist i Arktis.

Med undtagelse af havneområder er niveauerne af olieforbindelser, inklusiv PAH'er, relativt lave i det marine miljø og svarer til de normale baggrundsværdier.

Den foreliggende viden om forekomsten af forurenende stoffer i marine organismer i Grønland, inklusiv vurderingsområdet, er ganske god, da dette emne har været i fokus i mange år i regi af Arktisk Råds arbejdsgruppe om forurening (AMAP). Der foreligger derimod meget lidt viden om sammenhængen mellem kontaminantbelastning og biologiske effekter, inklusiv sundhedseffekter og funktionsnedsættelser. Der mangler desuden viden om artsspecifik følsomhed.

Miljøvurdering af olieaktiviteter

Vurderingerne i denne rapport bygger på viden om arternes nuværende fordeling og deres reaktioner og adfærd overfor olierelaterede aktiviteter. Klimaændringer forventes imidlertid at ændre meget på miljøet i vurderingsområdet i de kommende årtier, og det er derfor ikke givet, at konklusionerne vil være gældende for fremtidige forhold. Desuden kan ny viden også ændre på konklusionerne.

Efterforskning

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

De væsentligste påvirkninger fra efterforskningsaktiviteter er forstyrrelser fra støjende aktiviteter (f.eks. seismiske undersøgelser, boring og helikopterflyvninger) og udledninger til det omgivne miljø.

Støj

Seismiske undersøgelser skaber høje lydniveauer i det marine miljø og har potentialet til at bortskræmme især fisk og havpattedyr. Effekterne er midlertidige og eventuelt bortskræmte dyr forventes at vende tilbage når aktiviteten er ophørt.

I vurderingsområdet er der derfor en risiko for at hellefisk vil blive skræmt bort fra vigtige fiskeområder, hvis de seismiske undersøgelser foregår her. Rejer er derimod ikke sårbare overfor seismiske undersøgelser.

De overfor seismiske undersøgelser mest sårbare havpattedyr er hvalerne. Om sommeren er det især de mere almindelige arter som vågehval, finhval og pukkelhval, der risikerer at blive fordrevet fra vigtige fødesøgningssteder. Vintergæsterne narhval, hvidhval, grønlandshval og hvalros er også sårbare over for støjpåvirkninger, men den periode de forekommer i vurderingsområdet overlapper kun kortvarigt med den periode der kan udføres seismiske undersøgelser i, hvorfor der ikke forventes væsentlige påvirkninger på disse arter.

Da seismiske undersøgelser er midlertidige, er risikoen for langtidspåvirkninger af et enkelt seismisk togt lav. Der er dog en risiko for kumulative (dvs. ophobede) påvirkninger, for eksempel hvis der udføres flere undersøgelser samtidig, eller hvis der foregår undersøgelser i det samme område over adskillelige sæsoner i træk. Særligt de meget intensive 3D-seismiske undersøgelser, der typisk foregår i begrænsede områder, forventes at give anledning til mere markante midlertidige påvirkninger.

Støj fra boreplatforme er også midlertidig, og er i modsætning til støjen fra seismiske undersøgelser kontinuert og kilden er stationær. Hvaler og hvalroser vil undgå sådanne støjkilder. Såfremt alternative habitater er tilgængelige for hvalerne, forventes der ikke nogen negativ effekt af aktiviteten, men hvis flere platforme opererer samtidig i et område, er der risiko for kumulative effekter og bortskræmning selv fra alternative habitater, hvilket i yderste konsekvens kunne medvirke til bestandsnedgang.

Udledninger

Hvis der benyttes vandbaseret boremudder vil spåner og mudderrester normalt blive udledt til havbunden. 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. (jvf. den norske inddeling af OSPAR-konventionens klassifikations af kemialier) de såkaldte 'grønne' og 'gule', mens 'sorte' ikke må benyttes og 'røde' kun hvis der give særlig tilladelse.

Der skal 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 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 stoffer til luften. De tre boringer i 2010 forøgede de grønlandske udledninger af drivhusgasser med 15%.

Ved efterforskningsboring vil der være risiko for oliespild (blow-out), som er omtalt nedenfor.

Udvikling og produktion

Det er vanskeligt at vurdere påvirkninger fra udvikling og udnyttelse af et oliefelt i vurderingsområdet, når hverken placering eller omfang er kendt. Generelt vil påvirkningerne vare længe (årtier) og mange af aktiviteterne har potentiale til svære miljøpåvirkninger. Men de vil 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
De udledninger fra produktion af olie som giver størst årsag til bekymring for miljøpåvirkninger, er de meget store mængder af produktionsvand (vand der pumpes op sammen med olien). Dette vand indeholder små mængder olie samt mange forskellige mere eller mindre miljøbelastende stoffer, som for eksempel akut giftige stoffer, tungmetaller, radioaktive stoffer, stoffer med hormonvirkning og stoffer med gødningsvirkning. Nogle af disse stoffer kan ophobes i fødekæderne (bioakkumuleres). I Norge har undersøgelser påvist akutte effekter på fisk, der lever tæt på udslipskilden, men fortynding gør denne påvirkning meget lokal. Den foreliggende viden om produktionsvands langtidspåvirkninger i miljøet er begrænset. Udledt under is, kan man forestille sig at særligt polartorsk kan påvirkes, fordi disses æg og larver samles lige under isen om foråret.

Boring vil fortsætte under udviklings- og produktionsfasen, og boremudder og spåner vil blive produceret i meget større mængder end i efterforskningsfasen. Udledninger (fra brug af vandbaseret mudder) bør minimeres mest muligt, ved at genbruge og tilbageføre materialerne og ved kun at udlede af miljøvenlige kemikalier (se i øvrigt ovenfor).

Udledninger af ballastvand medfører en risiko for at introducere ikke-hjemmehørende eller 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 skal nævnes, nemlig drivhusgasser. Et producerende oliefelt vil bidrage markant til Grønlands udledning af disse. Som sammenligning kan nævnes at et af de store norske oliefelter i dag udleder mere end dobbelt så meget CO_2 som Grønland samlet udleder hvert år.

Støj
Støj fra positionering af platforme og boring, som vil fortsætte i udviklings- og produktionsfasen, kan 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, vågehval, finhval, marsvin og hvalros. Traditionelle fangstområder kan også blive påvirket ved at fangstdyr skræmmes væk herfra.

Fodaftryk
Installationer til havs og etablering af infrastruktur kan lokalt påvirke dyresamfund på havbunden og der er en risiko for at ødelægge vigtige fourageringsområder for dyr, der dykker for at æde bunddyr. Det gælder primært de overvintrende hvalrosser og kongeederfugle på Store Hellefiskebanke. Installationer i 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.

Endelig vil oplyste installationer og gasflammer (flares) kunne tiltrække havfugle når det er mørkt, og der er under særlige vejrforhold en risiko for at store mængder af specielt ederfugle og måske søkonger kolliderer med installationerne.

Kumulative effekter

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

Forebyggelse

Miljøpåvirkninger fra aktiviteterne i forbindelse med både efterforskning, udvikling og produktion begrænses bedst ved detaljeret miljøviden, nøje regulering, strikse HSE (Health, Safety and Environmental) procedurer, nøje planlægning og implementering af *Best Available Technique (BAT), Best Environmental Practice (BEP),* forsigtighedsprincippet og internationale miljøstandarder (f.eks. *OSPAR (HOCNF)* og *MARPOL*).

Oliespild

Det miljømæssigt værste uheld, der kan ske ved de ovennævnte aktiviteter er et stort oliespild. Et oliespild kan ske under selve boringen (*blow-out*) eller ved uheld i forbindelse med opbevaring eller transport af olien. Store oliespild er sjældne i dag, fordi de tekniske løsninger og sikkerhedsforanstaltninger til stadighed forbedres. Risikoen er imidlertid altid til stede, og i et område som Disko Vest er den forhøjet på grund af havis og isbjerge.

Oliespilds bevægelser i Disko West-området er blevet modelleret af DMI (se afsnit 11.2 og Appendix 1). Dette arbejde viser at spild med oprindelse langt fra kysten (>100 km) ikke ville nå ind til de sårbare kyststrækninger, mens spild tættere på kysten (<48 km) ramte kysten over varierende længder.

Store oliespild kan potentielt påvirke alle niveauer af det marine økosystem, fra primær-producenter til topprædatorer. De kan udgøre en trussel på bestandsniveau, og påvirkningerne kan vare i adskillelige årtier, som det er dokumenteret for Prince William Sund i Alaska.

Virkningerne af et oliespild i Disko West-området kan blive mere alvorlige end i sydligere farvande, fordi metoderne til at opsamle/fjerne oliespild i arktiske farvande med is endnu er utilstrækkelige eller stadig er under udvikling, og fordi Disko West-området er afsides med ringe udviklet infrastruktur.

Det kystnære område i vurderingsområdet er særlig sårbart, fordi olien her kan påvirke områder med høj biodiversitet. Sårbarheden skyldes også at olien kan blive fanget i bugter og fjorde, hvor høje og giftige koncentrationer af olie kan opstå i vandsøjlen. Der vil være risiko for negativ påvirkning af gydende fisk som lodde og stenbider om foråret, af fjeldørred som samles foran elvene og af mange havfuglebestande – både om sommeren, i trækperioderne og særligt om vinteren, da de samles i tætte flokke i åbenvandsområder.

Langtidspåvirkninger kan forekomme i det kystnære område, hvis olien indlejres i sedimentet, mellem sten, i muslingebanker eller i klippesprækker. Fra sådanne aflejringer kan olien langsomt sive og forårsage en kronisk forurening, der kan vare ved i årtier. I Prince William Sund i Alaska har sådanne olieaflejringer haft negative langtidseffekter for de fugle der udnytter de forurenede kyster og nogle bestande er endnu påvirket. Det kystnære område er også meget vigtigt for de lokale fiskere og fangere, og i tilfælde af et oliespild, kan deres aktiviteter blive markant påvirket af forbudszoner og ændrede fordelingsmønstre blandt fangstdyrene. Turistindustrien vil også blive negativ påvirket af et oliespild i det kystnære område.

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

Primærproduktion og zooplankton

Det vurderes, at påvirkningerne på primærproduktion og zooplankton fra et overfladespild i det åbne hav vil være ubetydelige i vurderingsområdet på grund af den store udbredelse i tid og rum af disse elementer af økosystemet. Men der kan dog være en risiko for en negativ påvirkning (nedsat produktion) på primærproduktionen lokalt i forårsperioden.

Denne konklusion dækker formentlig ikke et undersøisk spild, som det fra *Macondo*-brønden i den Mexicanske Golf i 2010. Her opstod store undersøiske skyer af dispergeret olie på forskellig dybde, og sådanne må forventes at påvirke primærproduktionen, zooplankton og fiske/reje-larver stærkere end et overfladespild.

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. Men sådanne høje koncentrationsområder for fiskelarver og -æg er ikke påvist i vurderingsområdet, og det er ikke sandsynligt at fiske- og rejebestanden vil blive påvirket af oliespild på denne måde. Polartorsk gyder under havisen og æg og larver samles lige under isen, hvor et oliespild også kan samles. Om der findes høje koncentrationer af polartorskeyngel i vurderingsområdet vides ikke, men de vil i givet fald være meget sårbare.

Bundfauna

Bundlevende organismer som muslinger og krebsdyr er sårbare overfor oliespild, om end der ikke forventes nogen effekter på det åbne hav, med mindre olien synker til bunden. På lavt vand (<10-15 m) kan høje koncentrationer af olie dog nå havbunden og dræbe de bundlevende dyr. Det kan medføre påvirkninger på de bestande af hvalros, ederfugl og kongeederfugl, som udnytter disse bunddyr.

Voksne fisk

Der forventes ikke påvirkninger fra et overfladespild på voksne fisk i det åbne hav. Et stort undersøisk *blow-out* vil derimod kunne ramme pelagiske og bundlevende fisk langt til havs, enten direkte eller indirekte gennem fødekæden. Olie i isdækket farvand, vil også kunne ramme polartorsk, som opholder sig lige under isen. I de kystnære områder, hvor høje og toksiske koncentrationer af olie kan opbygges i beskyttede bugter og fjorde vil fiskebestande derimod kunne påvirkes, og her er lodde, stenbider og ørred særligt sårbare i vurderingsområdet.

Havfugle
Havfugle er meget sårbare overfor olie i det marine miljø, idet de normalt tilbringer megen tid på havoverfladen. Sårbarheden er knyttet til deres fjerdragt, som blot ved meget små mængder olie mister isolations- og opdriftsevne. Olieramte fugle dør som regel hurtigt af underafkøling, sult eller drukning. I vurderingsområdet er det kystnære område særligt sårbart, fordi der forekommer store koncentrationer af fugle det meste af året. Om sommeren er særligt de høje koncentrationer af ynglefugle ved fuglefjeldene og fugleøerne udsatte, og om vinteren er de store forekomster af ederfugle og kongeederfugle langs kysterne af den sydlige del af vurderingsområdet og på de lavvandede banker meget sårbare.

I trækperioderne efterår og forår skal store mængder af havfugle igennem vurderingsområdet, og disse vil også være sårbare over for oliespild, især hvis de raster i store flokke i området.

Havpattedyr
Isbjørne og sælunger er blandt de mest sårbare havpattedyr overfor den direkte kontakt med olie. Selv en begrænset eksponering kan være dødelig, idet olien dels reducerer pelsens isolationsevne, dels er giftig, hvilket særligt isbjørne er sårbare overfor, fordi de slikker pelsen ren.

Hvaler, sæler og hvalrosser kan påvirkes af oliespild på havoverfladen. Bardehvalerne kan få barderne indsmurt i olie og derved indtage olien med deres føde. Det kan påvirke filtreringsevnen eller føre til forgiftning og skader i maveregionen. De risikerer også at indånde oliedampe og at få olie i øjnene. I hvilken grad havpattedyr aktivt kan undgå at komme i kontakt med et oliespild og samtidig hvor skadelig olien er for de ramte individer, er dog usikkert, men hvaler er observeret svømmende direkte ind i oliespild på havoverfladen.

Oliespild i farvande med is udgør et særligt problem for de havpattedyr, som skal til overfladen for at ånde. I høje iskoncentrationer kan de blive nødt til at dykke ud i våger med olie og her indånde oliedampe. Efter oliespildet i Prince William Sund fandtes sæler med hjerneskader, som formentlig skyldtes indånding af oliedampe, og også spækhuggere menes at være gået tabt på grund af dette fænomen. I vurderingsområdet vil især vintergæsterne, narhval, hvidhval, grønlandhval, remmesæl og hvalros være sårbare i denne sammenhæng.

Erhverv
Et oliespild på det åbne hav vil primært påvirke fiskeri ved at det vil i en periode blive stoppet i de oliepåvirkede områder. Dette gøres for at forhindre fangst og markedsføring af forurenede fisk. I vurderingsområdet er fiskeri efter hellefisk og rejer meget vigtigt, og stop herfor vil give væsentlige økonomiske tab i regionen. Men også mindre vigtige fiskerier kan blive påvirket, for eksempel dem efter krabber og stenbider. I den Mexicanske Golf var fiskeriet i store områder lukket i op til et år efter *Macondo*-udslippet.

Fangst kan påvirkes dels ved at områder lukkes for fangst dels ved at de jagtede arters fordeling i området ændres.

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 af forsigtighedsprincippet.

Sker spildet, skal grundige beredskabsplaner (inklusiv kortlægning af kysternes sårbarhed overfor olie) være på plads ligesom effektivt teknisk udstyr skal være tilgængeligt.

I den sammenhæng er det væsentligt at påpege at foreliggende viden om oliespilds adfærd og skæbne i isdækkede farvande er begrænset, ligesom at den tilgængelige teknologi til bekæmpelse af olie i isdækket farvand endnu er utilstrækkelig, men at den er under stadig udvikling og forbedring.

Manglende viden og nye undersøgelser

På trods af de i 2009 til 2011 gennemførte undersøgelser (Boxe 1-8) er der stadig mangel på information om økologiske komponenter og processer i Disko Vest-området. En foreløbig identifikation af vidensbehov i forhold til en miljømæssig forvaltning og regulering af kommende olieaktiviteter i Davis Strædet er at finde i kapitel 12. For at forvalte kommende olieaktiviteter behøves der mere viden for at kunne a) vurdere, planlægge og regulere aktiviteterne, således at påvirkninger minimeres mest muligt; b) identificere de mest sårbare områder og herunder, at opdatere de eksisterende sensitivitetsatlas for oliespild; c) etablere *baseline*-viden til brug i studier før og efter et eventuelt stort oliespild og til brug for selskabernes miljøafvejninger (NEBA).

Kalaallisut naalisagaq

Aallaqqaat

Imartami Disko Vest-imi, Kitaani allorniusat sanimukartut 67° og 71° N (Figur 1), akornanniittumi uuliasiorluni uuliamillu qalluinermi ingerlatanut tunngatillugu nalunaarut una siumut isigaluni avatangiisinik nalilersuineruvoq.

Una tassaavoq siusinnerusukkut taamatut siumut sammisillugu avatangiisinik nalilersuinerup 2007-imi saqqummersinneqartup allanngortiterlugulu nutarternera. Nutarterneqarnerani pingaartumik paasisiniaanerit 2009-miit 2011-mut ingerlanneqartut nutaanik paasisaat tunngavigineqarput (takuuk sektion 12), aammali ilaatigut avatangiisinut tunngatillugu oqartussat avatangiisinut piumasaqaataat tunngavigalugit uuliasioqatigiiffiit umiarsuaanni sajuppillatitsisarluni misissuisunialaatsinaattuusut (MMSO) paasisaasigut ilisimalikkanik tunngaveqarlutik.

2007/8-mi Disko Vestili akuersissutaateqarfiit arlallit neqeroorutigineqarput, taamaattut arfineq marluk neqeroorutaapput taakkualu ataasiinnarmik 2011-mi ilaneqarput. Tamanna tamakkerlugu 2010-mi 2011-milu ingerlatsivimmit Capricorn Greenland Exploration (ingerlatsivik skottit pigisaata Cairn Energy-p ataaniittumit) sajuppillatitsisarluni misissuiffigineqarpoq tallimanillu misissuilluni qillerisoqarluni.

Avatangiisinik nalilersuineq DCE - Nationalt Center for Miljø og Energi-mit pinngortitaleriffimmillu Kalaallit Nunaanni Aatsitassarsiornermut Ikummatissarsiornermullu Pisortaqarfimmik sullissisumit suliarineqarpoq. Siumut sammisillugu avatangiisinik nalilersuinermi politikikkut aalajangernissami tunngavissaqalersitsinissaq aammalu ilisimasatigut tunngavissanik pisortat uuliasioqatigiiffiit ingerlataannut tunngasunik killilersuinermillu suliaqarneranni ilisimasanik atorneqarsinnaasunik pissarsiorfissanik pilersitsinissaq siunertarineqarpoq. Aammalumi ingerlatseqatigiiffiit ingerlataminnut aalajangersunut tunngatillugu avatangiisinik nalilersuinerminni imaluunniit (*Net Environmental Benefit Analysis* – NEBA) aaqqiissutissat assigiinngitsutigut avatangiisinut sunniutigisinnaasaannik nalilersuinerminni ilisimasanik nutaanik tunngavissaqartinniarlugit.

Imartaq nalunaarummi sammineqartoq nalinginnaasumik nalilersuiffimmik (*the assessment area* eller *Disko West assessment area*) taagorneqarpoq tassaallunilu Kitaani imartaq avannamut allorniusap sanimukartup 78° N-ip tungaanoortoq massakkut (2012-imi 2013-imilu) siumut isigaluni avatangiisinik naliliinerusimasunik nutarteriffigiuneqartoq.

Nalunaarummi tamaani uumasoqarnikkullu pissusit, sumiiffiit illersorneqartut, uumasunut nungutitaanissamik ulorianartorsiortinneqartut, mingutitsinerup annertussusia aammalu uumasut iluaqurtigineqartut ilanngullugit sammineqarput. Tamakkiununnga tunngatillugu ullumikkut pissutsit tunngavigalugit uuliasiornikkut ingerlatat (ilaatigut tamaani uuliaarluernerup) avatangiisinut sunniutigisinnaasaat nalilersorneqarput. Kiisalu ilisimasatigut siunissami avatangiisinik nalilersuinerit pisariaqartittarumaagaat, avatangiisit eqqarsaatigalugit nalilersuinerit, pisortat ingerlatanut tunngatillugu inatsisiliorneri il.il. takussutissiissutigineqarput.

Uuliasiorfiup aallatinneraniit matuneranut ingerlataasartut naatsumik nassuiarneqarput, avatangiisinut sunniutit pingaarnerit nassuiaanermi pingaarnerutillugit. Kaslaallit Nunaannili uuliamik qalluineq misilittagaqarfigineqanngimmat ingerlatamut taamaattumut atatillugu ingerlanneqartartunik nalilersuineq eqqorluinnarsinnaanngilaq, misilittakkalli allani maani pissutsinut eqqaanartuni ingerlanneqartunik tunngaveqarpoq. Pingaartumik Prince William Sundimi, Alaskamiittumi 1989-imi uuliaarluerujussuarnermut tunngatillugu allaatigisarpassuit, norgemiullu Barentshavemi (2003) uuliasiornermut atatillugu avatangiisinik nalilersuinerat aammalu Arktisk Rådip Arctic Oil and Gas Assessment (AMAP 2010) pissarsiorfigineqarput. Aammalu 2010-mi Mexicanske Golf-imi immap iluani uuliaarlerujussuarneq pissarsiffigineqarpoq, naak tassannga misilittakkat suli killeqaraluartut.

Silap pissusii ukiumilu sikuusarlunilu upernaakkut sikoqartarnera pissutigalugu uuliasiorluni ngerlatat majimiit decemberimut ingerlanneqartarnissaat naatsorsuutigineqarpoq. Uuliamik qalluinivik aallartissagaluarpat naatsortsuutigineqarpoq ingerlatat ukioq kaajallallugu ingerlerumaartut ilimagineqarpoq.

Avatangiisit

Disko Vest issittumniippoq tamaanilu klimamut naleqquttunik uumasoqarfiulluni. Imaappoq uumasut assigiinngitsut amerlanngillat (immap natermiut eqqaassanngikkaanni), nerisareqatigiinnerit naatsuinnaapput aammalu amerlasoorujussuusartunik uumasuaqarfiulluni. Uumasut assigiinngisitaat ikittuinnaanerat uumasut tamakkua ilaasa amerlasoorujussuunerannik illuatungilerneqarpoq, tamakkualu ilaat uumasoqatigiiffimmut pingaaruteqarluinnartuupput. Imaappoq uumasoqarfinnut uumsoqatigiinnermullu uumasut tamakkua tamaaniinnerat apeqqutaalluinnarluni. Ilisarnaatinullu ilaagujoq uumasut tamakkua ilarpassuisa annertuumik orsoqarnerat, nerisassakilliornermut sillimmataallunilu issimut illersuutaasumik. Taamatut annertuumik orsoqarnerat tamaani avatangiisit mingutsineqarneranni pingaaruteqarluinnarpoq, stoffimmi mingutitsissutigineqartut ilarpassui orsumi arrortinneqarsinnaasarmata taamaattumillu uumassut orsuanni katersuutilersinnaallutik.

Nalilersuiffigineqartumi uumasoqarnikkut/uumasoqatigiinnikkut pisoorujussuarqartiterpoq. Upernaakkut pinngoqqaartoqartarnera annertuvoq, immap mnaqqani uumasoqaqaaq ammalu pingaarutilinnik timmiarpassuaqarlunilu imarmiunik miluumasorpassuaqarpoq.

Nalilersuiffiusumi pissusiusut naatsumik nassuiarneqarput oceanografii sikoqassuserlu pingaarnerutillugit. Tamatuma annersaa ukiumi upernaakkullu sikuusarpoq. Iluliarpassuaqarpoq, pingaartumik Disko Bugtimi.

Disko Bugtip kujataani sinerissap ilaa ukiuunerani sikoqarneq ajorpoq (aakkarnerusarluni), sarfarnerujussua pissutaalluni, aakkarnerillu tamakkua uumasoqassutsimut pingaarluinnartuupput taamattumillu uuliasiornikkut ingerlatanut misikkarissorujussuullutik.

Tappiorarnartut

Immami uumasoqarnikkut pisartoq malunnaateqarnerpaaq tassa tappiorarnartut naasuussut, nerisareqatitiinnermi pilersuisuusut pingaarnerpaat, upernaakkut amerleriarujussuartarnerat. Tamakkua tappiorarnartunit uumasuusunit nerisarineqartarput, ilaatigut kingunnit pingaarutilinnit *Calanus*-vandloppinit, tassaasunit immami uumasoqatigiinnermi pingaaruteqarluinnartunit.

Immap naqqata naasui uumasuilu

Immap naqqata uumasuisa pinngorartuni ilarujussui nerisarpaat taamaattumillu aalisakkanit, timmissanit imarmiunit miluumasunillu imarmiunit nerisaallutik pingaaruteqartut. Immap naqqani uumasoqatigiijaat amerlasooujussuusarput aammalu uumasut assigiikkuutaat amerlasoorujussuusinnaasarput uumasullu assigiinngisitaat qanoq katitigaanerat assigiinngisitaartorujussuusarluni. Avasissumi immap naqqata uumasuisa najortakkamikkut takkusimaartarnermikkullu allanngorarnerannut tunngatillugu ilisimasat suli amigaateqarput.

Makroalgit (qeqqussat) sinerissap qanittuani naqqa manngertumiittarput 50 meterilu tikillugu itissusilimmiittarlutik. Uumasoqassusia makroalgillu pinngorarnerat annertuujusinnasarpoq aammalumi nerisareqaritiinnermi qaffasinnerusuniittunut arlalitsigut pingaaruteqartuullutik. Qeqqussat tassaapput organismit nipinngavii qeqquarpassuillu aalisakkat piaqqiorfigilluartarpaat toqqorfiullutik, panernaveersaarutaallutik sarfamut malinnullu illersuutaallutik qeqqussallumi aamma nerisarineqartartuupput. Nalilersuiffimmi qeqqussanut tunngatillugu apeqqutit akissutissaqartinngisat suli amerlaqaat.

Immap naqqani uumasut qeqqussallu nalunaarusiap uuma nutarternissaanut tunngatillugu misissukkanut ilaapput. Box 2 qeqqussanik misissuinerup inernerinik Box 3-lu immap naqqani uumasunik misissuinerup inernerinik oqaluttuarput.

Aalisakkat

Avataasiorfimmi, ikkannersuaqarfiit (ikkannerit 200 m angullugu itissusillit nunap toqqammavianiittut) ilanngullugit aalisagarineruaat immap natermiut, qalerallit, nataarnat, suluppaakkat, qeeqqat eqalussuit aammalu aalisakkat allat aalisarnermut soqutiginaateqanngitsut. Aalisakkat pingaarnersaraat qaleralik, itisoorsuarmiuusoq nunap toqqammaviata sivingarnini kangerlunnilu uumasuusut. Qalerallit nalilersuiffimmi piaqqineq ajorput, amerliartuutaalli ilaartuutaapput Davisstrædemi kujasinnerusumi erniaasuupput sarfaatitillutik tamaaniilersartut. Putooruttut amerlasoorsuullutik ikkannersuarniittarput aalisakkat ilaannut, timmissanut imarmiunut arfernullu soqqalinnut nerisaallutik (Box 4-mi takuuk aalisakkap taassuma misissuiffigineqarnera). Putooruttut tamaani aalisakkani aasaanerani suffisartortatuaavoq.

Sinerissap qanittuani aartit marluk pingaarutillit upernaakkut suffisarput: ammassak nipisalu. Ammassak aalisannit annernit, timmkissanit imarmiunit miluumasunillu imarmiunit nerisaanermigut pingaaruteqarpoq. Eqaluittaaq immami sinerissap qanittuaniipput, kuutsigut majorlutik tamakkunani suffillutillu ukiisarlutik.

Timmissat imarmiut

Tamaani timmissat assigiinngitsut katillugit 16-iusut piaqqisarput (Tabel 5). Taakkunannga 15-imit innani qutaarluusunit imaluunniit qeqertani pukkitsuni amerlasuukkuutaarlutik piaqqisarput. Tamaani innat timmiaqafiit pingaaruteqarluinnartut arlaqarput, taakkununnga ilaalluni Appat sanianni innaq taateraanik appanillu timmiaqarfissuaq, qeqertat Saattuarsuit (Grønne Ejland) Kalaallit Nunaanni imeqqutaalaqarfiunerpaaq, aammalu timmissanit qaqutigoortunit thorshane-nit rosenmågenillu najorneqartut, qeqertaaranguit Rotten Silaqanngitsulivillu qilanngaqarfiusut. Tamakkua erniorfiit ilaat timmissanit nungutaasinnaasutut kalaallit nalunaarsuiffianni nalunaarsorneqarsimasunit piaqqiviusarput (Tabel 11).

Nalilersuiffiup kujasinnerusortaa mitit, mitit siorakitsut appallu ukiisarfiattut pingaaruteqartuuvoq. Pingaartumik ikkannerit Store Hellefiskebankmiittut miternut siorakitsunut pingaarutilerujussuupput, tassami timmissat millionit affaat angullugit ataatsikkut tamaaniissinnaasarmata.

Upernaakkut ukiakkullu timmissat imarmiorpassuit nalilersuiffikkut ingerlaartarput erniortarfimminnut Kalaallit Nunaata avannaani kitaaniittunut aammalu Canadap issittortaaniittunut aamma Kujataani Newfoundlandimilu ukiisarfimminukarnerminni.

Nalunaarummi uani ilisimasanut ilanngutassanik timmissanik misissuinerit arlallit nutaat ilaapput: Box 1-ip oqaluttuarai tappiorarnartut, aalisakkat timmissallu septemberimi 2009-mi imaannarmi tamaaniittut. Box 5-ip oqaluttuara mitit siorakitsut qaammaatsakkortumik nalunaaqutsikkanik misissuinerup inerneri, Box 6 taamatut misissuinerit Appani appanik misissuineq Box 7-ilu imaannarmi timmissat sumiinnerat.

Miluumasut imarmiut

Miluumasut imarmiut immami uumasut pingaarnerit ilagaat. Nalilersuiffimmiipput puisit assigiinngitsut tallimat, taaakunannga natsiit, ussuit qasigissallu tamaani piaqqiortuullutik, natsersuit aataallu tamatuma avataani erniorfimminneersut aqqusaartugaralugu (Tabel 8). Aarrit tamaani pingaarutilimmik ujiisarfeqarput Store Hellefiskebankimi, tamaaniittut 2300 3000-illu akornanniittutut nalilerneqarlutik. Tamakkua Davis Strædip Canadamut atasortaani aasisarput.

Arferit ilaat ukiuunerani nalilersuiffimmiittarput - qilalukkat qaernertat, qaqortat arfiviillu, amerlasuullu aasaanerani tamaaniittarput. Tamakkua ilagaat tikaagulliit, tikaagulliusaat qipoqqaallu amerlanerusarput. Nanoq ukiukkut upernaakkullu sikuunerani tamaani naapitassaavoq.

Miluumasut imarmiut tamakkua nalilersuiffimmiittut ilaat arlallit kalaallit nunallu allat nungusdsinnaasutut nalunaarsuiffiini nalunaarsorsimapput (Tabel 11 aamma13).

Ukiuni 2009-2011-mut tunuliaqutassatut miluumasut imarmiut marluk misissuiffigineqartunut ilaapput. Taakkua marluk qaammataasatigoortunik nalunaaqutserlugit malittarineqarput: nannut (Box 8) aamma arfiviit (Box 9).

Uumasoqarfiit immikkut pingaaruteqartut

Uumasoqarfiit immikkut pingaaruteqartut, taaneqarajuttut *hot-spots*, Store Hellefiskebankimiittut paasineqarput, pingaartumik ikkannersaani (50 m tikillugu ititigisumi) Disko Bugtimilu.

Store Hellefiskebanke ukiuunerani immikkut aavernut, qilalukkanut qaqortanut, ussunnut miternullu siorakitsunut pingaaruteqarpoq. Immap naqqa assigiinngitsorpassuarnik uumasoqarfiuvoq putooruttoqaqalunilu.

Disko Bugti timmissanut imarmiunut piaqqiortunut pingaaruteqarpoq, tamaaniippummi innat qeqertallu timmiaqarferujussuit. Ukiukkut upernaakkullu Disko Bugti arfivinnut pingaaruteqarluinnarpoq, aammalu qilalukkat qernertat piffissap ilaatigut tamaani amerlasoorsuusarput. Aammalu aalisarnermut pingaartut marluk, qaleralik kinguppaallu annertuumik aalisarneqartarput.

Baffin Bugtip qiterpasinnerusortaa (nalunaarusiorfiup avannamut kangimut isua) qernertanut ukiisunut pingaaruteqartuuvoq.

Sumiiffiit taakkua pingasut PAME-mit (Aktisk Rådep ataani suleqatigiissitaq) imartatut issittumi avannarlermi uumasoqarnikkut kulturikkullu pingaarutilittut toqqarneqangajalerput, aammalu toqqarneqarlutik nunat assigiinngitsut tungaanniit immatut uumasoqarfittut pingaarutilittut immakkullu angallannermut misikkarissutut.

Inuussutissarsiorneq

Piniarneq aalisarnerlu

Pineqartoq tamarmi inunnit isumalluutimigut pinngortitamiittutigut iluaquteqarfiuvoq. Piniarneq aalisarnerlu annertunngitsumillu sinerissap qanittuani aalisarneq akissarsiorfittut ingerlanneqarpoq, avataasiorfimmili Disko Bugtimilu annertuumik aningaasarsiutigalugu aalisarneqarluni. Inuussutissarsiutigalugu aalisarnermi pingaartumik kinguppaat itisoormiut qalerallillu piniarneqarlutik.

Sinerissap qanittuani upernaakkut pingaartumik ammassat (nammineq atugassat) pisarineqartarput, nipisallu suaat tunineqartarlutik. Eqaluit sinerissap qanittuani isumalluutinut pingaartunut ilaapput. Aalisakkat allat arlallit, soorlu qeeqqat nataarnallu annertunnginnerusumik iluaqutigineqarput, nammineq nerisassatut nioqqutissatullu.

Nalilersuiffimmi piniarnermi pingaartumik puisit, arferit timmissallu imarmiut sammineqartarput, nannullumi ataasiakkaat tamaani pisarineqartarlutik.

Takornariaqartarneq
Takornariaqartarneq inuussutissarsiutaavoq kaslaallit Nunaanni annertusiartortoq massakkullu nuna tamakkerlugu isigigaanni inuussutissarsiutinut pingaarnernut pingajunngorsimalluni. Inuussutissarsiornermi pingaartumik sinerissap qanittua atorneqarpoq nalilersuiffimmiipporlu Kalaallit Nunaata takornariaqarfiisa pingaarnersaat: Ilulissat, sermimik aniatitsivia UNESCO-p nunarsuarmiut kingornutaattut toqqarsimasaa, takornariallu umiarsuarniit nunamut ikaarartarput.

Klimap allanngorneri

Klimap allanngornerisa annertuumik immap uumasoqarfia sunniuteqarfigisussaavaat, pingaartumik issittortaaniittut. Taamaattumik nalilersuiffiusumi uumasoqatigiinneq allannguuteqarumaartoq ilimagisariaqarpoq, assersuutigalugu uumasut pingaarnerit amerlassusiatigut sumiittarneratigullu aammalu uumasut assigiinngitsunik akuleriissimanerat allanngorumaarluni, uumasummi ilaat tammarumaarput nutaallu takkukkumaarlutik.

Qularutissaanngitsumik piniarneq aalisarnerlu sunnerneqarumaarput. Klimap allanngorneri miluumasut timmissallu imarmiut ilaannut misikkarinnerulersitsiumaarput, assersuutigalugu uuliaarluernernut soorlu aallaaniarneqarnertulli. uumasut ilaat takussaanerulerumaarput amerliartorlutillu, tamakkualu uuliaarluernernut akiuussinnaanerujumaarput.

Stoffit mingutitsissutit

Stoffinut mingutitsissutinut, soorlu POP-it, PAH-t saffiugassanullu oqimaatsunut pinngortitameereersunut ilisimasaqarneq pingaaruteqarpoq avatangiisit uuliasiornikkut ingerlatanut sunniutinut eqqoruminannassusiannik naliliinissamut pingaaruteqarpoq.

Kalaallit Nunaanni stoffit mingutitsisut, ilaatigut POP-t annertoreerput, pissutigalugu tamakkua maanga ungasissorsuarmi suliffissuaqarfiusuniit assartorneqarmata. Tamakkua annertunerpaapput nerisareqatigiinnermi qutsinnerpaamiittunmut; arfernet nannunullu. Mingutitsissutillumi nutaat - ikuallannaveeqqutit bromitallit forbindelsillu perflureredesut - Issittumi avannarlermiittut paasisineqarsimavoq.

Umiarsualiveqarfiit eqqaassanngikkaanni uuliakujuit, ilaatigut PAH-t immami annertugisassaanngillat nalinginnaasumillu tamaanneereersunit annertunerunatik.

Kalaallit Nunaanni, nalilersuiffik ilanngullugu, stoffit mingutitsisut immami uumasuniinneraammik ilisimasat ajoriinnagassaanngillat, tamannami Arktisk Rådemi suleqatigiissitamit (AMAP)-imit sammineqarluarsimammat. Akerlianilli mingutitsinerup uumasoqarnermut qanoq ataqatigiinneranut tunngatillugu, soorlu peqqissutsimut sunniutai sulisinnaassutsimillu annikillisitsisinnaanerannut tunngatillugu ilisimasat annikitsuararsuupput. Aammalumi uumasoqatitigiikkuutaat qanoq misikkaritsisiginerannut ilisimasat amigaatigineqarput.

Uuliasiornikkut ingerlatanut tunngatillugu avatangiisinik nalilersuineq

Nalunaarusiami uani naliliinerit uumsut assigiinngitsut ullumikkut sumiinnerat aammalu uuliasiornermut tunngatillugu ingerlatanut qanoq iliornerat tunngavigalugu naliliineruppput. Ilimagineqarporli klimap allanngornerisa nalilersuiffiusumi avatangiisit annertuumik allanngortikkumaarai, taamaattumik nalunarpoq inerniliinerit siunissami ungasinnerusumi pissutsini aamma atuukkumaarnersut. Aammami ilisimalikkat nutaat inerniliinerit allanngortissinnaavaat.

Ujarlerneq

Ujarlerluni ingerlata utaqqiisaannaapput, amerlanertigut ulialunnik sivisussuseqartarlutik aammalu akuersissutaateqaarfimmi sumi tamaani piumaarlutik. Uuliamik iluaqutigineqarsinnaasumik nassaartoqanngippat ingerlatat unissapput. Uuliamik piassallugu akilersinnaasumik nassaartoqarpat ingerlatat uuliasiorfimmik iluaquteqarnermut nuunneqassapput (ataaniittoq takuuk).

Ujarlernikkut ingerlatat akornusersuutaasumik sunniutiginerusartagaat tassaapput nipiliortunik ingerlatat (assersuutigalugu sajuppillatitsisarluni misissuinerit, qillerineq helikopterillu angallannerat) aammalu avatangiisinut aniatitsineq.

Pisorpaluk

Sajuppillatitsisarluni misissuinerit immami sakkortuumik nipiliortarput aammalu aalisakkanik, pingaartumillu miluumasunik imarmiunik nujuttitsisinnaallutik. Tamakkiuali qaangiuttussaapput aammalu uumasut nujutsinneqarsimasinnaasut ingerlatat unippata uterumaartut ilimanarpoq.

Taamaattumik nalilersuiffiusumi aalisarfinnit pingaarutilinniit qalerallit nujutsinneqarumaarput tamaani sajuppillatitsisarluni misissuisoqarpat. Kinguppaalli sajuppillatitsisarluni ingerlatanit akornuseruminartuunngillat.

Sajuppillatitsisarluni misissuinernit miluumasut imarmiut eqqoruminarnerpaat tassaapput arferit. Aasaanerani pingaartumik nalinginnaanerusarput tikaagulliit, tikaagulliusaat qipoqqaallu neriniartarfimminniit pingaarutilinnit nujutsinneqarsinnaagamik. Ukiukkut tamaaniittarput qilalukkat qernertat, qaqortat, arfiviit aarrillu aamma pisorpalummit skornuseruminartuusut, piffissarli tamaaniittarfiat sivikitsuinnarmik sajuppillatitsisarluni misissuinernik ingerlatsinermit attorneqartussaammat uumasut tamakkua annertunerusumik sunnerneqarnissaat ilimagineqanngilaq.

Taamaattumik sajuppillatitsisarluni misissuinerit kipiumaarmata ataasiaannarluni sajuppillatitsisarluni misissuineq sivisuumik atuuttumik akornusiinissaaq ilimanarpallaanngilaq. Assigiinngitsulli ataatsimut sunniutigisinnaasaat, assersuutigalugu misissuinerit arlallit ataatsikkut ingerlanneqarnerisigut , imaluunniit misissuiffimmi ataatsimi uteqqiattumik ukiut arlallit misissuisoqarneratigut sunniuteqarnerlussinnaaneq aarlerinarsinnaavoq. Pingaartumik sumiiffimmi annikitsumi sajuppillatitsisarluni misissuinerit 3D-seismiske undersøgelsenik taaneqartut annertuut annertuumik sunniuteqarumaartut ilimagineqarpoq.

Qilleriveqarfinniit nipiliorneq aamma utaqqiisaannaagallarpoq, tamannali sajuppillatitsisarluni misissuinernit alaalluni ingerlaavartuauvoq nipiliorfillu nikerartuunani. Nipiliorfiit aamaattut arferit aarrillu ingalassimaniarumaarpaat. Arferit allamik illikarfissaqqissumik nassaassaqarpata tamanna akornutaasussatut ilimagineqanngilaq, kisiannili qilleriveqarfiit allallit ataatsikkut tamaani ingerlassappata ataatsimut sunniutit najortagaliutaasinnaasumiit nujutitsisinnaapput tamannalu ajornerpaassaguni uumasoqatigiit ikileriarnerannik kinguneqarsinnaavoq.

Aniatillugit eqqakkat
Maralluk qillerinermi atorneqartoq imermik akuugaappat taava qillernerlukut immap naqqanut eqqarneqartussaapput. Maralluk qillerinermi atorneqartoq kemikalianik arlalissuarnik akoqarpoq tamakkualu aammalu qillernerlukut tamaani immap naqqata uumasui sunnersinnaavaat (qillerivimmiit 250 m missiliorlugu ungasissusilik angullugu). Kalaallit Nunaanni akuutissat avatangiisinut akornutaanngitsut aniatiinnarneqarsinnaapput, imaappoq 'qorsunnik' 'sungaartunillu' taaneqartut (norskit OSPAR-konventionimi kemikalianik tulleriiaarineranik immikkoortiterinerat malillugu) kisimik atoqqusaapput, 'aappaluttullu' taamaallaat immikkut akuerineqarsinnaappata.

Marullukj qillerinermi atorneqartoq qillernerlukullu aniatinneqalersinnagit immap naqqa misissorneqaqqarsimasussaavoq. Misissuinerit tamakkua uumaffiusut akornuseruminartut sunnernerlunneqannginnissaat qularnaassavaat. Aniatitsinerit unippata misissuinerit taamaattut ingerlanneqaqqissapput peqqussutit malinneqarsimanersut iluaqutaasimanersullut paasiniarlugu.

Ujarlerluni qillerineq ingerlataavoq nukimmik annertuumik piumasaqartoq annertuumillu naatsitsiviit gassiinik stoffinillu allanik silaannarmut aniatitsiviusoq. 2010-mi qillerinerit pingasut taakkua kalaallit naatitsiviup gassiinik aniatitsinerat 15%-imik annertusitippaat.

Ujarlerluni qillerinerit uuliamik aniasoortitsisinnaanerat (*blow-out*), ataani eqqartorneqartoq, arlerigisassaavoq.

Ineriartortitsineq tunisassiornerlu

Nalilersuiffiusumi uuliaqarfimmi ineriartortitsionermiit sunniutit nalilersoruminaatsuupput, sumiinnissaammi qanorlu annertutiginissaat ilisimannginnatsigu. Nalinginnaasumik sunniutit sivisuumik (ukiuni qulikkuutaani arlalinni) sunniuteqarumaarput ingerlatallu ilarpassui avatangiisiinik annertuumik artorsartitsisinnaasuummata. Aammali apeqqutaassaaq ingerlatat qanoq amerlatiginerat, sumiinnerat qanorlu sivisutigisumik tamaaniinnissaat, tassungalu atatillugu ataatsimut sunniutit annikitsuinnaassagunanngillat.

Aniatitsinerit
Uuliamik piiaanermit aniatitat avatangiisinut sunniuteqarnerlunnissaat isumakulunnarnerpaavoq, imermi tunisassiornermi atorneqartartoq annertoorujussuuvoq (imeq uuliamut ilanngullugu qallorneqartoq). Imeq taanna uuliamineerarpassuarnik avatangiisinullu annikinnerugaluartumik artorsartitsisunik assigiinngeqisunik akoqarpoq, assersuutigalugu toqunartut toqunarluinnartut, saffiugassat oqimaatsut, stoffit radioaktiviusut, stoffit hormoninut sunniuteqartartut stoffillu naggorissaatitut sunniuttartut. Stoffit tamakkua ilaat nerisareqatigiinnermi annertusiartorsinnaapput (timimut akuliussinnaapput). Norgemi misissuinerit takutippaat aniatitsinerup aalisakkanut aniatitamut qanittumiittunut imaaliallaannaq sunniuteqartarnerat, imerpallaanikkulli qanittuaniinnaq sunniuteqalersinneqarsinnaasut. Erngup tunisassiornermi atukkap sivisuumik avatangiisinut sunniusimasarneranut tunngatillugu ilisimasat annikitsuinnaapput. Sikup ataanut aniatinneqarpat takorloorneqarsinnaavoq eqalukkat sunnerneqarsinnaanerat, tamakkuami suaat piaraallu tukerlaat sikup ataanut upernaakkut katersuuttarmata.

Ineriartortitsinerup qalluinerullu nalaani qillerineq ingerlaannassaaqa, marallullu qillerinermi atotugaq qillernerlukullu misissuinerup nalaanut sanilliullugit annertunerujussuussapput. Aniatitat (maralluup imermik akusap atorneranit) sapinngisamik annikinnerpaatinniartariaqarput, tamakkua atoqqinneqarnerisigut aammalu piiarnerlukut uterartinnerisigut kemikaliallu avatangiisinut navianannginnerusut kisiisa aniatinnerisigut (qulaaniittoq takuuk).

Erngup ballastitut atorneqartup aniatinneratigut uumasut maaniittuunngikkaluanik maanilu amerliartulersinnaasunik akoqarnissaa aarlerigisassaavoq. Taamaattumik imeq ballastiutut atorneqartup aniatinneqarnerani peqqussutit aalajangersut malillugit tamanna ingerlasariaqarpoq. Uumasut allameersut amerliartulersinnaasut ajornartorsiutaanerat Issittumi Avannarlermi imatut ajornartorsiutaasimanngikkaluarpoq, aarlerinartorli tamanna klimap allanngoriartornera malillugu Issittumi Avannarlermi umiarsuit uuliamik assartuutit uuliamik piaaveqarnerup kinguneranik amerleriartorneratmalillugu ajornartorsiut annertusiartussaaq.

Aniatitsineq alla pingaarutilik taaneqartariaqartoq tassa naatitsiviup gassiinik aniatitsineq. Kalaallit Nunaanni uuliamik qalluiveqarlerpat tamakkunminnga aniatitsineq annertusisitseriarujussurtussaavoq. Assersuutitut taaneqarsinnaavoq norgimiut uuliamik qalluivissuisa ilaat ullumikkut Kalaallit Nunaata CO_2-mik aniatitaata marloriaataanik ukiut tamaasa aniatitsimmat.

Pisorpaluk
Qilleriviit inissinneqarneranni qillerinermillu pisorpalutitsineq inerartortitsinermi tunisassiornermilu ingerlaannartussaavoq, tamatumalu arferit neriarfimminnit pingaaruteqartuniit nujutsinneqarnerat kingunerisinnaavaa. Ajornartorsiullu tammanna suli annerussaaq uuliasiorfiit arlallit ataatsikkut ingerlappata. Pisorpalutitsineq umiarsuarneersoq (sikunik aserorterutit ilanngullugit) helekopterineersorlu massakkut ujarternerup nalaaniit annertunerulersimassaaq, tamatumalu aamma miluumasut imarmiut timmissallu neriniarfigilluartagaanniit nujutsissinnaavai. Tassunga atatillugu nalilersuiffimmi uumasut akornuseruminarnerpaat tassaapput timmissat imarmiut amerlasoorsuullutik piaqqiortartut, arfiviit, qilalukkat qernertut, qaqortat, tikaagulliit, tikaagulliusaat, niisat aarrillu. Piniariarfiusartutoqqat amma sunnerneqarsinnaapput uumasut piniarneqartartut tamaannga nujutsinneqarpata.

Takussutissaalersut
Sanaartukkat immamiittut atortulersuinerullu tamaani immap naqqani uumasuusut sunnersinnaavaat aarleqqutissdaavorlu uumasut aqqarlutik neriniarfinnaavissuinik innarliinissaat. Pingaartumik tassani aarrit mitillu siorakitsut Store Hellefiskebankimiittut eqqarsaatigalugit. Nunami sanaartukkat tamaani timmissat erniortartut ajoquserlugit, eqaluit suffiartoraluartut suffiffissaminnut anngussinnaajunnaarsissinnaavaat, sinerissap qanittuani uumasut naasullu sunnersinnaallugit aammalu nunap allanngortitersimanngitsup takuminartua sunnersinnaallugu. Kingulleq taanna takornariaqarnermut sunniuteqarsinnaavoq.

Tamatumunnga atatillugu aalisarneq sunnerneqarsinnaavoq tikeqqusaanngitsunik ungasisssusilersuilluni killilersuinikkut (500 meteriugajuttumik) immami utaqqiisaasumik ataavartussamilluunniit atortulersuiffiusut avataanni, pingaartumik tamakkua annertuumik qaleralinnik kinguppannillu aalisarfiusumut inissinneqarsimappata.

Aammami sanaartukkat qaammarsakkat gasilu ikumatitaq (flares) taartillugu timmissanit imarmiunit taartoorfigineqarsinnaapput, silalu pissutigalugu pingaartumik miterpassuit immaqalu appaliarsuit tamakkununnga aportarsinnaapput.

Ataatsimmortumik sunniutit

Ingerlatat assigiinngitsut ataatsikkut ingerlanneqarpata aammalu tamakkua ujigulukuttuusimappata tamanna ataatsimut sunniuteqarsinnaavoq. Assersuutigalugu sajuppillatitsisarluni misissuinerit ataatsimut sunniuteqarnissaat isumakulunnartorujussuuvoq. Ataatsimut sunniutit aamma pisinnaapput inuit ingerlataannut allat peqatigalugit, soorlu aallaaniarneq, imaluunniit klimap allanngorneri.

Pinaveersaartitsineq

Ujarlernermut, ineriartortitsinermut qalluinermullu atatillugu avatangiisinik sunniinerit avatangiisinut tunngatillugu sukumiisumik ilisimasaqarnikkut killilersimaaneqarsinnaalluarnerupput, isumatuumik inatsisiliornikkut, sakkortuunik HSE-mik (Health, Safety and Environmental) maligassaqarmikkut, sukumiisumik pilersaarusiornikkut aammalu pilersaarusiorlunilu *Best Available Technique (BAT), Best Environmental Practice (BEP)*-mik malititsinikkut, nunarpassuit avatangiisinut mianersuussinissamik piumasaqaataannik (assersuutigalugu OSPAR (HOCNF) og MARPOL) malinnillu ingerlatsinikkut.

Uuliaarluerneq

Avatangiisit eqqarsaatigalugit ajornerpaamik pisinnaasoq tassa ingerlatat qulaani taagorneqartut uuliaarluerujussuarnermik pilersitsisinnaammata. Uuliaarluerniarneq qillerinerup nalaani pisinnaavoq (*blow-out*) imaluunniit uuliap toqqortornerani angallanneraniluunniit ajutoornikkut. Ullumikkut uuliaarluerujussuarnerit qaqutigoortuupput, ilaatigut teknikikkut aaqqiissutit isumannaallisaatillu pitsanngorsarneqartuarnerat pissutaallutik. Navianartuali taannaajuarpoq, Disko Vestitullu ittumi navianartoq tamanna sikumit ilulissanillu annerulersinneqarpoq.

Disko Vestimi uuliaarluernerup qanoq ingerlasinnaanera DMI-mit missingersuusiorneqarsimavoq (tak. immikkoortoq 11.2 aamma ASppendix 1). Suliap taassuma takutippaa sineriak ungaseqalugu (>100 km) pisup sineriak isumakulunnartortalik aangussanngikkaa, tiffasinnerusumili (< 48 km) uuliaarluernerup sineriak assigiinngisitaartumik annertussuseqarluni uuliaarluernerup tippivigiumaaraa.

Uuliaarluernerujussuup immami uumasoqaarfiit tamaasa sunnersinnaavai, pinngoraleqqaaniit nerisareqatigiinnermi qullerpaanut. Qanoq uumasoqartiginera navianartorsiortissinnaavaa, sunniutaalu ukiuni qulikkuutaani arlalinni sunniusimasinnaapput, soorlu tamanna uppernarsaatissaqartoq Alaskami Prince William Sund-imi pisukkut.

Disko West-imi uuliaarluernerup sunniutai kujsasinnerusumi pisumit annertunerusinnaapput, issittummi imartaani sikulimmi uuliaarluernermik katersuineq/peersineq suli naammaginartumik angusaqarfiusimanngilaq sulilu ineriartortinneqarluni, Disko West-ilu avinngarusimasumiippoq annertunerusumik atortulersuiffigineqanngitsumi.

Sineriak nalilersuiffimmiittoq ajoquseruminartorujussuuvoq, uuliammi tamaani assdigiinngisitaartunik uumasorpassualimmut ajoqusiisinnaavoq. Ajoquserneqarsinnaassutsimut ilaavortaaq uulia iterlannut kangerlunnullu uninngalersinnaammat, tamaanilu uuliap toqunartoqarnerujussuaq immap itissusia tamaat sunniusimalersinnaalluni. Aalisakkat, soorlu ammassak nipisalu upernaakkut suffisartut, eqaluit kuuit akuini katersuuttartut aasami ingerlaarnerminnilu katersuuttartut, pingaartumimmi ukiukkut ingerlaartartut imarnersanili eqimattarsuullutik uninngaartartut eqqorneqarsinnaapput.

Sinerissami sivisuumik sunniusimasarneq tamaani pisinnaavoq uulia kinnernut, ujaqqat akorninut, uiloqarfinnut imaluunniit quppanut unippat. Tamakkuninnga uulia arriitsumik aniarusaarsinnaavoq taamaalillunilu ataavartumik mingutitsilersinnaalluni ukiunik qulikkuutaanik sivisussuseqarsinnaasumik. Alaskami Prince William Sund-imi taamaattuni uuliaarluernerit sivisoorsuarmik timmissanut tamatuminnga iluaquteqartunut sunniusimavoq suli atuuttumik. Sinerissattaaq qanittua tamaani aalisartunut piniartunullu pingaaruteqartorujussuuvoq, uuliaarluertoqarpallu ingerlataat annertuumik sunnerneqarsinnaapput tikeqqusaanngitsulersuinermit piniakkallu allanngornerannit. Takornariartitsineq aamma sinerissap qanittuani uuliaarluernermit ajortumik eqqorneqaarsinnaavoq.

Imaq sikuutillugu uuliamik aniasoornermi uulia aallaqqaammut sikut akorninut aammalu sikut ataanni itersiumanernut unerassaaq. Aallaqqaammut sikup uuliap siaruarnissaralua pakkersimaassavaa, sikumulli uulia nipinngammat uuliaarluerneq sikumit ungasissorsuarmut ingerlanneqarsinnaavoq (annertunerusumik nungujartorani), uuliallu avatangiisit, assersuutigalugu timmissanik miluumasunillu imarmiunik uuliaarluerfimmit ungasissorsuarmiitt5unik mingutitsisinnaalluni. Uulia aamma sikup sinaavani sinaanullu qanittumi uniinnarsinnaavoq, pingaartumik tamanna upernaakkut pinngorartorpassuarnik, timmissanik miluumasunillu imarmiunik mingutsikkuminartullu amerlasoorsuarnit najorneqartarpoq.

Pinngorartitsineq tappiorarnartullu uumasuusut

Nalilerneqarpoq pinngorartitsineq tappiorarnartullu uumasuusut imaannarmi nalilersuiffimmi immap qaavata mingutsinneqarneratigut annikitsuinnaajumaartut pissutigalugu siammarsimaffiat piffissarlu uumasoqatigiitm tamakkua takkusimaartarfiat annertoqimmata. Qanittumili pinngorartoqarnerata upernaakkut ajoquserneqarnissaa aarlerinarsinnaavoq (annikinnerusumik pinngorartitsineq).

Naliliinerup taaassuma immap iluani mingutitsineq, soorlu *Macondo*brøndimi, Mexico Golfimi 2010-mi pisutut ittoq pigunanngilaa. Tamaanimi immap iluani itissutsini assigiinngitsuni uuliaarluerneq pujuusarsuanngorluni tissumarpoq, taammaattullu pinngorartoqarneranut tappiorarnartunullu uumasuusunut aalisagaaqqanullu sunniuteqarnerlunnissaa immap qaavani mingutitsinermiit ilimanarneruvoq.

Aalisakkat peqquillu piaraat

Nalinginnaasumik aalisakkat pequillu suaat inersimasuninngarnit ajoquseruminarnerusarput, eqquinerlukkaannilu uuliaarluerneq aalisagaaqqat / suaat eqimmateruttornerisa nalaanni pisappat tamaakkua amerliartornerat eqqornerlunneqarsinnaavoq. Aalisagaaqqalli suaallu taama amerlatigisarnerat nalilersuiffimmi malugineqanngilaq, aalisakkat kinguppaallu taamatut uuliaarluerneqarpat sunnernerlunneqarnissaat ilimanarpallaanngilaq. Eqalukkat sikup ataani suffisarput suaallu tukerlaallu sikup ataani katersuuttarput uuliaarluernerup katersuuffigisinnaasaani. Annertuumik nalilersuiffimmi eqalukkat piaraqarfeqarnersoq ilisimaneqanngilaq, taamaassimappalli assut akornuseruminartussaapput.

Immap naqqani uumasut

Uumasut soorlu uillut peqquillu uuliaarluernikkut ajoquseruminartuupput, naak tamatuma imaannarmi pinissaa ilimagineqanngikkaluartoq uulia immap naqqanut kivinngippat. Ikkattumili (< 10-15 m) annertuumik uuliaqarpat uumasut nalermiut toqorarneqarsinnaapput. Taamaappat immap natermiunik tamakkuninnga iluaquteqartunut, aavernut, miternut siorakitsunillu miteqarneranut sunniuteqarsinnaavoq.

Aalisakkat inersimasut

Ilimagineqanngilaq immap qaani uuliaarluernermit aalisakkat inersimasut imaannarmiittut sunnerneqarumaartut. Annertoorsuarmik immap iluani *blow-out*-ili avasissorsuugaluartumi aalisakkat ikerinnarmiut toqqaannartumik nerisareqatigiinnikkulu toqqaannanngikkaluartumik eqqornerlussinnaavai. Uuliap immami sikuusumiittup eqalukkat sikup atinnguaniittut aamma ajoqusersinnaavai. Sinerissap qanittuani uuliap toqunartuisa annertuneruffianni uulia iterlanni kangerlunnilu tamakkua annertusiartorfigisinnaasaanni aalisakkat sunnrneqarsinnaapput, tamaaniipput ammassat, nipisa eqaluillu pingaartumik nalilersuiffiusumi sunneruminartorujussuusut.

Timmissat imarmiut
Timmissat imarmiut immami avatangiisiniittut uuliaarluernermit ajoquserumianrtorujussuupput piffissap ilarujussua tamaani mitsimaartaramik. Tamatumunnga pissutaavoq meqqoqarnerat, meqquimi annikitsunnguamilluunniit uuliaarluer-aangamik oqorunnaartarput puttasinnaanerallu aserorneqartarluni. Timmissat uuliaarluersimasut erninna qiullutik, perlerlutik ipillutillunniit toqugajupput. Nalkilersuiffimmi sinerissap qanittua aarlerinarnerpaavoq, tamannami ukiup annersaa timmiarpassuit najortarpaat. Aasaaneranitimmiarpassuit innani qeqertanilu piaqqiortut isumakulunnarnerupput ukiumilu miterpassuit siorakerpassuillu nalilersuiffiup kujasinnerusuani sinerissami qanittuaniittut ikkannersuarniittullu assut aarlerigisariaqarput.

Ukiakkut upernaakkullu timmiarpassuit imarmiut nalilersuiffik aqqusaallugu ingerlaartartut aammab uuliaarluertoqassappat navianartorsiortorujussuussapput, pingaartumik eqimattarsuullutik tamaani uninngaarnerminni.

Miluumasut imarmiut
Nannut puisillu piaraat toqqaannartumik uuliaarluernissamut aarlerinartorsiornerpaapput. Annikikkaluartumilluunniit uuliaterneq toqussutaasinnaavoq, uuliammi amiata oqussusia annikillisittarpaa, aammalumi toqunartoqarpoq, tamannalu pingaartumik nannunut ulorianartuuvoq meqqutik aluttorlugit salittarmatigit.

Arferit, puisit aarrillu immap qaavani uuliaarluernermit sunnerneqarsinnaapput. Arferit soqqallit soqqaat uuliakutersinnaapput taamalu nerisamikkut uuliatulerlutik. Soqaasa nakkartitsivittut atornerat sunnersinnaavaa imaluunniit toqunartoqalersitsillutik aqajaqqumikkullu ajoquserneqarsinnaallutik. Uuliallumi aalarnera anersarnerminni najuussorsinnaavaat isimikkullu uuliakutersinnaallutik. Qanoq miluumasut imarmiut uuliaarluerneq ingalassimaniarsinnaatigineraat aammalu uulia uuliaarluertunut qanoq ajoqutaatiginnaasoq suli nalorninarpoq arferilli takuneqartarput immap qaavani uuliaarluerneq aqqusaarlugu ingerlasut.

Immami sikulimmi uuliaarluerneq suli immikkut ajoqutaavoq miluumasunut imarmiunut anersaariartorlutik puisariaqartartunut. Sikut eqingatillugit ammalatatigut uuliaarluersimasutigut pikiarsaartariaqartarnerat pisariaqarsinnaasarpoq tassanilu uuliap aalanngornerinik najuussuillutik. Prince William Sundimi uuliaarluernerup kingornagut puisit qaratsamikkut ajoquteqalersimasut naammattoorneqartarput uuliap aalanngornerinik najussuisimanerannik pissuteqarunartumik, aarluittaaq tamanna pissutigalugu toqusarsimagunarput. Nalilersuiffimmi pingaartumik ukiuunerani tamaaniittarut, qilalukkat qertat, qaqortat, arfiviit, ussuit aarrillu tamatuminnga eqqoruminarnerussapput.

Inuussutissarsiorneq
Imaannarmi uuliaarluernerup pingaartumik aalisarneq eqqortussaassavaa uuliaaluerfiusimasunimi piffissap ilaatigut aalisarsinnaajunnaartassammata. Taamaaliortoqassaaq aalisakkanik minguttitaasimasunik pisaqartoqaranilu nioqquteqartorqarsinnaanera unitsinniarlugu. Nalilersuiffimmi qaleralinniarneq kinguppanniarnerlu pingaarutilerujussuupput, unitsinneqarpatalu tamanna tamaani aningaasarsiornermut mikigisassaanngitsumik annaasaqaataasussaavoq. Aalisarnerittyaaq pingaanginnerugaluartut sunnerneqarsinnaapput, assersuuti-

galugu saattuarniarneq nipisanniarnerlu. Mexicanske Golfimi aalisarfinni annertoorsuarni *Macondo*-mi uuliamik aniasoorrujussuarnerup kingorna ukioq ilivitsoq angullugu matoqqatinneqarpoq.

Piniarneq sunnerneqarsinnaavoq piniarfiit ilaasa matuneqarnerisigut aammalu piniagassat tamaaniittut takkiusimasarnerisa allannguuteqarnerisigut.

Uuliaarluersinnaanerup pitsaaliorneqarnera
Uuliaarluersinnaaneq sapinngisaq tamaat pinaveersaartittariaqarpoq. Tamanna anguneqarsinnaavoq pisortat killilersuinerisigut, sakkortuumik HSE atorlugu (Health, Safety and Environmental) aammalu *Best Available Technique (BAT), Best Environmental Practice (BEP)* periaaseqarnikkut aammalu mianersdortussaanerup atorneqarneratigut.

Aniasoortoqarpallu peqqissaartumik iliuuseqarnissamut pilersaarutit (sinerissallu uuliaarlueqffigineqarnissamut qanoq navianartorsiortigineranni nalunaarsuineq ilanngullugu) piareersimalluinnartariaqarput aammalu teknikikkut atortussat pitsaasut piareersimatinneqartariaqarlutik.

Tassunga atatillugu tikkuassallugu pisariaqarpoq sikulimmi uuliaarluernerup qanoq pisarneranik ilisimasat pigineqartut killeqarmata, aammalu uuliap immami sikulimmi akiorniarneqarneranut teknologi pigineqartoq suli naammanngimmat, kisiannili ineriartortittuarlugulu pitsanngorsartuarneqarluni.

Ilisimasatigut amigaatit misissuinerillu nutaat

Naak 2009-miit 2011-mut misissuinerit ingerlanneqaraluartut naammassineqarsimagaluartut (Boxit 1-8) suli Disko Vestimi uumasoqarnermi pissutsinut tamatumunnalu pisunut tunngatillugu paasissutissanik amigaateqarpoq. Utaqqiisaagallartumik Davis Strædemi uuliasiornikkut ingerlataajumaartut kapitali 12-imiipput. Uuliasiornikkut ingerlanneqalerumaartut pisortatigut aqussinnaaqjumallugit a) nalilersuisoqarsinnaavoq, ingerlatassat pilersaarusiorlugit ingerlallut peqqussusiorfigalugit sunniutit sapinngisamik annikinnerpaatinniarlugit; b) sumiiffiit uuliaarluernermit ajoquseruminarnerusut suuneri paasiniarlugit ilanngullugulu misikkarissutsimut atlasit pigineqartut nutarterlugit; c) ilisimasat *baseline*-viden taaneqartut pilersillugit paasiniaanerit annertuumik uuliaarluerneq sioqqullugu kingornatigullu ingerlatsiviit avatangiisinut tunngatillugu qanoq iliuusissaannut (NEBA) atugassanik.

1 Introduction

In 2006 an area offshore West Greenland between 67 and 71° N (= the Disko West Area) was opened for hydrocarbon exploration, and licences were granted in 2007 and 2008. The area includes the north-eastern part of the Davis Strait and the south-eastern part of Baffin Bay, with Disko Island as the most prominent land feature on the Greenland coast (Figure 1).

This document is a strategic environmental impact assessment (SEIA) of expected activities related to exploration for and exploitation of hydrocarbones in the Disko West area in the Greenland part of southern Baffin Bay. The SEIA was initiated and funded by the Bureau of Minerals and Petroleum (BMP), and prepared by DCE – Danish Centre for Environment and Energy – formerly National Environmental Research Institute (NERI), Denmark – and the Greenland Institute of Natural Resources (GINR).

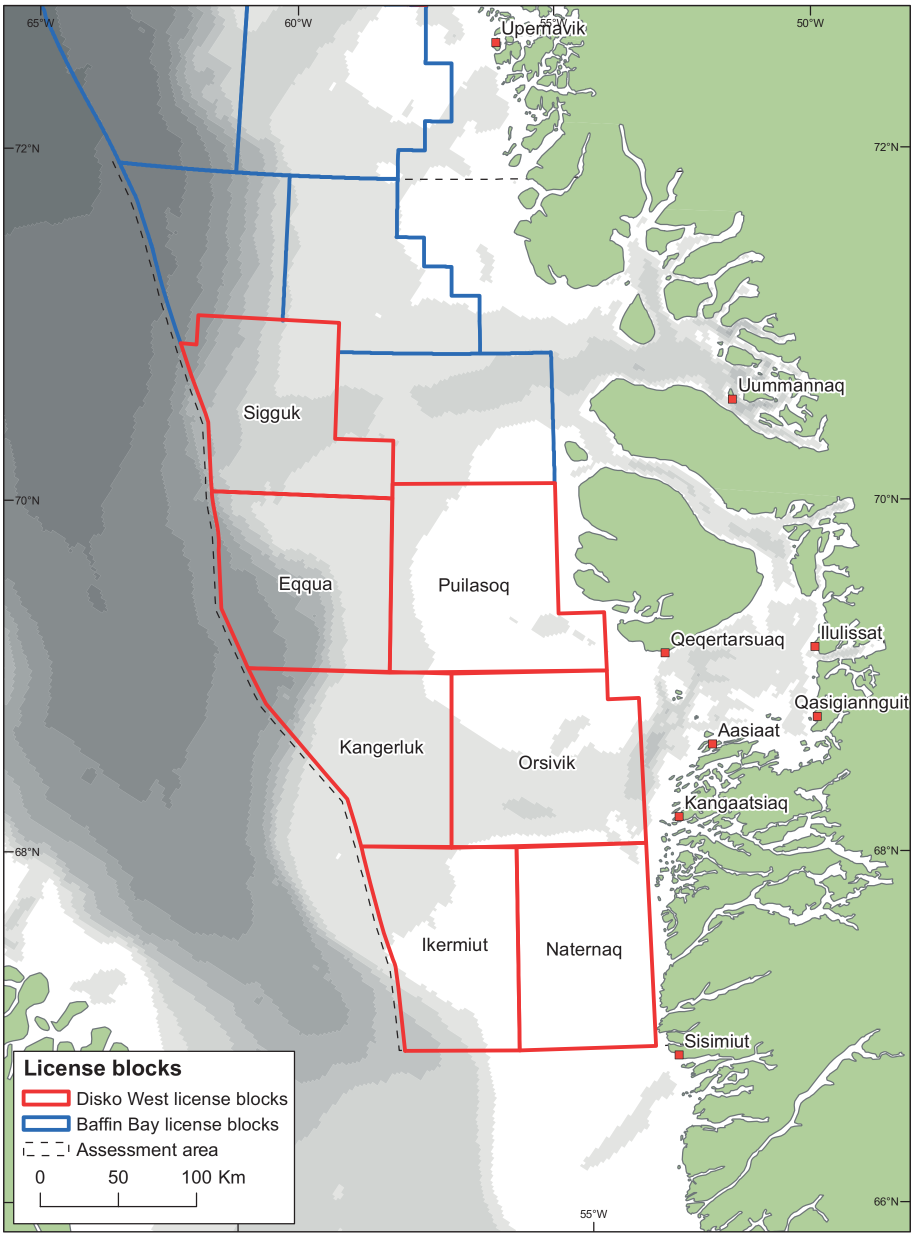


Figure 1. The assessment area, existing licence blocks and the surrounding areas in central West Greenland, including main cities and important shallow-water shelf banks.

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 (Anon 2003b) and the white paper No. 8 (2005) and No. 10 (2011), concerning the integrated management of the marine environment of the Lofoten-Barents Sea area have been drawn upon for comparison of potential impacts, because the environment there is comparable to West Greenland waters in a number of respects. Another important source of information is the Arctic Council's working group's (AMAP) Oil and Gas Assessment (AMAP 2010) available on the AMAP homepage (www.amap.no). In addition, the extensive scientific literature and various reports form the *Exxon Valdez* oil spill in 1989 has been a valuable source of information.

Several strategic background studies were initiated to supplement the background knowledge and fill data gaps relevant to this assessment (Section 12). Many results from these studies are included in a preliminary form, as they have not yet been published in a scientific context.

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

In this context an important issue is climate change which is expected to have a strong impact on the Arctic region, affecting both the physical and the biological environment.

Most of the data used for this SEIA has been collected over a number of decades. As oil activities, particularly development and exploitation may be initiated 10-15 years from now, environmental conditions could be very different from the conditions described in this report.

1.1 Coverage of the SEIA

The offshore waters and coastal areas between 67° N to 72° N (from Sisimiut town and northwards to southern Upernavik district) are in focus, as this is the region which potentially can be most affected by hydrocarbon activities, particularly from accidental oil spills originating from oil activities in the licence blocks (Figure 1). This area will be referred to as 'the assessment area'. However, the oil spill trajectory models developed by DMI indicate that oil may drift further, outside the boundaries of this area and into the Canadian EEZ (Nielsen et al. 2008). The area to the north of the assessment area has also been described in a strategic environmental impact assessment covering the eastern Baffin Bay (Boertmann & Mosbech 2012).

1.2 Abbreviations and acronyms

AMAP	Arctic Monitoring and Assessment Programme, working group under Arctic Council
APNN	Ministry of Fisheries, Hunting and Agriculture, Greenland Government
AU	Aarhus University, Denmark
BACI	Before After Control Impact
BAT	Best Available Technique
bbl	barrel of oil
BC	Black carbon
BEP	Best Environmental Practice
BFR	Brominated flame retardants
BMP	Bureau of Mineral and Petroleum, Greenland Government
BTX	Benzene, Toluene and Xylene components in oil, constitute a part of the VOCs
BTEX	Benzene, Toluene, Ethylbenzene and Xylene, constitute a part of the VOCs
CAFF	Conservation of Arctic Flora and Fauna, working group under Arctic Council
chl. *a*.	chlorophyl *a*
CI	Confidence Interval
CRI	Cuttings Re-Injecting
CTD	Conductivity, Temperature and Depth
CV	Coefficient of Variance
DDT	Dichloro-Diphenyl-Trichloro-ethane
DEGN	Department of Environment, Government of Nunavut
DHI	Danish Hydraulic Institute
DKK	the Danish currency, *krone*
DMI	Danish Meteorological Institute
DPC	Danish Polar Centre
dw	dry weight
EBSA	Ecologically or Biologically Significant Areas
EDCS	Endocrine-disrupting chemicals
EEZ	Exclusive Economical Zone
EIA	Environmental Impact Assessment
EPA	U.S. Environmental Protection Agency
FPSO	Floating Production, Storage and Offloading unit
GBS	Gravity Based Structure
GCM	General Circulation Models
GEUS	Geological Survey of Denmark and Greenland
GINR	Greenland Institute of Natural Resources
HCB	Hexachlorobenzene
HCH	Hexachlorocyclohexane
HOCNF	Harmonized Offshore Chemical Notification Format (OSPAR)
HSE	Health, Safety and Environment
ICES	International Council for the Exploration of the Sea
IMO	International Maritime 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
MARPOL	International Convention for the Prevention of Pollution from Ships
MIZ	Marginal Ice Zone
NAMMCO	The North Atlantic Marine Mammal Commission
NAO	North Atlantic Oscillation

NEBA	Net Environmental Benefit Analysis
NERI	National Environmental Research Institute, Aarhus University, Denmark
NGO	Non-Governmental Organisation
NMDA	N-methyl-D-aspartate
NOW	North Water polynya
OBM	Oil based drilling mud
OC	Organochlorines
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 under Arctic Council
PBDE	Polybrominated diphenyl ethers
PCB	Polychlorinated biphenyls
PFC	Perfluorinated compounds
PFOS	Perfluorooctane sulfonate
PLONOR	OSPARs list over substances which Pose Little Or No Risk to the Environment
PNEC	Predicted No Effect Concentration
POP	Persistent Organic Pollutants
pp	peak to peak (in units for sound pressure levels)
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
REKPRO	Recruitment processes in West Greenland waters (Research programme)
rms	root mean squared
SBM	Synthetic based drilling mud
SEIA	Strategic Environmental Impact Assessment
sd	Standard deviation
SM	Synthetic drilling mud
t	tonnes
TAC	Total Allowable Catch
TBT	Tributyltin
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
WBM	Water based drilling mud
WSF	Water Soluble Fraction
VSP	Vertical Seismic Profile
ww	wet weight

2 Summary of petroleum activities

D. Schiedek and D. Boertmann

Oil and gas project lifecycles usually comprise several phases which overlap to some degree. These include exploration, field development and production, and finally decommissioning. The main activities during exploration are seismic surveys, exploration drilling and well testing. During field development, drilling continues (production wells, injection wells, delineation wells), and production facilities, pipelines and shipment facilities, etc. are constructed and maintained. Finally, during decommissioning, all structures and facilities are dismantled and removed. These phases occur over long periods of time, usually several decades. For example, in the North Sea, oil exploration was initiated in the 1960s and production continues today.

Seismic surveys

The purpose of seismic surveys is to locate and delimit oil/gas fields, to identify drill sites and later during production to monitor developments in the reservoir. Marine seismic surveys are usually carried out by a ship that tows a sound source and a cable with hydrophones which receive the echoed sound waves from the seabed. The sound source is an array of airguns (for example 28 airguns with a combined volume of 4330 inch^3) that generates a powerful pulse at 10-second intervals. Sound absorption generally is much lower in water than in air, causing the strong noise created by seismic surveys to travel very long distances, potentially disturbing marine animals (see the guidelines to EIA of seismic surveys in Greenland waters issued by National Environmental Research Institute (NERI) in 2010 (Boertmann et al. 2010) and updated in 2011 (Kyhn et al. 2012)). Regional seismic surveys (2D seismic) are characterised by widely spaced (over many kilometres) survey lines, while the more localised surveys (3D seismic) usually cover small areas with densely spaced (e.g. 500 m) lines. Rig site investigations and shallow geophysical investigations use comparatively much smaller sound sources than used during 2D seismic surveys. For example, during site surveys a single airgun (150 inch^3) may be applied. Vertical seismic profiles (VSPs) are essentially small-scale seismic surveys carried out during exploration drilling. They are highly localised and of short duration (a few days), and their effects will be covered by the discussion of seismic surveys in general.

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 they are fully secured 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 have been used in the Disko West area 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 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.

It is assumed that the drilling season in the waters of Baffin Bay is limited to summer and autumn by the presence of ice and harsh weather conditions during winter and spring. Drilling requires the disposal of cuttings and drill mud. In the SEIA of the Lofoten-Barents Sea area it is assumed that approx. 450 m^3 cuttings are produced and approx. 2,000 m^3 mud is used per well (Akvaplan-niva & Acona 2003). The drilling of the three exploration wells in the Disko West area in 2010 generated between 665 and 900 m^3 cuttings/well and in total 6000 t of drilling mud. Energy consumption is very high during drilling, resulting in emissions of combustion gases such as CO_2, SO_2 and NO_x.

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

Drilling mud and cuttings

Drilling muds are used to optimise drilling operations. 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 were the mud and the cuttings can be brought to land for treatment or can be deposited safely. Water based muds and the cuttings are usually released to the seabed after the drilling, where they may impact seabed fauna in the immediate surroundings.

Appraisal drilling

If promising amounts of oil and gas are located during the exploration, the commercial potential shall be appraised by establishing the size of the field and the most appropriate production method. Appraisal may take several years to complete. Several appraisal wells are drilled to confirm the size and structure of the field, and well logging (analysis) provides data on the hydrocarbon bearing rocks. Well testing provides hydrocarbon samples and information on flow rate, temperatures and pressures. If a commercial reservoir is confirmed, the operator may then proceed to development.

Other exploration activities

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

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

Development and production

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

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

Produced water

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

Produced water has usually been discharged to the sea after a cleaning process which reduces the amount of oil to levels accepted by the authorities (in the North Sea sector of Norway, for example, 40 mg/l or 30 mg/l as recommended by OSPAR). In applying BAT, Norwegian operators have committed themselves to further reduce these levels. Discharges of produced water and chemicals to the water column appear, due to the dilution effect, to have acute effects on marine life only in the immediate vicinity of the installations. But long-term effects of the releases of produced water have not been studied, and several uncertainties have been expressed concerning, for example, the hormone-disrupting alkylphenols and radioactive components with respect to toxic concentrations, bioaccumulation, etc. (Meier et al. 2002, Rye et al. 2003, Armsworthy et al. 2005).

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^3 exhaust per day (LGL 2005). Flaring of gas and trans-shipment of produced oil also contribute to emissions. The emissions consist mainly of greenhouse gasses (CO_2, CH_4), NO_x, VOC and SO_2. The production activities produce large amounts of CO_2 in particular, and, for example, the emission of CO_2 from a large Norwegian field (Statfjord) was more than 1.5 million t in 1999 (SFT 2000), and the drilling of the three exploration wells in 2010 in the Disko West area resulted in the emission of 105,000 t of CO_2.

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

Other activities

Ship transport of produced oil will be an integrated part of the production phase. The APA (2003) assessment presents a scenario where ships containing 1 million bbl will depart, within a 5-day cycle, from a highly productive field off Disko Island.

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

Accidents

There are serious, acute and long-term environmental concerns in relation to accidents and off-normal operations. Especially large oil spills represent a major threat to the Arctic environment (AMAP 2010).

3 Physical environment

Michael Dünweber

The assessment area covers the north-eastern Davis Strait and the south-eastern Baffin Bay. It is located within the Arctic climate zone, which means the average air temperature in July does not exceed 10 °C. Baffin Bay is a semi-enclosed oceanic basin that separates western Greenland and Baffin Island. To the north it is connected to the Arctic Ocean through a network of straits and basins that constitutes the Canadian Archipelago. In the south it is connected to the Labrador Sea via the Davis Strait. In terms of hydrography, the area is characterised by sub-Arctic waters from the North Atlantic and Davis Strait (average July temperature higher than 5 °C) in the southern part and the high-Arctic waters of Baffin Bay (average July temperature below 5 °C) in the northern part. The most significant feature in the physical marine environment is the presence of icebergs and sea-ice throughout a large period of the year. In the Davis Strait, west of Disko Island, the sea-ice normally forms in November and melts early June, depending on the severity of the winter (Nazareth & Steensboe 1998). The assessment area is north of the Polar Circle; therefore, continuous daylight is present for a period in summer, and in winter there is a period of near continuous darkness.

The shelf of the assessment area is rather shallow with several large banks, typically ranging between 20 and 200 m in water depth. In the southern part of the assessment area the shelf is up to 120 km wide, while in the northern part it is narrower and less well defined towards the deep sea. The shelf is traversed by deep troughs, which separate the fishing banks. There is deep water down to 2,500 metres to the west of the shelf.

3.1 Weather and Climate

The weather in West Greenland is determined by the North American continent and the North Atlantic Ocean. However, the Greenland Inland Ice and the steep coasts of Greenland have also a fundamental impact on the local weather. Many Atlantic depressions develop and pass near the southern tip of Greenland and cause frequently very strong winds off West Greenland. Also more local phenomena such as fog or polar lows are common features near the West Greenland shores. The probability of strong winds increases close to the Greenland coast and towards the Atlantic Ocean. A more detailed description of the local weather can be found in the sensitivity map covering the region (Clausen et al. 2012).

3.2 Oceanography

3.2.1 Currents

Along West Greenland flows the West Greenland Current with two principal components. Closest to the shore, the surface layer (0-150 m) is dominated by the East Greenland Current (with cold polar sea water) which moves northward (Figure 2). On its way, this water is diluted by run-off water from the various fjord systems. The other component (depth layer of 150-800 m) originates from the North Atlantic Current deriving from the Irminger Sea. This relatively warm and salty water can be traced all the way along West Greenland from Cape Farewell to Thule (Qaanaaq). The East Greenland Current component loses its momentum on the way northward and at the latitude of Fylla Banke (64° N) it is no longer a strong and solid current. A great proportion of the water mass is deflected westward towards Canada where it joins the Labrador Current. Further north the deflection towards west continues resulting in a further weakening of the current (Buch 2000).

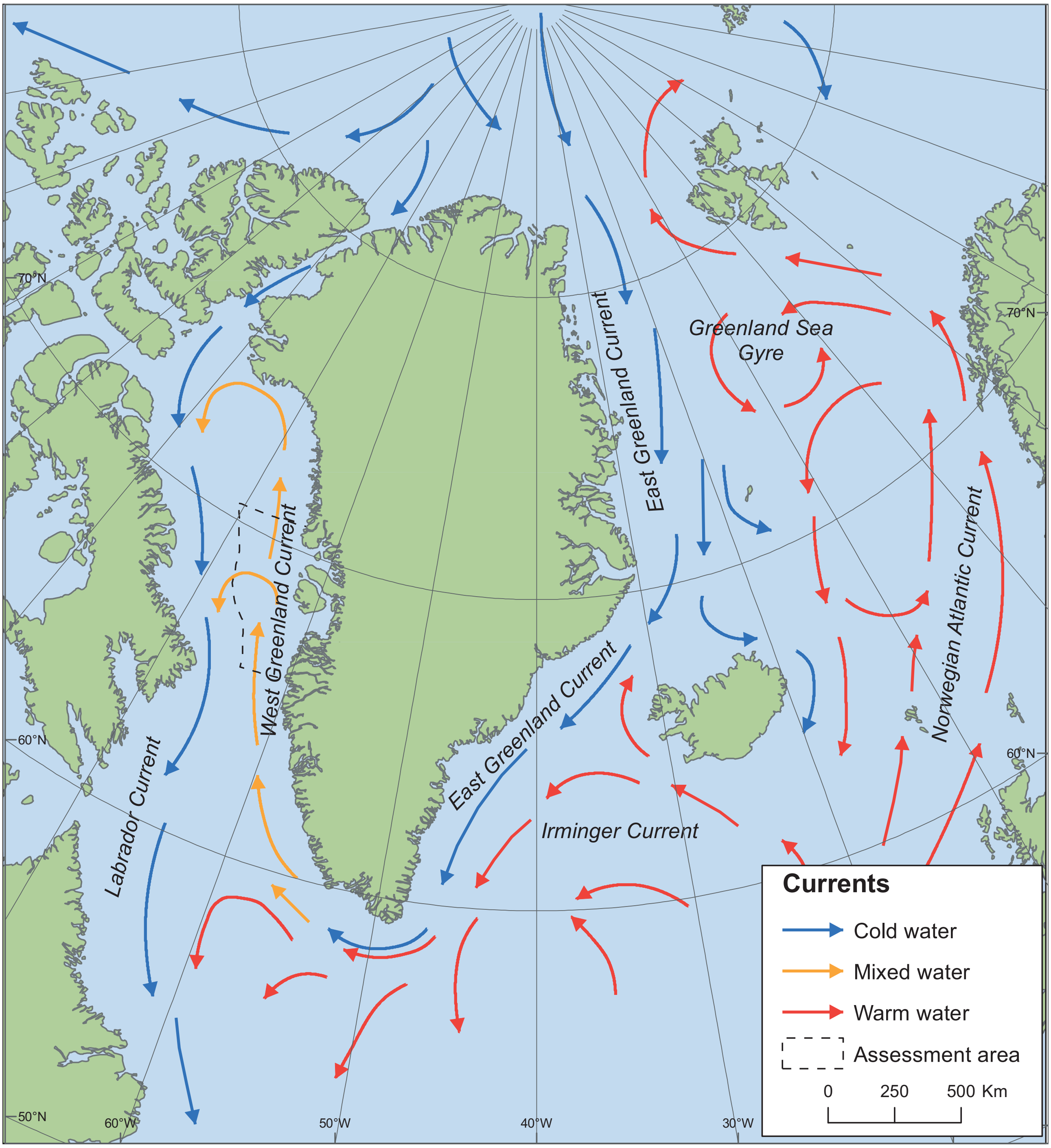


Figure 2. Major sea surface currents in the northern Atlantic. The red arrows indicate relatively warm sea surface water from the Atlantic, which meets with relatively cold sea surface water (blue arrows) of the East Greenland Current. Part of the Irminger Current turns towards Greenland south of the Denmark Strait moving southward and rounding Cape Farewell and continues northward as the West Greenland Current (orange arrows). The water moving southwards in Baffin Bay is part of the Baffin Current (or Baffin Island Current) which further south becomes the Labrador Current. Part of the water within the West Greenland Current moves northwards in Davis Strait, while another part turns west towards Canada at about 64°–67° N, and merges with the southward flowing Baffin Island/Labrador Current.

In the assessment area, including the Disko Bay the current patterns are influenced by the complex topography with several shallow banks that deflect the coastal currents and generate instabilities in the current field. (Söderkvist et al. 2006).

A fifty-year long time-series of temperature and salinity measurements from West Greenland oceanographic observation points has revealed strong inter-annual variability in the oceanographic conditions off West Greenland (Mosbech et al. 2004). However, over the past two decades there has been a tendency towards increased water temperatures and reduced ice cover in winter (Rothrock et al. 1999, Parkinson 2000, Hansen et al. 2006, Comiso et al. 2008).

3.2.2 Hydrodynamic discontinuities

Hydrodynamic discontinuities are areas where different water masses meet with sharp boundaries and steep gradients between them. This could be upwelling events where cold nutrient rich water is forced upwards to the upper layers, fronts between different water masses and ice edges (inclusive the marginal ice zone). Upwelling often occurs along the steep sides of the fishing banks driven by the tidal current, with upwelling thereby usually alternating with downwelling. Model simulations south of the assessment area predict that that most frequent upwelling occurs west of the banks, both north and south of the Disko Bay entrance and at the slopes of Store Hellefiskebanke. The upwelling events inside the Disko Bay and along the west coast of Disko Island were mainly wind driven during northerly and north-westerly winds (Figure 3 and 4).

3.2.3 The coasts

The coasts south of Disko Bay are dominated by bedrock shorelines with many skerries and archipelagos. In sheltered areas small bays with sand or gravel are found between the rocks. In the western Disko Bay and further north, the coast is more linear and often formed by sandy sediments or gravel. On Disko Island and

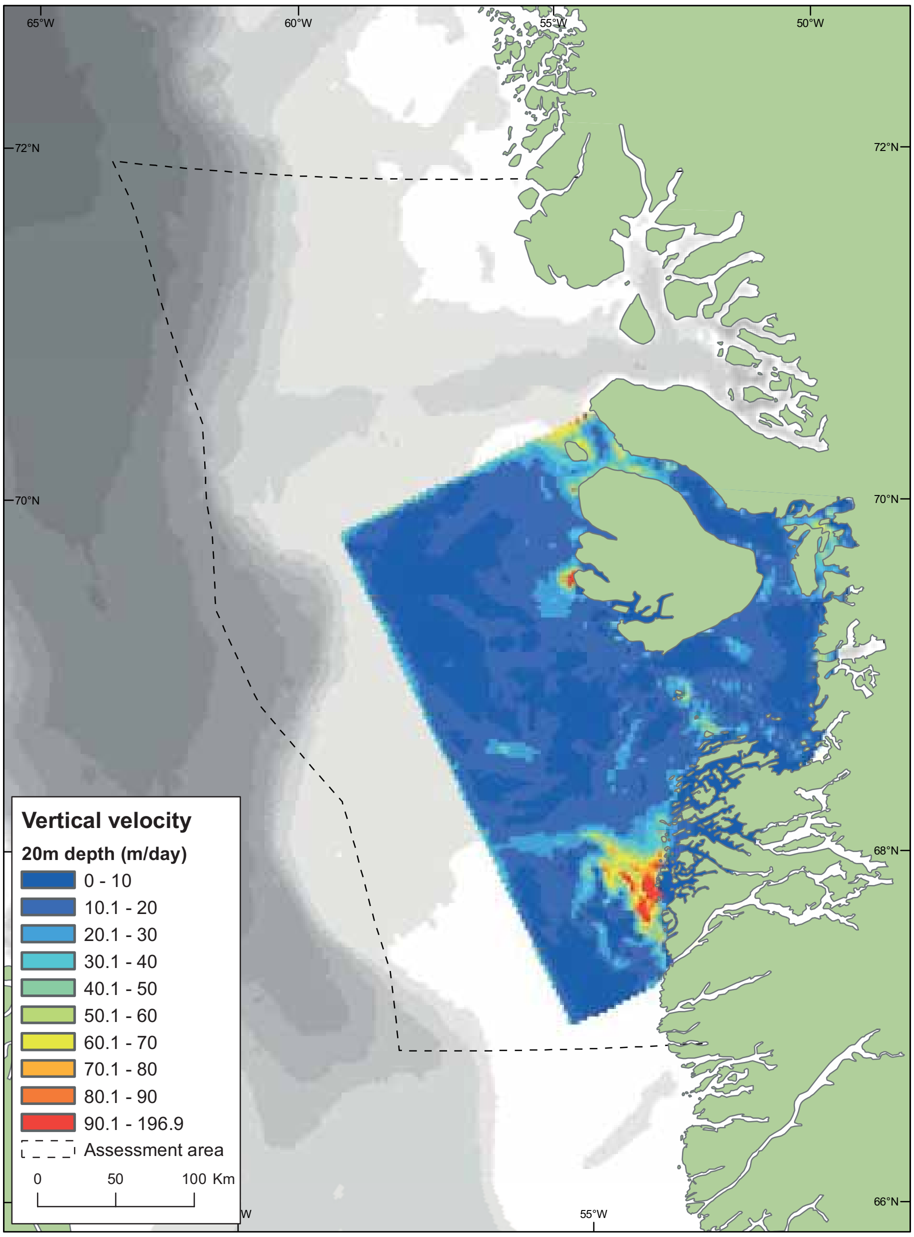


Figure 3. Areas with high rates of upwelling and downwelling as indicated by the standard deviation (sd) of the vertical speed in metres per day (m d^{-1}). The sd is calculated based on all the raw hourly data from the fine scale Danish Meteorological Institute (DMI)-model (DIS) within the period from April 1st to May 31st 2005 (at 20 m depth), in total 1463 time steps of 1 hour. Data is from DCE and DMI.

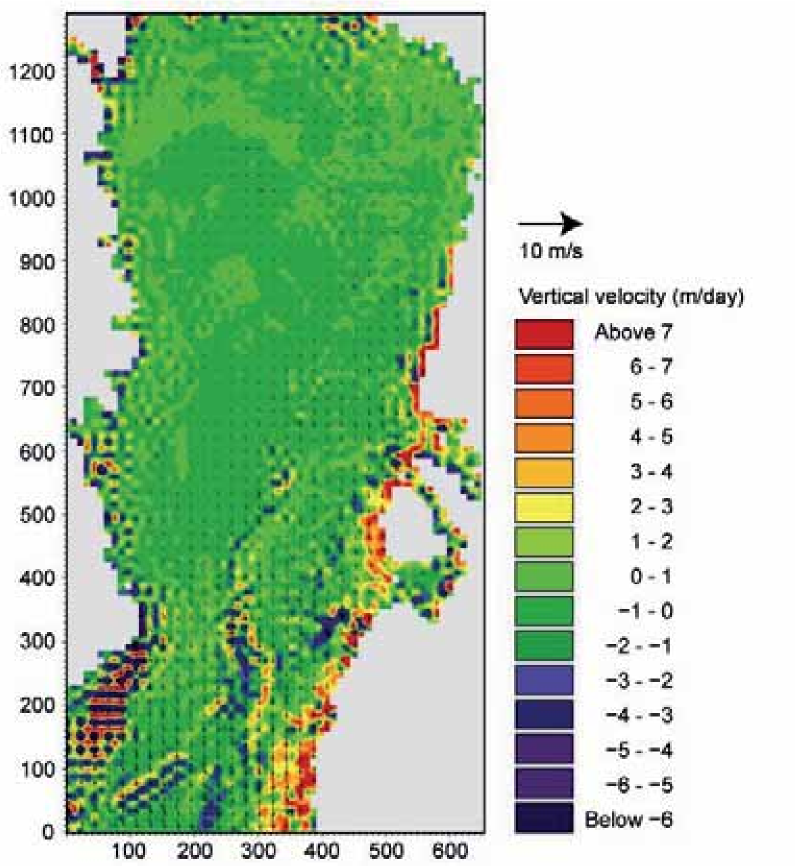


Figure 4. Daily mean value of vertical water velocity and wind speed in Baffin Bay on the 24th of April, 2005. Model results based on DMIs Hybrid Coordinate Ocean Model (HYCOM). The colour scale shows the upwelling velocity in metres per day and the arrows show wind speed. High vertical velocity suggests up/down-welling at 20 m depth. For this specific date there is strong upwelling along the Greenland west coast, especially near the Store Hellefiskebanke, which has an approximate coordinate on the map at (400, 300). Large vertical velocities as presented here is a very common model feature during late winter and spring 2005. The present model set up is described in detail in Ribergaard et al. (2006).

the Svartenhuk Peninsula several large river deltas with extensive tidal flats are found. In terms of shoreline length, the 'rocky coast' is by far the dominant shore type (61%). 'Rock' is the dominant substrate (71%); 'inclined' is the dominant slope (58%) and 'semi-protected' is the dominant exposure type (60%). The majority of the coasts within the 'archipelago' shore type are rocky coasts. Together the 'archipelago' and 'rocky coast' constitute 72% by length of the total investigated shoreline within the assessment area (Clausen et al. 2012).

3.3 Ice conditions

The assessment area is influenced by the relatively warm north or northwest flowing West Greenland Current and the south flowing Baffin Current transporting cold Arctic water. The West Greenland Current creates open water in winter along the southwest Greenland coast, usually to Disko Island. Ice starts to form in the open water in the northern Baffin Bay in September and the ice cover increases steadily from north to south reaching a maximum in March when the entire bay is covered by ice. Isolated from the offshore sea-ice conditions, ice forms locally throughout the winter in most of the fjords and coastal waters of the region. Generally freeze-up begins at the inner parts of the fjords in November or December, but very low temperatures can significantly affect the ice formation, or a formed ice cover can be reduced by very strong winds in the fjords throughout the winter (Nazareth & Steensboe 1998). The West Greenland Current delays the time of sea-ice formation in the eastern Davis Strait and results in an earlier breakup of the sea-ice than in the western parts. Thus, there is always more ice cover in the western than in the eastern half of Baffin Bay. The Baffin Island Current conveys large amounts of sea-ice from Baffin Bay to the Davis Strait and the Labrador Sea for most of the year, especially during the winter and early spring months. During this period sea-ice normally covers most of the Davis Strait north of 65° N, except areas close to the Greenland coast. Here a flaw lead (open water or thin ice) of varying width often appears between the shore and the West ice, as far north as latitude 67° N.

3.3.1 The West Ice and drift patterns

Two types of sea-ice occur in winter and spring: Drift ice, mainly first year ice, formed in the Baffin Bay and Davis Strait, but with some multiyear ice of Arctic Ocean origin. The other type is fast ice anchored to the coast. The drift ice is termed 'West Ice' and it is very dynamic and consists of floes in varying size and degree of density. In late summer there is almost complete clearance of sea-ice in the Davis Strait west of Disko Island (Nazareth & Steensboe 1998) (Figure 5). It seems that the average sea-ice extent in March has decreased in the past 15 years when compared to the situation in the 1980 (Figure 6).

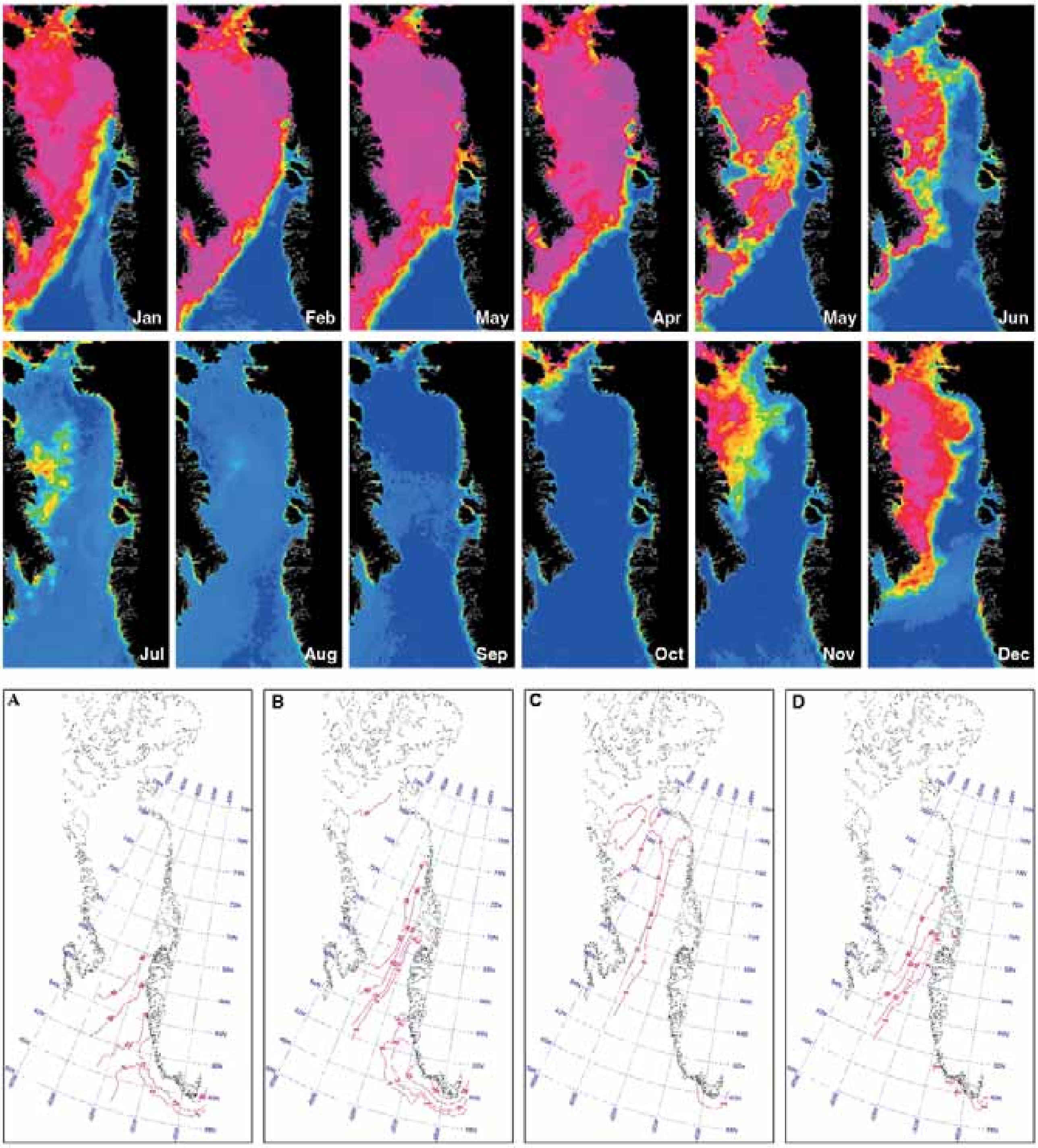
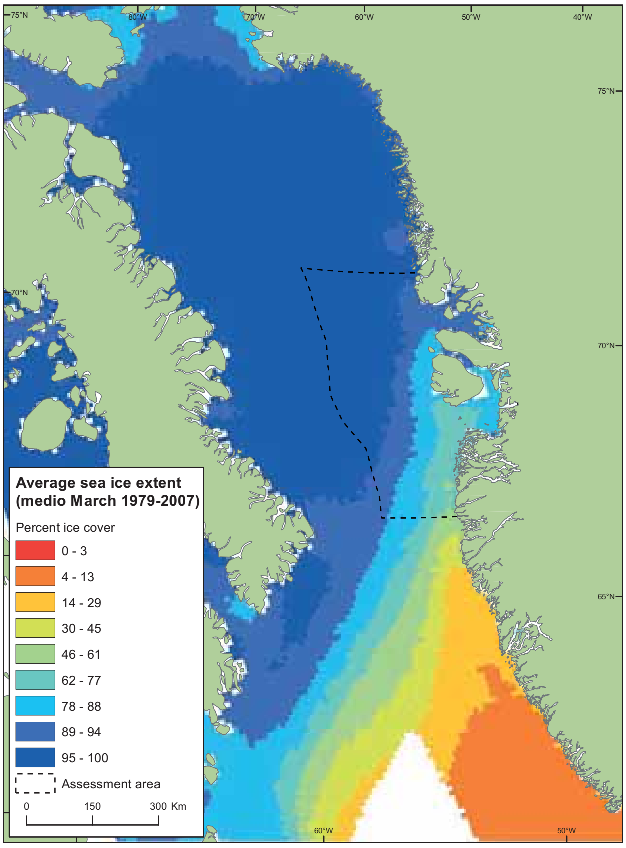
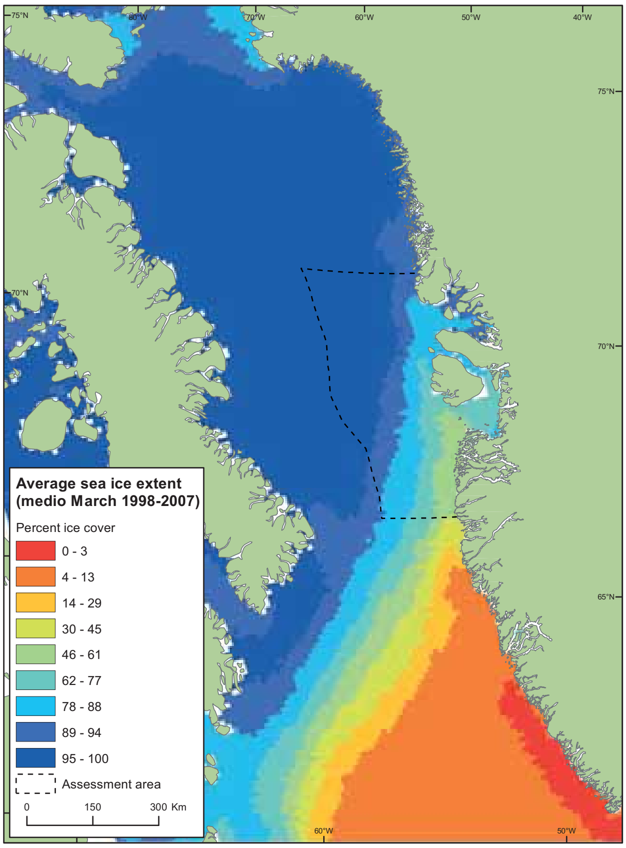
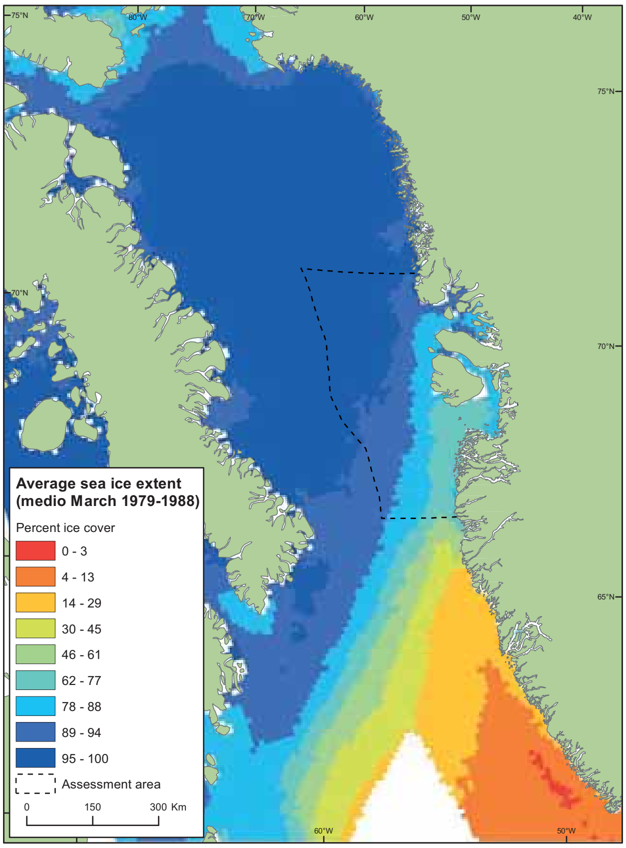


Figure 5. The upper panel is the monthly sea-ice cover in 2010. From the upper left row to the right are the months of January to June, and following July to December from the lower left row. Red and magenta in the maps in the upper two rows indicate the very dense ice (8-10/10), while yellow indicate somewhat looser ice. The loosest ice (1-3/10) is not recorded. Images based on Multichannel Microwave Radiometer (AMSR and SMMR). Lower panel is the probability of sea-ice in West Greenland waters based on data from the period 1960-96. (**A**) March 1st, (**B**) June 4th, (**C**) September 3rd and (**D**) December 3rd. Data source: The satellite pictures in the upper panel are processed by The Technical University of Denmark (DTU) with support from The European Space Agency (ESA)'s PolarView project and the maps in the lower panel is from The Danish Meteorological Institute (DMI) and Canadian Ice Service.

Figure 6. The average sea-ice extent (mid-March) as percentage ice cover in West Greenland waters. Upper map is based on data in the period 1979-2007 and lower maps are based on data in the period (to the left) 1979-1988, (to then right) 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 range from large floes of about 1 km wide to vast floes larger than 10 km. Near the marginal ice zone in the Davis Strait, the size of the common floes are reduced to less than 100 metres as a result of melting and break up by waves. These floes are however, often consolidated, forming extensive areas without any open water (Nazareth & Steensboe 1998).

The drift pattern of the sea-ice off West Greenland is not well known. The local drift is to some extent controlled by the major surface current systems, the West Greenland Current and Baffin Island Current. The strength and direction of the surface winds also affect the local drift of sea-ice, especially in the southern waters. However, only small amounts of the thicker packice drift to the assessment area through Lancaster Sound and Nares Strait. During winter and early spring, packice is conveyed south along Baffin Island to Davis Strait and Labrador Sea. In the beginning of the melt season the eastern part of the Davis Strait, south of Disko Island, is free of sea-ice during this period whereas drifting ice dominates to the west and north (Nazareth & Steensboe 1998).

The sea-ice drift pattern was studied in the assessment area in April 2006 (Valeur et al. 1996). In April 2006: two satellite transmitters were deployed on the sea-ice, west of Nuussuaq Peninsula. One was tracked until June, when it had moved approx. 500 km in total (entire length of track line), but overall it had only moved 66 km towards the southwest. The second transmitter was only tracked for a couple of days, when it moved 21 km towards the south (Mosbech et al. 2007a). (See Figure 9 in Appendix 1, p. 308).

3.3.2 Polynyas and shear zone

Polynyas are open waters in otherwise ice-covered waters. They are predictable in time, and are of high ecological significance. Small polynyas are found at several sites along the West Greenland coast.

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

Along the coast of the assessment area there are several areas where open water is present in the winter, or at least in spring. During a typical spring these are progressively included in the open waters advancing from the south. The most significant polynyas are found in mouth of the fjords where the tidal currents keep the water free of ice, as for example in the mouths of the Vaigat and the fjord Arfersiorfik. The open waters in the Disko Bay mouth could also be seen as a polynya, although it is often connected to the open waters further south.

3.3.3 Icebergs

Icebergs differ from sea-ice in many ways:

- they originate from glaciers
- they produce freshwater when melting
- they can be deep-drafted, and have appreciable heights above sea level
- they are always considered as an serious hazard to navigation and offshore activity

The process of calving from the front of a glacier produces an infinite variety of icebergs, bergy bits and growlers. Icebergs are described by their size according to the classification in Table 1.

The volume of icebergs produced varies only slightly from year to year. Once they are released from the glacier, meteorological and oceanographic factors begin to affect the icebergs, and they are carried by sea currents. However, wind also plays an important role, either directly or indirectly.

Table 1. International iceberg classification.

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

3.3.4 Iceberg sources

Glaciers are numerous in West Greenland; however, the most productive glaciers are concentrated between Nares Strait and Disko Bay e.g. Jakobshavn Isbræ glacier. In general, icebergs occur in all West Greenland waters, but with considerable variation in density. In Disko Bay for example, hundreds of icebergs are present throughout the year (Figure 7).

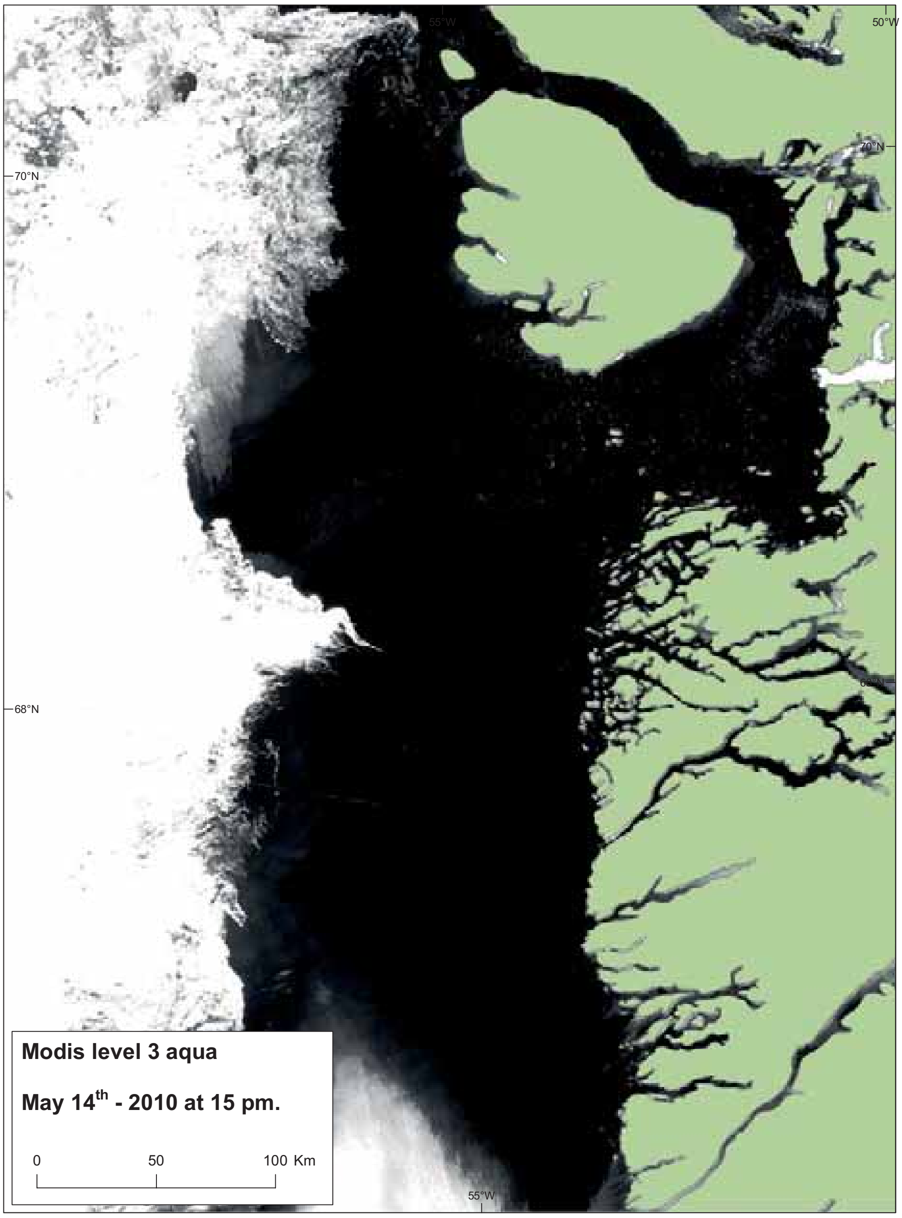


Figure 7. Modis Aqua image from May 24th 2010, 20 UTC of the Disko Bay area showing the distribution of large icebergs (white dots). Data source: The satellite picture is processed by The Danish Meteorological Institute (DMI) with support from The Greenland Climate Research Centre and The European Space Agency (ESA)'s PolarView project.

Figure 8. Major iceberg sources and general drift pattern in the West Greenland waters. Data source: The National Ice Centre (NIC).

Melville Bay, to the north of the assessment area, is a major source for icebergs. Over 10,000 icebergs are calved from 19 major glaciers each year (Figure 8). The volume produced in this region was estimated at 60 km^3 annually. Some of these glaciers are capable of producing icebergs of about 1 km in diameter. Several active glaciers in Uummannaq Fjord and Disko Bay produce 10-15,000 icebergs per year, and they are very important for the iceberg input to the northern Davis Strait and Baffin Bay. The most active glacier is located near Ilulissat, moving at the rate of 20 m/day. This glacier produces over 20 km^3 of ice per year. The total annual production of icebergs calved in the Baffin Bay and the northern Davis Strait is estimated to be about 25-30,000; estimates however vary, up to as high as 40,000 (Nazareth & Steensboe 1998). These estimates may not be current any more, due to climate change.

3.3.5 Iceberg drift and distribution

On a large scale the drift of icebergs in Baffin Bay and the northern Davis Strait is fairly simple. 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 north-eastern Baffin Bay and Melville Bay before heading southward, icebergs have also been observed to be diverted into one of the west-branching eddies without passing north of 70° N. Most of the icebergs from Baffin Bay drift southward in the western Davis Strait, joining the Labrador Current further south, although some may enter the eastern Davis Strait area west of Disko Island instead. Icebergs produced in Disko Bay or Baffin Bay generally will not reach the Greenland shores south of 68° N. Many icebergs produced in the Disko Bay enter the Davis Strait, partly to the north of Disko Island through Vaigat and partly along the southern coast of Disko Island. Some icebergs manage to drift towards or into southern Disko Bay from the Davis Strait due to the onshore component of the currents west of Aasiaat. Most of the icebergs south of Sisimiut are of East Greenland origin.

A study in the late 1970s, found that the density of icebergs in Disko Bay was significantly higher than outside the bay, with maximum concentrations of icebergs occurring in the northeastern part of Disko Bay (Nazareth & Steensboe 1998, Karlsen et al. 2001, and references therein).

3.3.6 Iceberg dimensions

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

In the eastern Davis Strait the largest icebergs were most frequently found south of 64° N and north of 66° N. South of 64° N, the average mass of an iceberg near the 200 m depth contour varied between 1.4 and 4.1 million t, with a maximum mass of 8.0 million t. Average draft was 60-80 m and maximum draft was 138 m. In between 64° N and 66° N, average masses were between 0.3 and 0.7 million t. The maximum mass was 2.8 million t. Average draft was 50-70 m and maximum draft was estimated to be 125 m. The largest icebergs north of 66° N were found north and west of Store Hellefiskebanke. The average iceberg mass was about 2 million t with a maximum mass of 15 million t. In Disko Bay, the average mass of icebergs was in the range 5-11 million t with a maximum recorded mass of 32 million t. Average draft was 80-125 m and maximum draft was 187 m. It is worth noting that many icebergs are so deeply drafted that they will not drift into shallow water regions (Nazareth & Steensboe 1998, and references therein).

The largest icebergs recorded in Baffin Bay in 1997 had a draft of more than 260 m, a mass of up to 90 million t and a diameter of more than 1,400 m.

4 Biological environment

4.1 Primary productivity

Michael Dünweber

4.1.1 General context

The primary production in the waters off West Greenland is generally high and equal to or even higher than the production at lower latitudes. Owing to the presence of winter ice and the marked variation in solar radiation is it highly seasonal with an intensive phytoplankton bloom in spring.

The spring phytoplankton bloom in the Disko West area

The development of the phytoplankton (microscopic algae) spring bloom is the single most important event determining the production capacity of Arctic marine food webs. The spring phytoplankton bloom (i.e. spring bloom) is indicated by a peak in the primary production in the water column. The time of the onset of the spring bloom is determined by withdrawal of the sea-ice covering the Davis Strait and Baffin Bay and with the increased solar input and stabilisation of the water column. However the onset of the spring bloom may vary between years depending on the time of ice break-up. Usually, the spring bloom is initiated in late April and develops through May and the biomass develops exponentially and quickly the nutrients in the surface layers (the euphotic zone) are depleted, presumably inhibiting the biomass production over a period of time (Figure 9).

In addition to the magnitude of the spring bloom, it is important to know the proportion of organic carbon recycled through the microbial loop, the proportion available to pelagic consumers and the amount which is 'lost' when sinking to the bottom, thus becoming food for benthic fauna (benthic-pelagic coupling) (Møller & Nielsen 2000, Juul-Pedersen et al. 2006, Dünweber et al. 2010).

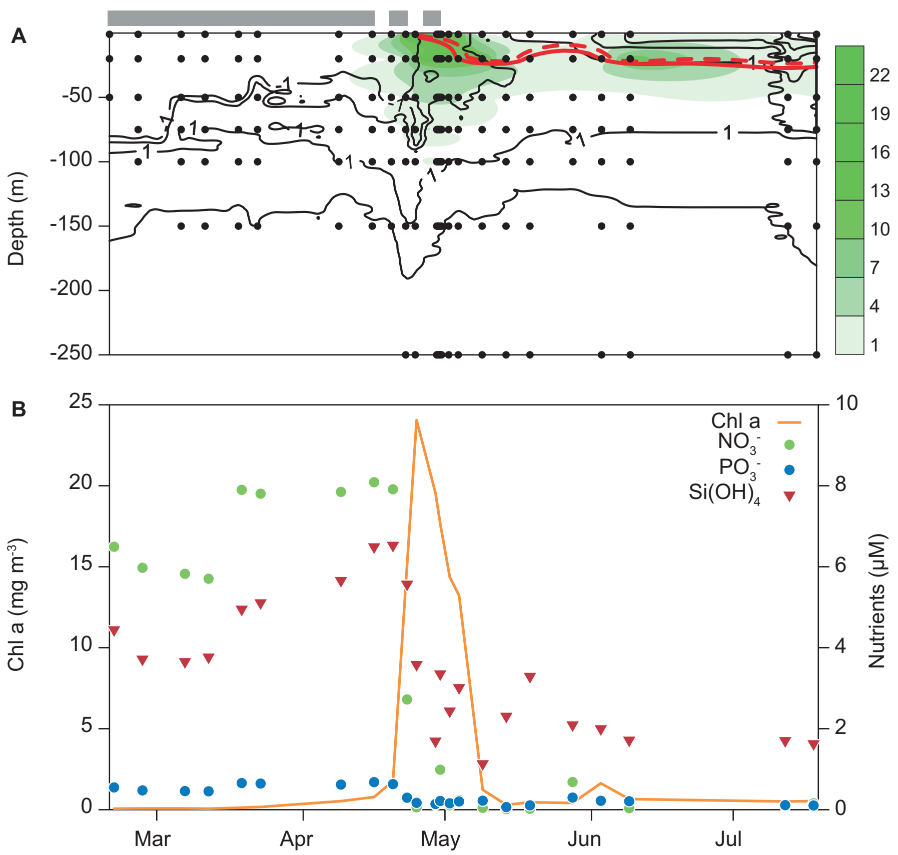


Figure 9. Water column characteristics in Disko Bay off Qeqertarsuaq in 2008 (Dünweber et al. 2010). Upper panel (**A**): Isolines are water temperature (°C) and the green coloration illustrates chlorophyll *a* (chl. a) concentrations (mg m^{-3}). The concentration of the limiting nutrient nitrate is displayed as red isolines (solid: 1.0 µM, broken: 0.5 µM). Points: sampling depths; grey bar on top of figure illustrates sea-ice and time of break-up. Lower panel (**B**): Succession in the surface layer (1 m) of chl. a (mg m^{-3}) and nutrients concentrations (µM). Immediately after sea-ice break-up, the spring phytoplankton bloom is initiated and followed by depletion of inorganic nutrients. Chl. a is a measure of amount of phytoplanktion.

At ice edges, the phytoplankton bloom is often earlier than in ice-free waters due to the stabilising effect of the ice on the water column. However, at sites where nutrients continuously are brought to the uppermost water layers, for example by upwelling or fronts, primary production may be high throughout the summer.

Upwelling events can be persistent over long periods, although those driven by the tidal currents vary with the tidal cycle, while others are wind driven and vary with the wind conditions. Upwelling areas are for example found at the northeastern corner of Store Hellefiskebanke and in outer Disko Bay and around Hareø (Figure 3 and 4). Upwelling areas may, besides enhanced production, also retain copepods and other plankton over the banks (Munk et al. 2003, Simonsen et al. 2006).

4.1.2 Productivity at polynyas, shear and marginal ice zones

In polynyas (Section 3.3.2) the primary production starts much earlier than in ice-covered areas; and they are often preferred feeding areas for marine mammals and seabirds. Also the mere presence of open water makes polynyas attractive for resting seabirds and for mammals which are dependent on open waters for breathing. Polynyas are also used by many migrating seabirds as staging areas on their way to the breeding grounds further north. Cracks and leads with open waters are frequent in the shear zone and may attract marine mammals and seabirds. When the West Ice reaches the coasts of the assessment area a shear zone and polynyas (e.g. in the mouth of Vaigat) are usually present (Section 3.3.2). At the marginal zone of the West Ice, primary production during the spring bloom is very intense and this attracts species higher in the food web including seabirds and marine mammals (Wassmann et al. 1999, Falk-Petersen et al. 2009).

In spring 2006, a multidisciplinary ecological survey was conducted in the assessment area with focus on the marginal ice zone. The programme included sampling of biological and oceanographic parameters on transects from open water and into the drift ice through the marginal ice zone. Sampling included CTD measurements, i.e. depth distribution of salinity and temperature, fluorometer measurements i.e. indicating depth distribution of chlorophyll a (chl. *a* – a measurement for amount of phytoplankton) fluorescence, and water samples for nutrients and chl. *a* as well as net hauls for zooplankton composition and biomass.

In summary, at the northern parts of Store Hellefiskebanke, the chl. *a* bloom started earlier and was much stronger than observed elsewhere in the region. In the deep water 'wedge' between the bank and the coast east and northeast of Store Hellefiskebanke there were also higher chl. *a* levels in the deep water layers. In half of the area investigated, concentration of chl. *a* increased more than 10 fold during the survey period, indicating initiation of the spring phytoplankton bloom during the study period. For more detailed description on the 2006 survey see Söderkvist et al. (2006), Mosbech et al. (2007a) and Frederiksen et al. (2008). North of Store Hellefiskebanke, in Disko Bay and west of Disko Island, the plankton bloom starts when stratification is stabilized and strong enough to keep the plankton in the upper photic parts of the water column, typically in late April. Söderkvist et al. (2006) showed that only a weak stratification is needed to initiate the plankton bloom, which was generated by upwelling of warmer and more salty water from below. The overall distribution of chl. *a* during the sampling period showed relatively high levels in central and southern part of Disko Bay as well as west of southern Disko Island (west of Disko Fjord). The marginal ice zone is an important habitat for a high productivity in the assessment area in spring.

4.2 Zooplankton

Michael Dünweber

4.2.1 General context

Zooplankton has an important role within marine food webs also in the Arctic, since it provides the principal pathway of energy from primary producers (phytoplankton) to consumers at higher trophic levels, such as fish, seabirds or marine mammals. The bowhead whale and the little auk are specialised feeders on large copepods of the genus *Calanus* (Karnovsky et al. 2003b, Laidre et al. 2007). In Arctic marine ecosystems most of the higher trophic levels rely on the lipids that are accumulated in *Calanus* (Falk-Petersen et al. 2009). Consequently, a great part of the biological activity e.g. spawning and growth of fish is synchronised with the life cycle of *Calanus*. Zooplankton not only supports the large, highly visible components of the marine food web but also the microbial community. Regeneration of nitrogen through excretion by zooplankton is crucial for bacterial and phytoplankton production (Daly et al. 1999, Møller et al. 2003). Zooplankton products (faecal pellets) also sustain diverse benthic communities such as bivalves, sponges, echinoderms and sea anemones when sinking down to the seabed (Turner 2002, and references therein). The *Calanus* copepods play an ecological key role in supplying the benthic communities with high quality food by their large and fast sinking faecal pellets (Juul-Pedersen et al. 2006).

4.2.2 The importance of *Calanus* copepods

Earlier studies on the distribution and functional role of zooplankton in the pelagic food web off Greenland, mainly in relation to fisheries research, have revealed the prominent role of *Calanus*. The species of this genus feed on algae and protozoa in the surface layers and accumulate surplus energy in form of lipids which are used for overwintering at depth and to fuel reproduction in the following spring (Lee et al. 2006, Falk-Petersen et al. 2009, Swalethorp et al. 2011). Their life cycles have been estimated to be 1–5 years, including 11 larvae stages. 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, shrimps and squid (Smith & Schnack-Schiel 1990, Dahl et al. 2000) and in the bowhead whale and the northern right whale (*Eubalaena glacialis*), which eat mainly *Calanus* (Hoekstra et al. 2002, Zachary et al. 2009). Consequently, many biological activities – e.g. spawning and growth of fish – are synchronised with the life cycle of *Calanus*. Larvae of Greenland halibut and sandeel from the West Greenland shelf had mainly various copepods species, including *Calanus* in their stomachs May, June and July. *Calanus* constituted between 88 % and 99 % of the ingested prey biomass (Simonsen et al. 2006).

Vertical distribution of the *Calanus* species varies through the year. They are in deep waters in the winter season and in the light spring/summer season they move into surface depths (Falk-Petersen et al. 2009). In late summer and autumn, *Calanus* descent to deep water layers for winter hibernation, changing the plankton community structure from *Calanus* to smaller copepods and protozooplankton dominance (Levinsen et al. 1999, Madsen et al. 2008). The grazing impact on phytoplankton by the smaller non-*Calanus* copepods community after *Calanus* has left the upper layer can be considerable higher than in spring. This is a result of shorter generation time and more sustained reproduction and a relaxed food competition and predation by *Calanus* (Hansen et al. 1999, and references therein). The importance of small non-*Calanus* populations in ecosystem productivity could be greater than implied by their biomass alone (Hopcroft et al. 2005, Madsen et al. 2008).

4.2.3 Zooplankton in the Disko West area

The zooplankton communities in the waters off West Greenland are dominated by the large copepods of the genus *Calanus* (incl. their larval stages) during the greater part of the year (Pedersen & Smidt 2000, and references therein). Investigation performed in the Disko Bay area clearly corroborates the hypothesis that most of the biological activity in the surface layer is takes place in the spring and early summer in association with the spring phytoplankton bloom (i.e. spring bloom) and the appearance of the *Calanus* populations. The peak abundance of shrimp and fish larvae is also observed in the early summer in association with the peak abundance of their plankton prey (Söderkvist et al. 2006). *Calanus* occur widespread in the West Greenland waters where high numbers have been recorded in Disko Bay and both on the banks and west of the banks in deep waters (Figure 10).

However, not very much is known about the autumn situation, when different seabird species migrate to the south crossing the Disko West area, and if and how their distribution is linked to the distribution of lower trophic level organisms (e. g. fish and zooplankton). In the North Water Polynya (NOW), northern Baffin Bay, many millions little auks breed and consume large amounts of *Calanus* spp. (Karnovsky & Hunt 2002, Karnovsky et al. 2003b, Karnovsky et al. 2008).

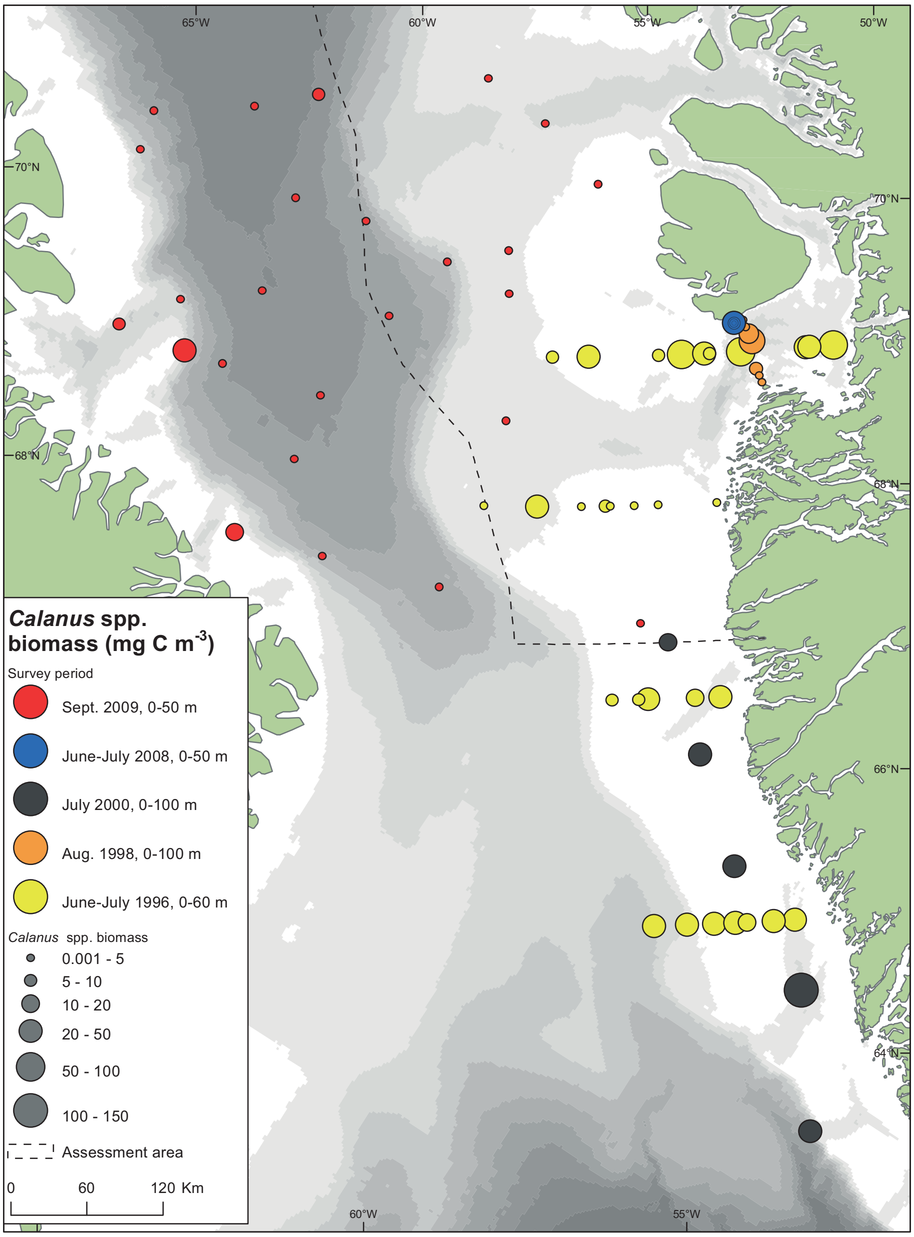


Figure 10. *Calanus* spp. biomass (mg C m^{-3}). The coloured dots represent biomass values from different studies; Red dots: Disko West survey, September 2009 (NERI). at 0-50 m; Blue dots: July 2008 (Dünweber et al. 2010) at 0-50 m; Dark grey dots: July 2000 (Pedersen & Smidt 2000) at 0-100 m; Orange dots: August 1998 (Møller & Nielsen 2000) at 0-100 m; Yellow dots: June-July 1996 (Munk et al. 2003) at 0-60 m column. The biomass values of *Calanus* spp. from different studies in summer and an autumn period indicate high biomasses near the coastal zones. Seasonal descend towards winter hibernation is presumed to have been initiated in September. Note: Biomass values are calculated based on different length-carbon regressions and different sampling gear e.g. net types vary between studies.

In order to locate areas of particularly importance for both zooplankton and seabird accumulations a study was performed in the central parts of the assessment area in September 2009. Ship-based oceanographic sampling along transects were combined with ship-based and airborne seabird observations. Ship-based sampling included CTD measurements, i.e. depth distribution of salinity and temperature, chl. *a* measurements, as well as net hauls and trawls for zooplankton composition and biomass. The main results of the study are described in Box 1.

4.2.4 Zooplankton dynamics in the coastal areas

The possible link between hydrographical processes and plankton variability was studied in the Disko Bay and across important fishing banks off the west coast of Greenland (Munk et al. 2003). That study found a close relationship between plankton distribution and hydrographical fronts. And also that specific plankton communities were established in different areas of the important fishery banks of West Greenland. It seems that the direction of major currents and the establishment of hydrographical fronts are of primary importance of structuring the plankton communities in the West Greenland shelf area, influencing plankton assemblage and the early life of fish.

Other important areas of potential high biological activity are the upwelling areas. Møller & Nielsen (2000) revealed a three time higher biomass of mesozooplankton close to the Hunde Ejland in Disko Bay, than in samples taken farther away. Hunde Ejland is situated in the mouth of Disko Bay with extensive upwelling areas around the islands.

4.2.5 Higher trophic levels – large zooplankton and fish larvae

Distribution of larger zooplankton species and fish such as krill (*Meganyctiphanes norvegica*) and capelin (*Mallotus villosus*) was examined in September 2005 by Bergström & Vilhjalmarsson (2007) as well as their association to large baleen whales in West Greenland (Laidre et al. 2010). Krill were found in scattered aggregations in most of the area with a pronounced increased occurrence between 66° and 70° N, e.g. in Disko Bay (Figure 11). Capelin was absent on the banks but present in the fjords and near shore areas (between 70° and 60° N) (Figure 12). Biomass of capelin in these fjords and near shore areas was estimated to be between 170-200 thousand t. In West Greenland waters, capelin is spawning in coastal waters and usually staying in the many fjords and fjord systems.

Larvae of fish and shrimp are important components of the plankton, and their movements and behaviour have been studied for some of the commercially utilised species. The horizontal distribution of shrimp (Pedersen et al. 2002, Storm & Pedersen 2003, Söderkvist et al. 2006) and fish larvae (Munk 2002, Munk et al. 2003, Simonsen et al. 2006) has been investigated in relation to hydrography and potential prey along West Greenland. The highest abundance of shrimp and fish larvae was found 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, shrimp and fish larvae confirm that the productive cycle in Disko Bay is highly pulse-like in nature, and that the important sites for the development of large zooplankton, shrimp and fish larvae are the slopes of the banks and the shelf break and in Disko Bay where the highest biomass of their prey (copepods) was located.

Box 1. Coupling lower trophic level to seabird distribution

M. Dünweber, S. Kjellerup, D. Schiedek, D. Boertmann, A. Mosbech and K.L. Johansen

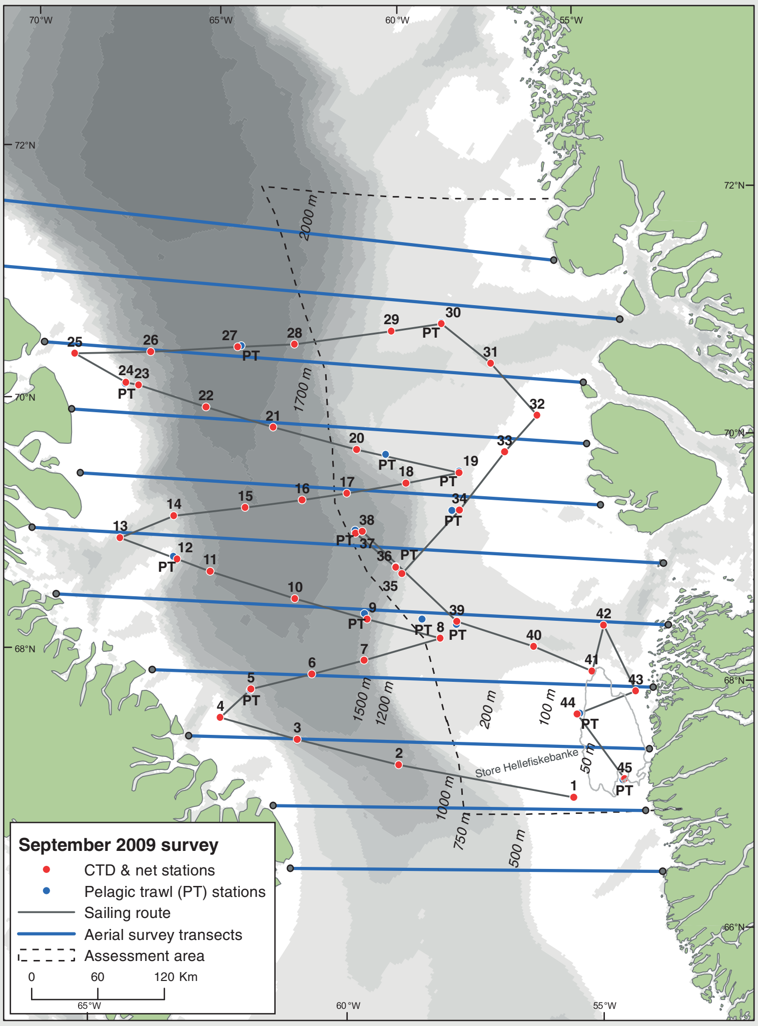


Figure 1. Map showing the ship-based transects (red line) and the aerial transects (blue line) during the Disko West survey in September 2009. Station numbers and positions of CTD measures and zooplankton samples (red dots, n=45), pelagic trawls - PT (blue dots, n=15).

In September 2009, a ship-based study was carried out in the Davis Strait/southern Baffin Bay along a range of transects covering the area between the west coast of Greenland and Baffin Island (Canada) from 68-72º N (Fig. 1). Water temperature, salinity and in situ chlorophyll a (chl. a) measured in 0-500 m depths followed the general hydrographical characteristics of the late summer situation (Fig. 2). Surface chl. *a* concentration based on remote sensing satellite data from September 2009 (Fig. 3) supported these findings. Measurement of in situ chl. *a* concentrations revealed a maximum in the subsurface (30-50 m water depths). Thus, spatial distribution of the phytoplankton bloom was often restricted to subsurface rather than the surface waters and therefore not detected by the remote sensing during September.

Zooplankton communities, their distribution and link to higher trophic levels

The zooplankton assemblage was represented by copepod taxa characteristic for the marine Arctic environment and was mainly composed of the following large copepod species (importance in terms of biomass): Calanus hyperboreus, *C. glacialis* and *C. finmarchicus* and *Metridia longa*, and non-copepod species such as *Chaetognatha* spp., *Oikopleura* spp., *Themisto libellula* and *Aglantha* spp. Smaller copepod species such as *Pseudocalanus* spp., *Oithona similis* were also present and a few *Oncaea* spp. and *Microcalanus* spp. (data not shown).

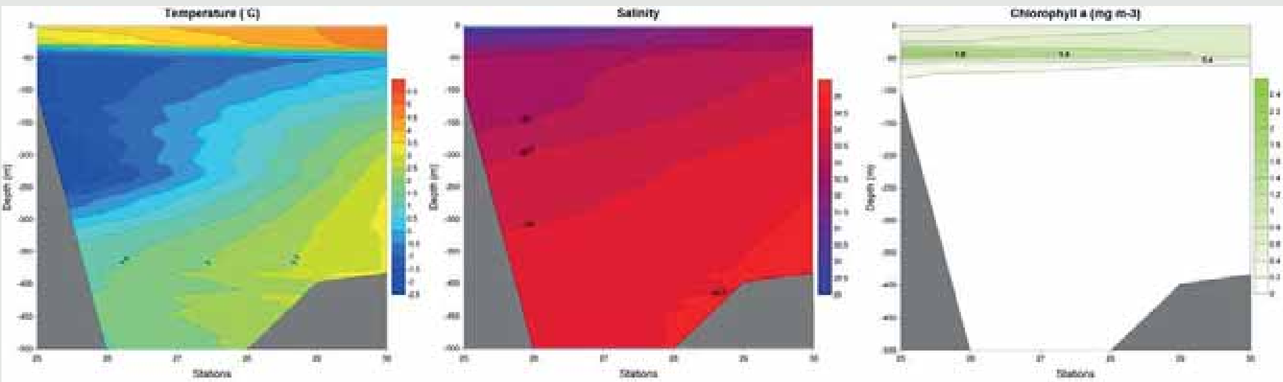


Figure 2. Transect performed during the ship based survey in September 2009 documenting temperature (ºC), salinity and chlorophyll *a* (chl. *a*) concentration (mg m^{-3}); Figure 1 for transect station numbers. Relative warm surface waters (up to 5-6 °C) and salinity around 30 is typical during summer and autumn as a result of solar heating and glacial melting. The cold intermediate waters (50-250 m column), with a cold core (-2 °C) close to the Canadian Shelf is presumably caused by the Baffin Island Current, originating from polar water through the Nares Strait. The relatively warm and high saline bottom water close to the Greenland Shelf is presumably due to the warm Irminger Current which is sub-ducted under the Polar Current, forming the West Greenland Current. The relatively cold, low saline intermediate water mass between 50-100 m close to the Greenland Shelf is presumably a mixing zone of glacier water and the West Greenland Current. The main chl. a concentration seems to be associated with a pycnocline in 40-50 m depth.

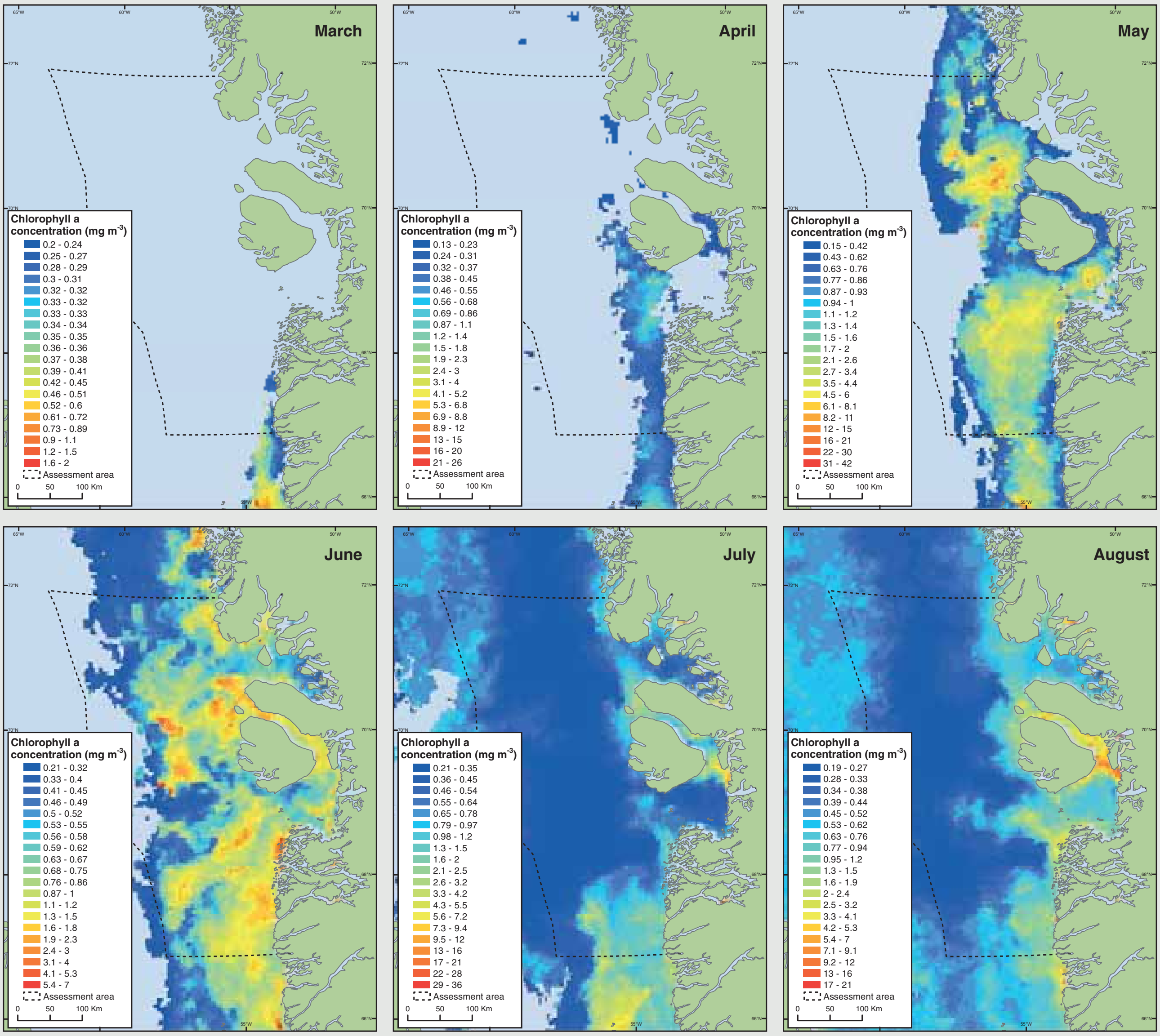


Figure 3. Sea surface chlorophyll *a* (chl. *a*) concentrations (mg m^{-3}) in September 2009. Data are presented as a monthly average from MODIS level 3 aqua. The colours indicate different chl. a concentrations: blue areas – very low; red – high chl. *a* concentration; white – no data. The chl. *a* concentration showed relatively high levels, mainly in the northern Davis Strait, at Store Hellefiskebanke and close to the Greenlandic coast. A high chl. *a* concentration was also observed more locally in Disko Bay, Vaigat, Nuussuaq and in the northern limits of the assessment area. (Source: Oceancolor homepage, NASA).

The relatively high biomass on the Canadian Shelf (CS) as well as the spatial distribution of the zooplankton are likely a result of the surface and subsurface chl. *a* concentrations in that area. A high zooplankton biomass was also found at Store Hellefiskebanke (0-50 m), in the southern part of the assessment area, where the main surface chl. *a* bloom was located (Fig. 4). *Calanus* represented the main species on the CS (0-50 m depth stratum; Fig. 5 and 6), as well as in the deeper waters in the Deep Basin (DB) and on the Greenlandic Shelf (GS). Some spatial trends were observed for the three *Calanus* species and *M. longa* (Fig. 7).

Polar cod, *Themisto* and seabirds (little auk and thick-billed murre)

The occurrence and distribution of juvenile polar cod (*Boreogadus. saida*) (Fig. 8) was estimated in the survey area to approximately 97×10^9 individuals or equivalent to 56×10^3 t. Other fish species such as juvenile Atlantic cod (*Gadus morhua*) and sandeel (*Ammodytes marinus*) were only found at a southern station and only in very low numbers.

The relative abundance and distribution of larger zooplankton (e.g. *Themisto*) and polar cod is also apparent from the analyses of the acoustic values measured during the survey up to a water depth of 500 m (Fig. 9 and 10).

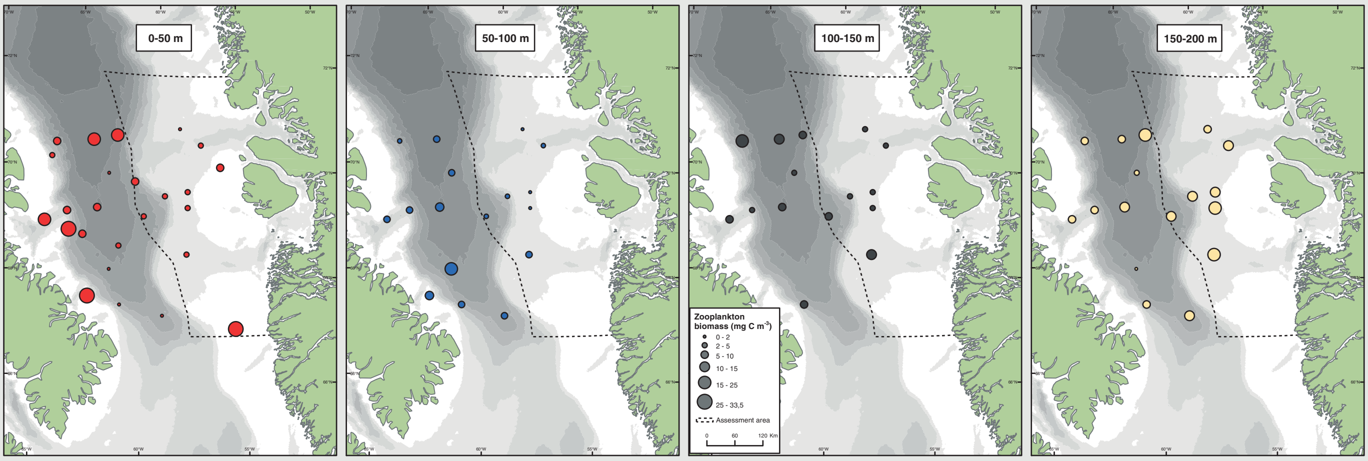


Figure 4. Zooplankton biomass (mg C m^{-3}) during the Disko West survey in September 2009 in 0-50 m, 50-100 m, 100-150 m and 150-200 m water depth. In general, the highest zooplankton biomass was found on the shelf-breaks, mainly on the Canadian shelf-break (0-100 m). On the Greenland shelf-break, the zooplankton biomass was low in the upper water column but increased with depth (150-200 m). The average zooplankton biomass in the upper 200 m was 0.6 mg C m^{-3} and varied widely, from 0.2 to 33 mg C m^{-3} among stations and depth strata.

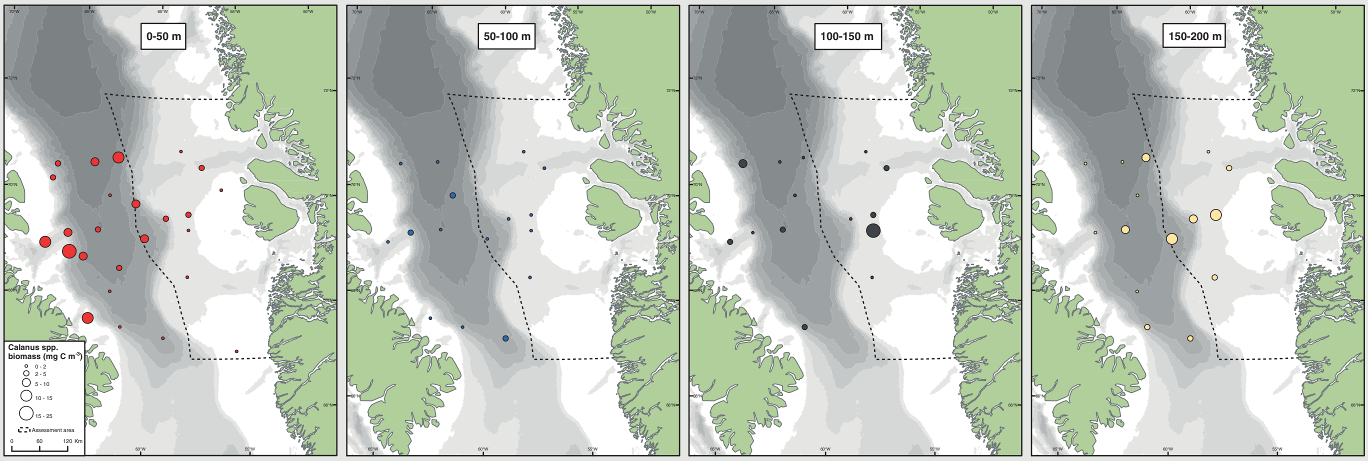


Figure 5. *Calanus* spp. biomass (mg C m^{-3}) during the Disko West survey in September 2009 in 0-50 m, 50-100 m, 100-150 m and 150-200 m water column. In the surface layer (0-50 m), a relatively high Calanus spp. biomass was observed on the Canadian shelf-break compared to the Greenland shelf-break. *Calanus* spp. biomass increased at the Greenland shelf-break towards deeper water layers (100-200 m). In the 200-500 m (data not shown), high biomass of solely *C. hyperboreus* were found, occupying this column, indicating that the seasonal decent for dormancy has already been initiated in *C. hyperboreus*. The *Calanus* biomass accounted for 37 % of the total zooplankton biomass (0-200 m) measured during the study (*C. hyperboreus* 19 %, *C. glacialis* 14 % and *C. finmarchicus* 4 %). Another important species was the non-*Calanus* copepod *Metridia longa*, contributing with 9 % to the overall zooplankton biomass.

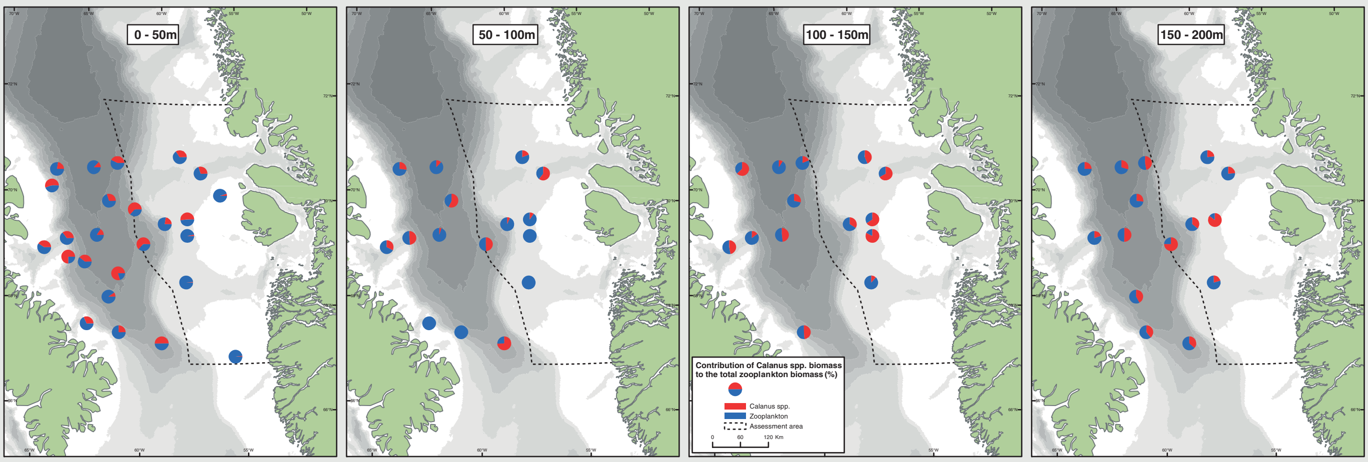


Figure 6. Pie chart of relative zooplankton biomass distribution (%) in the water column during the Disko West survey in September 2009; *Calanus* spp. (red colour) compared to the remaining zooplankton assemblage (blue) in the 0-50 m, 50-100 m, 100-150 m and 150-200 m column.

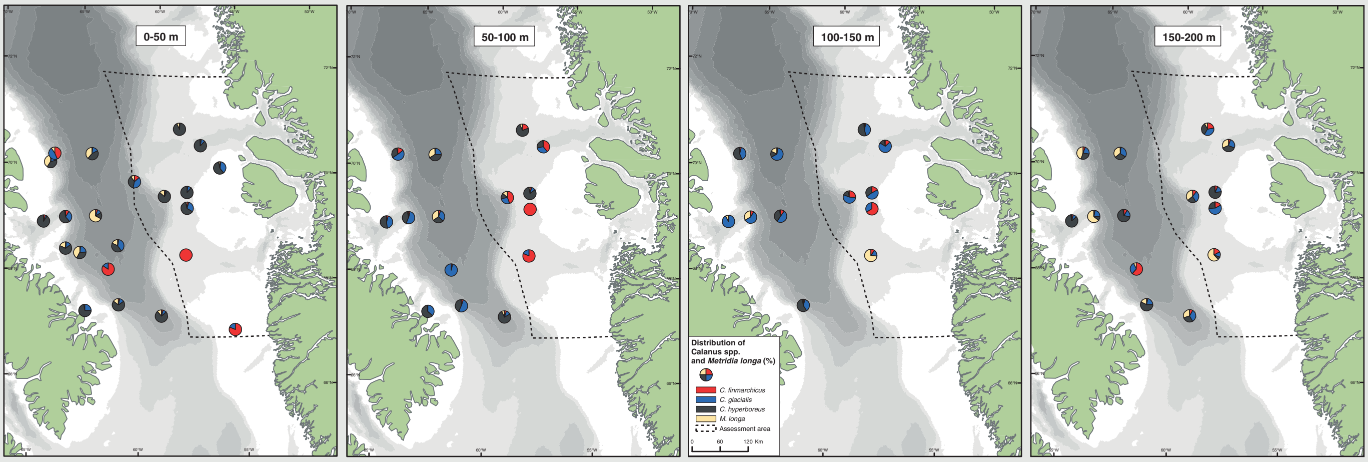


Figure 7. Pie charts of *Calanus* spp. and *Metridia longa* relative biomass contributions (%) during the Disko West survey in September 2009 in the 0-50 m, 50-100 m, 100-150 m and 150-200 m depth strata. *C. finmarchicus* is dominating the *Calanus* biomass along the Greenland coast from 68° to about 69° N in the upper 100 m. The southern distribution of the North Atlantic species *C. finmarchicus* could be a result of its transportation into the Disko West area from the south with the West Greenland Current. At the northernmost stations of the assessment area and along the Canadian coast, *C. glacialis* and *C. hyperboreus* biomasses dominated in the upper 200 m. *C. glacialis* which is of Arctic origin seems mainly abundant on the Canadian Shelf (CS) in the 50-150 m column, probably a result of the south-going cold Baffin Island Current. *C. hyperboreus*, which is predominantly Arctic, is almost exclusively dominant in the 200-500 m, mainly on the Greenland shelf (GS) (data not shown). This may indicate that the seasonal decent of *Calanus*, mainly *C. hyperboreus*, towards winter hibernation has been initiated. *M. longa* which is predominantly Arctic and living in deep water is mainly found in the 150-200 m stratum.

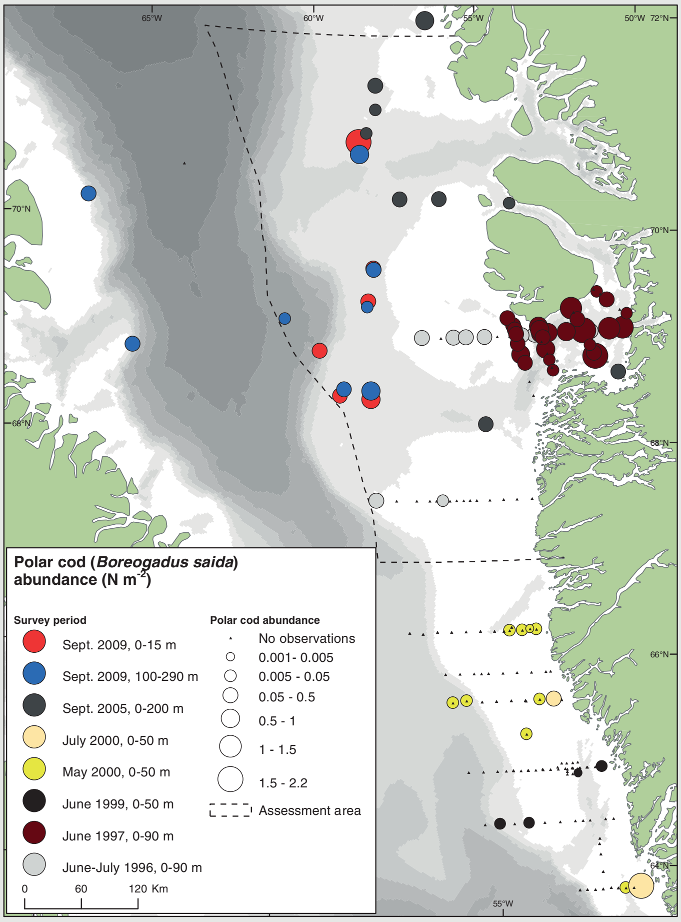


Figure 8. Abundance (N m^{-2}) of larvae and juvenile polar cod during the Disko West survey in September 2009 (red and blue dots) and during other surveys. Dark grey dots – September 2005 (Bergstöm & Vilhjalmarsson 2007), yellow, pale green, black, dark-red and light-grey dots – May-July 1996-2000 (Munk et al. 2000, 2003, Munk pers. comm. and REKPRO-data from C. Simonsen and S.A. Pedersen pers. comm.). Juvenile polar cod seems to be widely abundant in the southern Baffin Bay and Disko Bay and appeared to be more abundant in the surface waters (0-15 m) than in the deeper layers (100-290 m) during the survey in September 2009. The distribution in the northern Davis Strait is more patchy and e.g. east and west of the important fishery banks. High abundances of juvenile polar cod were found at station PT30 (25 m and 100 m) and PT39 (25 m and 120 m), respectively (see Fig. 1 for station locations). Here, potential prey items were present, indicated by a high biomass of *Calanus* in the 50-150 m column, and the amphipod *Themisto libellula* which were found in the 25-120 m depth stratum (data not shown). Note: sampling gear e.g. net types vary among studies.

Bird observations were carried out during the ship based survey according to the Distance Sampling method (Webb & Durinck 1992, Buckland et al. 2001). Observations were performed when the ship was sailing with constant speed between sampling stations, but not when trawling or operating other sampling instruments. This method allows calculating densities of the species present (Fig. 11). In order to gain a better overview of the seabird distributions, an aircraft based survey was performed simultaneously, applying the same observations methods (Fig. 12).

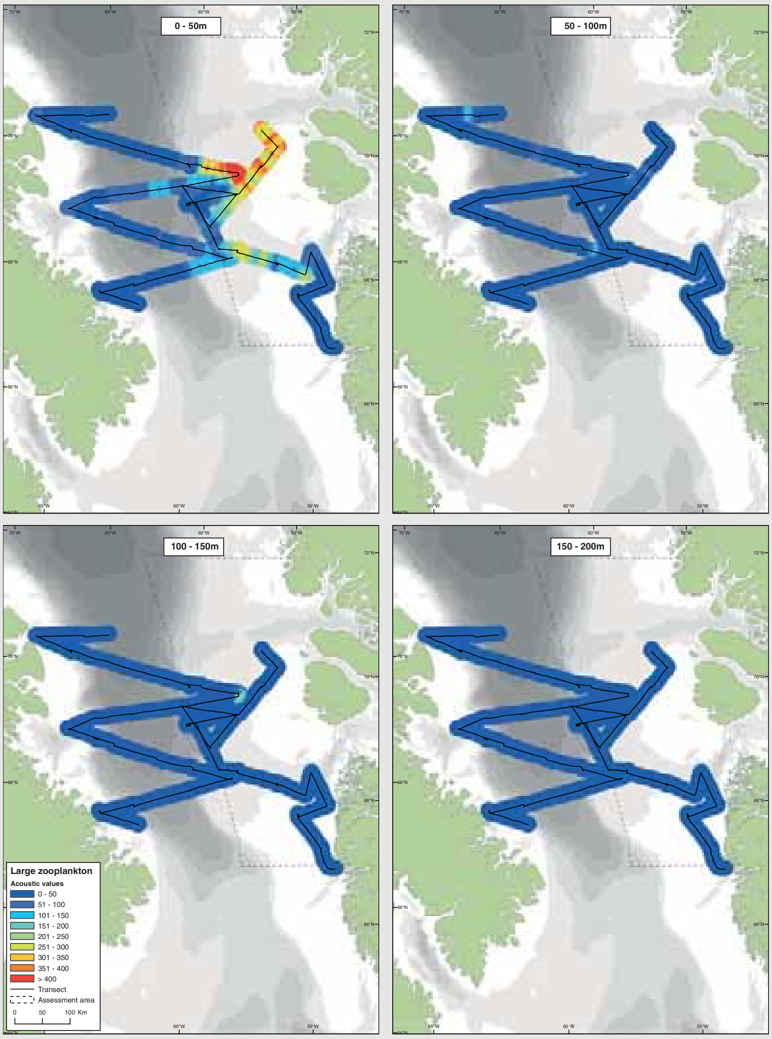


Figure 9. Spatial distribution of larger zooplankton (i.e. mainly Themisto libellula, size >5 mm) based on relative acoustic values (SA-values) in the 0-50, 50-100, 100-150 and 150-200 m water columns. Acoustical separation between the different zooplankton groups (e.g. amphipods, euphausiids or copepods) was not possible using the traditional scrutinizing procedure. However, from the catch composition of trawl and bongo net samples, it was concluded that these represent mainly the larger zooplankton species (in particular the amphipod *Themisto libellula*). The analyses of the acoustic values document that large zooplankton is predominantly found in the upper water column and on the Greenland shelf. Acoustic scatters were recorded continuously during the survey. An exception was at two parts of the survey from station 1 to 3 (~22:30 on Sept. the 8th until ~18:00 on the 9th) and 27 to 31 (from ~19:00 on Sept. the 15th until ~23:00 on the 16th) where no data were collected. Continuous recording of acoustic data (measurements of volume backscattering strength (Sv, dB re 1 m^2) of echo signals were obtained using a Simrad EK 500 echo sounder with hull-mounted transducer. The acoustic data from one frequency (38 KHz) were scrutinized by using BI 500 post-processing software with a Sv threshold in decibels (dB) set at −72 dB. The species identification during the scrutinizing procedure was based on information from the catch composition of the trawl and bongo net samples, the Sv threshold, and the frequency distribution of the target strength (TS, dB re 1 m^2) values. Characteristics of the depth distribution of organism from the net samples were also used.

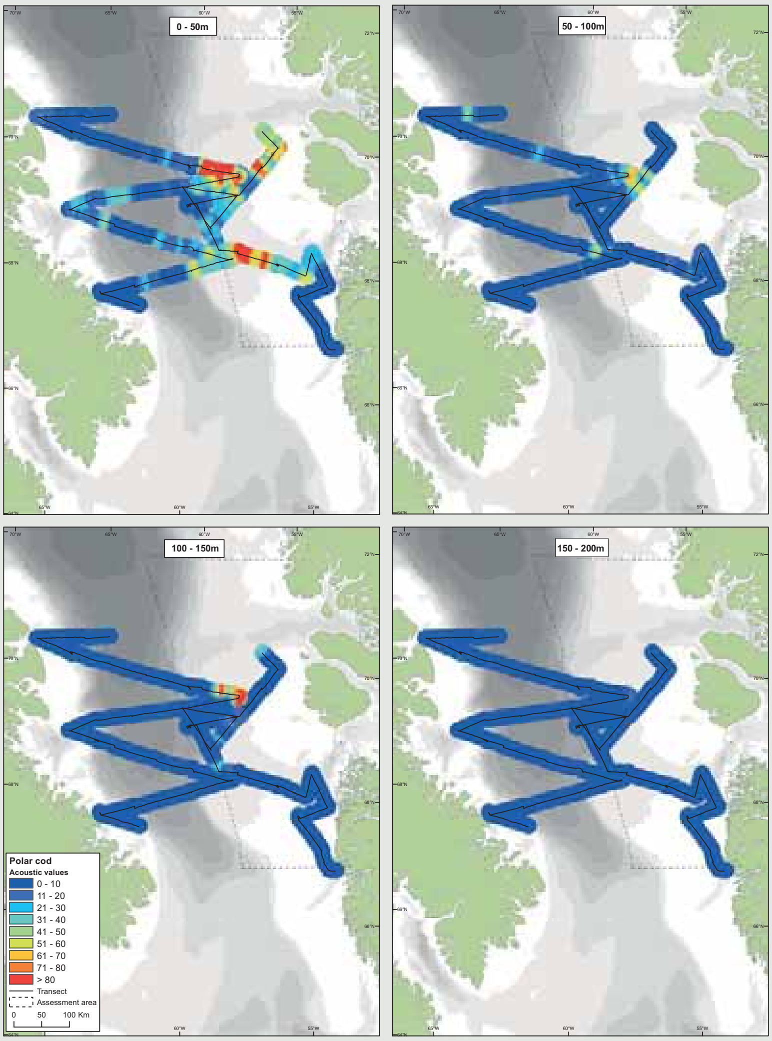


Figure 10. Spatial distribution of juvenile polar cod based on relative acoustic values (SA-values) in the 0-50, 50-100, 100-150 and 150-200 m columns. The distribution of juvenile polar cod is very similar to those of the large zooplankton (see Fig. 9) and the distribution of the total acoustic registrations is therefore similar. The acoustic signal decreases with depth; however a strong signal was measured in the 100-150 m for both large zooplankton and polar cod on the Greenland shelf (St. 19).

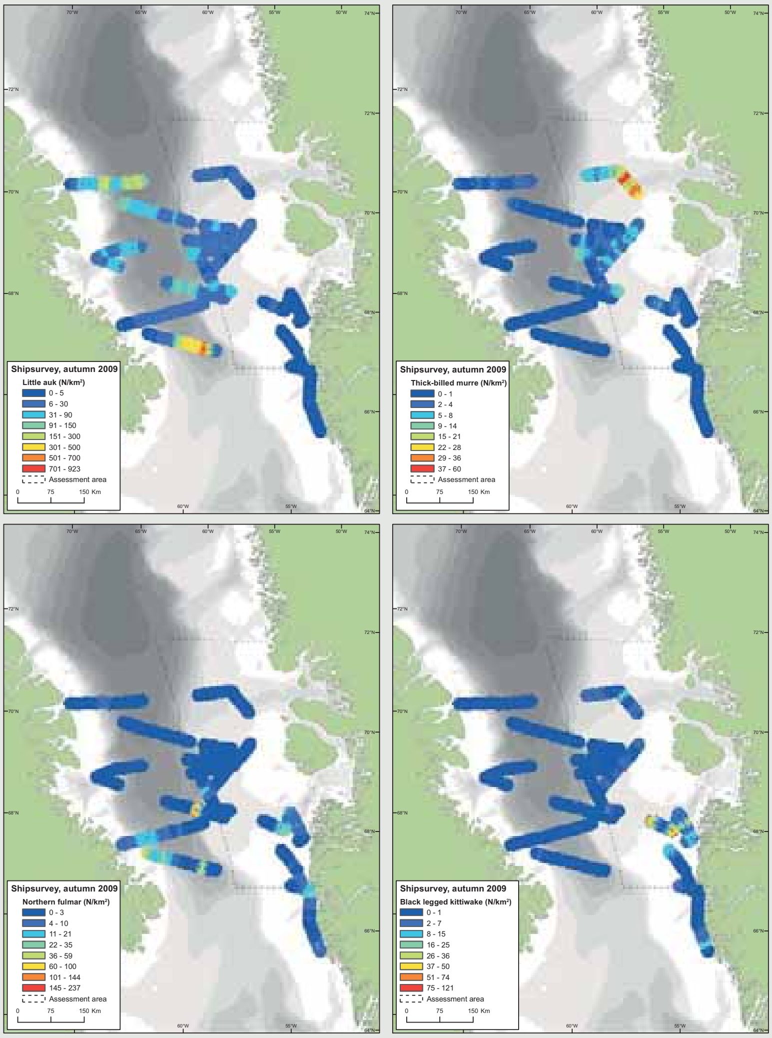


Figure 11. Densities (n/km²) of the most numerous seabird species recorded during the ship based survey in September 2009. Little auk was the most numerous species (n = 29,000 individuals, on transect) and they were mainly found and concentrated in parts of the Canadian shelf. These post breeding birds were either on passage on their way to winter quarters further south in the Labrador Sea or birds assembled in moulting areas (Mosbech et al. 2011). The highest densities (n = 2000 individuals on transect) of another species, thick-billed murres were observed on the northeastern transect on the Greenland shelf, while lower densities were found further south also on the Greenland shelf. Very few were observed on the Canadian shelf. Note that the same high density area was also recorded during the aerial survey and that it overlaps with the high-density zooplankton and polar cod area. Northern fulmar (n = 4600 individuals on transect) were also sighted, but more widespread and dispersed, and high density areas were usually found in areas with fishery. Black-legged kittiwakes (n = 2600 individuals on transect) were almost exclusively observed on the Greenland shelf with the highest densities on the northern part of the Store Hellefiskebanke.

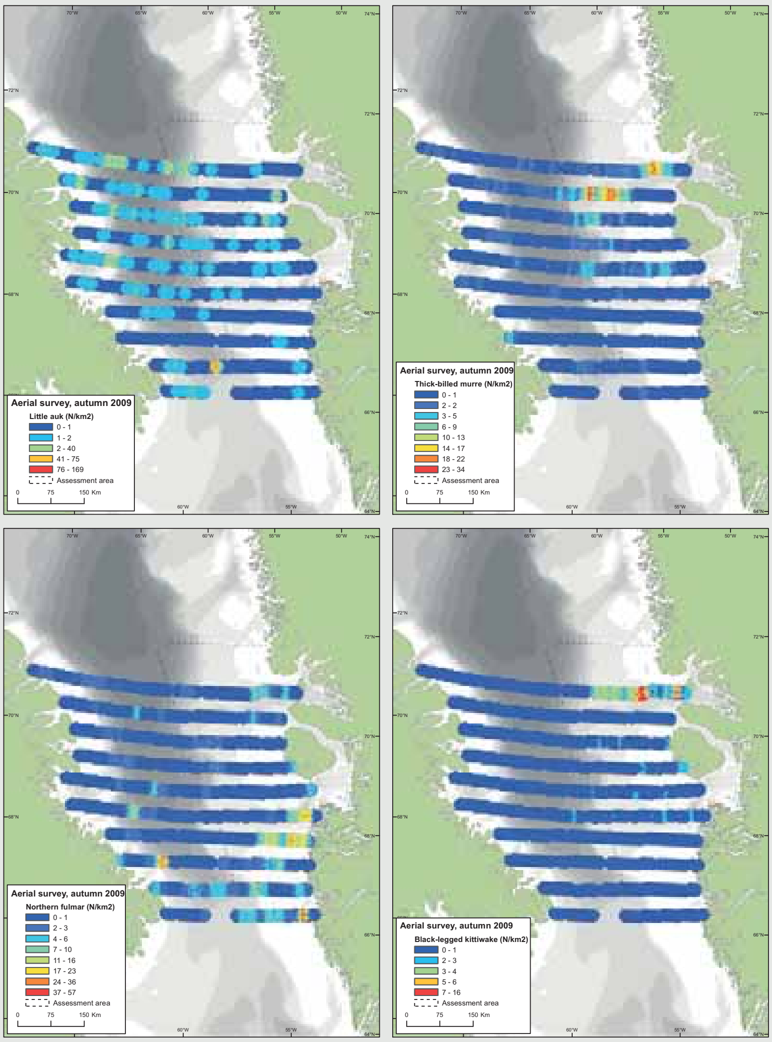


Figure 12. Densities (n/km²) of the most numerous seabird species recorded during the aircraft based survey in September 2009. Little auks (n = 550 individuals on transect) were more dispersed than observed during the ship based survey, but generally found outside the shelf waters. Thick-billed murres (n = 1800 individuals on transect) were concentrated in the same area as recorded during the ship based survey (Fig. 11). Northern fulmar (n = 3700 individuals on transect) were concentrated on Store Hellefiskebanke (see also text to Fig. 11). Black-legged kittiwakes (n = 370 individuals on transect) were primarily observed on the northernmost transect on the Greenland shelf.

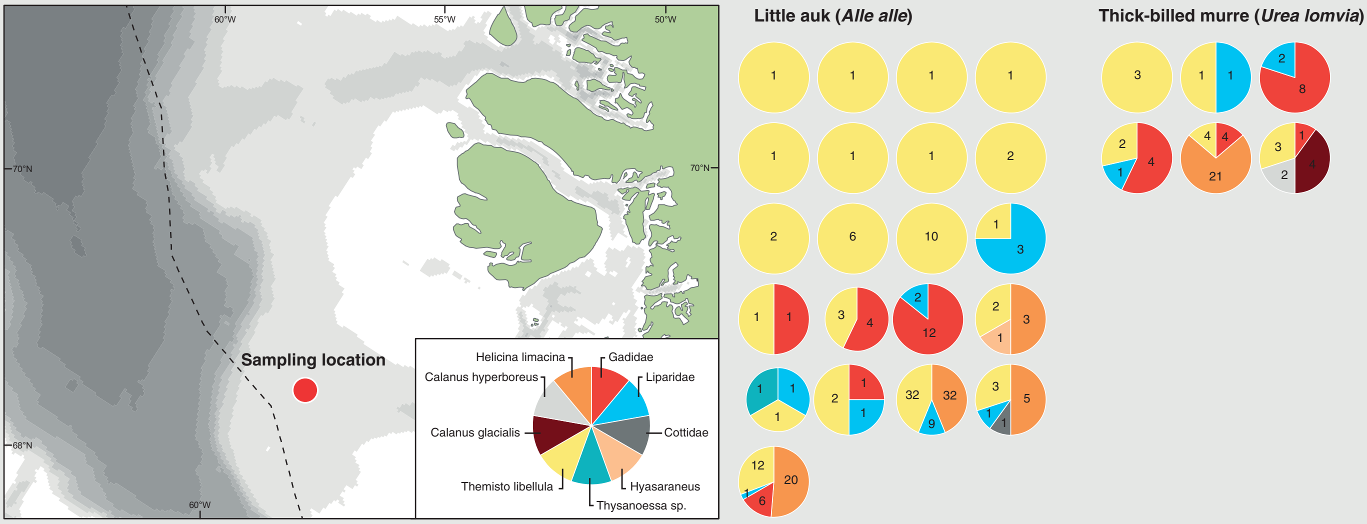


Figure 13. Pie charts of stomach contents of individual little auks (n = 21) and thick-billed murres (n = 6) collected during the Disko West survey in September 2009. Values inside pies indicate numbers of individuals of the different species (n Ind^{-1}) present in the stomachs; the different colours indicate the relative abundance of species and/or families. *Themisto libellula* was found in almost all stomachs. Other species found in the stomachs of the two seabird species were juvenile fish of the cod family Gadidae. It can be assumed that this was polar cod (*B. saida*), since it is the only cod species found in this part of the assessment area. The cod remains in the stomachs corresponded well with the findings of relatively high abundance in net samples close to the sampling location (PT8 and PT39, see Fig. 1 for station numbers). The wing snail (*Helicina limacina*) seems also to be an important food item for little auk in this area. *Calanus* occurred only in one thick-billed murre stomach. Analysis of *Calanus* from multinet and bongonet samples taken at the same location clearly showed that these species were mainly found in the 100-200 m column. Feeding on *Calanus* in that depth is considered to be rare for thick-billed murre and unlikely for little auk which is only feeding in the 0-50 m column.

Stomach analysis of little auk and thick-billed murre collected at one location on the Greenlandic Shelf showed that the amphipod *Themisto libellula* was predominately present in stomachs of both seabird species (Fig. 13).

Summary

The results from the cruise in September 2009 clearly indicate that the phytoplankton was in a post bloom phase with max chl. *a* concentration in the subsurface (30-50 m). The distribution of zooplankton in the water column followed a similar trend as the chl. *a*. The seasonal downward migration of *Calanus* was most likely already initiated. The species distribution patterns also document well known distribution patterns.

The low zooplankton biomass in the upper water layers could also be a result of top down grazing by the present juvenile polar cod and thick-billed murre on the Greenlandic Shelf (Fig. 14). The much higher abundance of little auk just off the Canadian shelf compared to the Greenlandic shelf could be a result of feeding on the relatively high concentrated zooplankton in the 0-50 m column.

It also seems that *Calanus* is widespread in Baffin Bay but mainly abundant in the shallower coastal areas. Juvenile polar cod seems also widespread in the Baffin Bay, particularly east and west of the important fishery banks. In these areas high upwelling occur bringing nutrients to the surface and creating local bloom events. These areas are of high importance for successful linkage of lower to higher trophic levels of the marine food web.

The most interesting result is the spatial overlap of a high density area for thick-billed murres and high density areas for both larger zooplankton and polar cod, indicating that the occurrence of polar cod/larger zooplankton govern the offshore density of staging thick-billed murres.

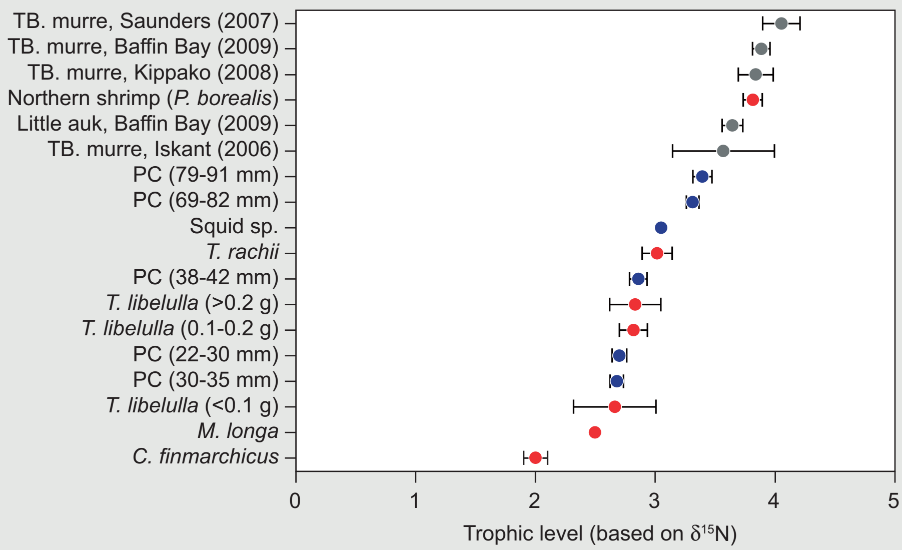


Figure 14. Trophic levels of selected zooplankton species and seabirds based on stable isotope analyses. Thick-billed murre (*TB. Murre*) and little auk are represented from different areas along West Greenland e.g. Saunders Island (Thule), Baffin Bay (September 2009 survey), Kippako (Upernavik) and marginal ice zone, while the zooplankton species are all from the September 2009 survey. As expected, seabirds represent the highest trophic level (~4) since they feed on the lower trophic levels such as juvenile polar cod (PC), *Themisto libellula* and copepods (*Calanus finmarchicus* and *Metridia longa*). *T. libellula* and polar cod (of different lengths, mm) feed on copepods and therefore represent trophic level ~3. Additional information for the seabird studies from the different areas can be found in Frederiksen et al. (2008) and Mosbech et al (2009).

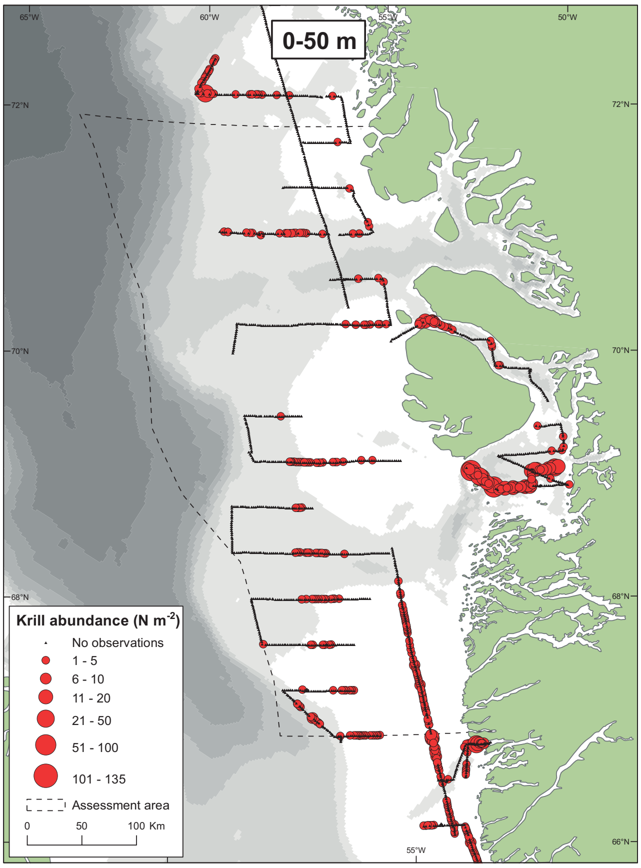


Figure 11. Krill abundance (N m^{-2}) in the 0-50 m water column in September 2006 estimated from acoustic measurements (data GINR). High krill abundance, mainly (*Meganyctiphanes norvegica*), is evident in the Disko Bay (Bergström & Vilhjalmarsson 2007).

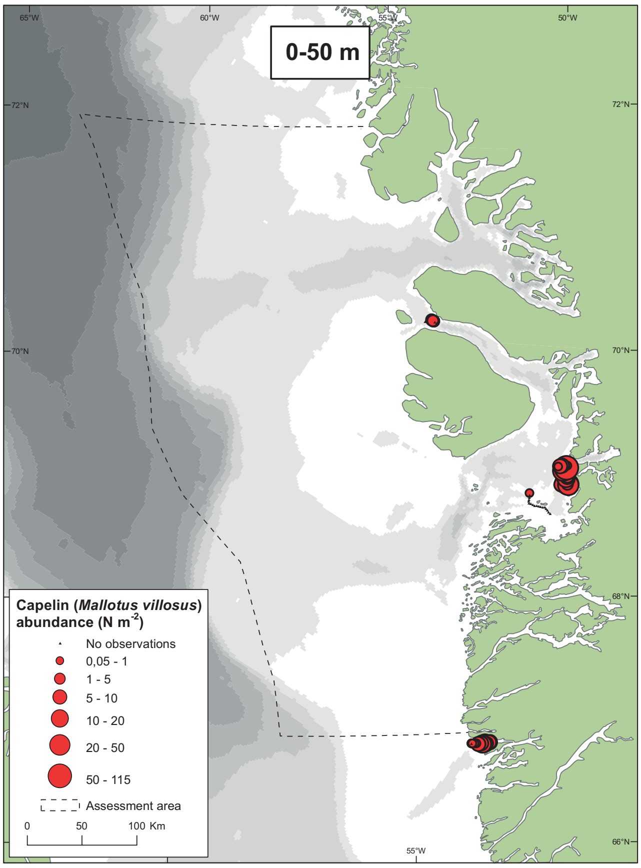


Figure 12. Capelin abundance (N m^{-2}) in the 0-50 m column in September 2006 estimated from acoustic measurements (data: GINR). High capelin abundance was found in some fjord systems (Bergström & Vilhjalmarsson 2007).

Pedersen & Smidt (2000) analysed shrimp and fish larvae data sampled along three transects during summer in West Greenland waters over 34 years. It was estimated that shrimp larvae travel up to 500 km away from their release site before they settle. Computer simulations have indicated several of such 'release sites' on the banks south of Disko Bay. The shrimp larvae were generally more abundant in waters less than 200 m deep and showed high abundance mainly over the West Greenland shelf (GS) and in the Disko Bay area (Pedersen & Smidt 2000). Shrimp larvae are usually released from the females at water depths (<150 m), which are much shallower than where the fishery usually occurs (100-600 m). Larvae are possibly released in August in Disko Bay (S.A. Pedersen, ICES pers. comm.).

Although shrimp and fish larvae and other planktonic organisms are expected to move with the currents, there seem to be retention areas over the banks, where plankton is concentrated and entrapped for periods (Pedersen et al. 2005).

It is not clear whether the shrimp stocks in Disko Bay are self-recruiting or to what degree influx of larvae from the south contributes to the stock (S.A. Pedersen, ICES pers. comm.). Shrimps in waters north of Disko Bay are probably recruited from Disko Bay (S.A. Pedersen, ICES pers. comm.). Within the assessment area high numbers of shrimp larvae were found on the northern edge of Store Hellefiskebanke, in Disko Bay and in the waters around Hareø (Mosbech et al. 2007a).

4.2.6 Conclusions

The occurrence of large zooplankton and fish larvae is highly seasonal in the assessment area, primarily governed by the spring bloom of phytoplankton, currents and upwelling phenomena. Considering all the information summarised above there seem to be important plankton occurrences on the outside of Store Hellefiskebanke, west of Disko Banke and in the Disko Bay.

4.3 Benthic flora

Susse Wegeberg

Shorelines with a rich vegetation of marcroalgae (e.g. kelp) are of high ecologically importance. The littoral- and sub-littoral canopies of macroalgae are important for higher trophic levels 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). The abundance of macroalgae is related to exposure and icecover and some very exposed coasts may even appear as barren grounds. Owing to strong biological interactions in rocky intertidal and kelp forest communities, cascades of delayed, indirect impacts (e.g. biogenic habitat loss and changes in prey-predator balances due to species specific mortality) may be much more severe than a direct impact of oil contamination (Peterson et al. 2003). Thus in order to identify important or critical areas robust baseline knowledge on the littoral- and sub-littoral flora and its ecology is essential.

4.3.1 General context

The marine macroalgae are found along shorelines with hard and stable substratum, such as stones, boulders and rocky coast. The vegetation is distinctly divided in zones, which are most pronounced in areas with high tidal amplitudes. Some species grow above the high-water mark, the supra-littoral zone, where sea water reaches them as dust, spray or by wave action. In the littoral zone the vegetation is alternately immersed and emersed, and characterised by fucoid species. The majority of the macroalgal species, however, grows below the low water mark within water depths with sufficient light. In the Arctic, the length of the ice-free period is an important controller of the light reaching the sea floor and the depth range of the kelp belt increases from north towards south along Greenland's coast parallel to the increase in length of the ice-free period (Krause-Jensen et al. 2011). In north Greenland, a relatively dense macroalgal flora can be found down to water depths of about 20 m (Krause-Jensen et al. 2011), while they occur deeper than 50 m in South Greenland and around Disko (Wegeberg et al. 2005).See also Box 2.

4.3.2 Macroalgae in Greenland and the assessment area

Shorelines with a rich inter- and sub-tidal macroalgal flora are widespread in Greenland. Marine macroalgae were collected at different expeditions to West Greenland during the 19th century, and were identified and described by Rosenvinge (e.g. 1893, 1898). A check-list to the marine algae of Greenland for the east and west coast separately was compiled by Pedersen (1976) supplemented for the assessment area by Hansen & Schlütter (1992) and in relation to the study presented in Box 2. An overview of the species present in the assessment area is given in Table 2.

Box 2. Mapping of macroalgae in the Disko West coastal zone

J.L.S. Hansen, M. Hjorth, M.B. Rasmussen, A. Bruhn, P.B. Christensen and P.M. Pedersen

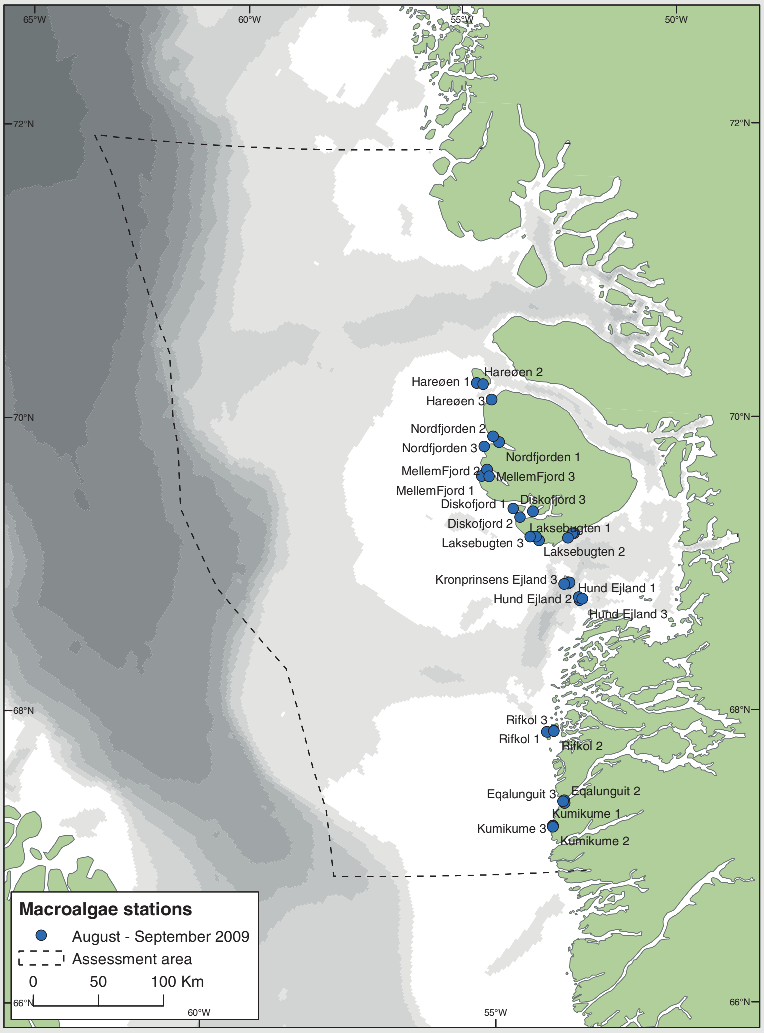


Figure 1. Stations sampled during the 2009 survey (blue symbols).

Benthic vegetation and macroalgae are important elements of the coastal marine ecosystem in the Arctic, since the not only represent a significant amount of the primary production (Krause-Jensen et al. 2007). They also play a major role as habitat for a diverse community of benthic invertebrates and fish, and in particular as nursery areas for juvenile fish. In coastal regions of the Arctic the macroalgae vegetation occurs from the tidal zone to water depth of more than 50 m and is often dominated by large brown algae with several meter long thalli (leaves) also known as kelp. Like other Arctic organisms, the vegetation is adapted to low temperatures and extreme seasonal changes in the light regime. Their abundance and distribution are partly determined by light availability, physical disturbances such as tides, wave exposure and ice scouring and, as in boreal regions, by grazing from certain invertebrates (e.g. centric sea urchins) which can control the vegetation completely and in the worst case could permanently change the habitat from dense kelp forests to barren ground. In some areas, disappearance of the macroalgae vegetation has been attributed to a lack of top predator control of sea urchins. However, these examples come from the temperate zone and the potential of sea urchins to control the macroalgae vegetation in the Arctic is largely unknown.

As part of the Environmental Studies in the Disko West area a survey was carried out in August/September 2009. The study aimed at obtaining a general description of the macroalgae community in terms of species composition, depth distribution and limits, and relation to substrates and sea urchin abundance.

Table 1. Grouping of bottom types according to coverage (%) of different substrates.

	Sand	Stones SM	Stones ML	Stones L	Stones SML	Stones SL	Mixstones SL	Litho
Sand/gravel	100	–	–	–	–	–	20-40	–
Small stones (2-10 cm)	–	30-60	–	–	Oct-35	30-40	Oct-35	–
Medium stones (10-30 cm)	–	40-70	30-50	–	Oct-30	–	–	–
Large stones (30 - >60 cm)	–	–	50-70	70-100	Oct-35	60-70	25-40	–

The ship based survey covered the coast line from Sisimiut to Nuussuaq (Fig. 1) 11 stations were sampled including diver observations, collection of macroalgae as well as photo and video documentation together with observations of bottom topography and sediment composition. All transects were located in areas with suitable substrates for macroalgae either determined by the presence of brown algae or, alternatively, barren grounds with stones or solid rock with crustaceous red algae and epifauna (Fig. 2). Furthermore, it was judged whether or not the substrate was stable. The substrates present in the study area included solid rocks, stones and boulders of varying sizes, gravel and sand (Fig. 3 and Table 1). The highest coverage of stabile substrate was found in the shallow waters and the same pattern was evident from the video survey based data Fig. 4). There were only a few observations of solid rock below 50 m. Each video recorded transect covered the depth range from the tidal zone to the depth limits of macroalgae distribution. However, some macroalgae apparently grew deeper than the depth limit of the instrument (65 m).

The macroalgae community was totally dominated by brown algae with *Laminaria, Desmarestia, Fucus* and *Agarum* as the dominant genera. The foliose red algae contributed with only 5 % of the total macroalgae coverage along the entire transect from 0 m to the deepest recordings. *Fucus* was only found between 5 and 30 m water depth and with a very low coverage. *Agarum* tended to be relatively more abundant at depths below 40 m. However, in general there was no clear depth zonation of the dominating genera or the groups of brown and red algae.

Figure 2. Coastal epibenthic communities. Upper picture: Brown algae community in the tidal zone dominated by *Laminaria* species (and *Agarum*). Lower picture: Typical hard bottom community dominated by grazing epifauna such as sea urchins and crustaceous red algae. In the tidal zone (0 to 5 m water depth), 70-80 % of the coastline was covered by macroalgae (Fig. 4). The total macroalgae cover showed a gradual decrease with increasing depth, i.e. from 70-80 % in the tidal zone to about 40 % at 25 m and the deepest recorded macroalgae were found at 65 m depth. There were considerable variance between locations and also between transects from the same location. For example 100 % coverage was found down to 30 m depth at *Kronprinsens Ejland* and at depths below 55 m there was still more than 50 % coverage. On the other hand, the macroalgae was almost absent in the Disko Fjord.

The depth distribution of the macroalgae community was clearly related to the availability of substrates. This is clearly exemplified in two transects at the location *Hunde Ejland* in Disko Bay where the depth limit in transect 2 was only 20 m whereas the depth limit was about 55 m in the nearby transect 3 at the same location. In both cases the bottom is covered with unstable substrate at a depth below the algal depth limit. At another location in Disko Bay (*Kronprinsens Ejland*) the coverage declined from 100 % at depths shallower than 30 m to 0 % over the depth range from 30 to 45 m concomitant with a change from stabile to unstable substrate. The macroalgae cover was related to grazing from sea urchins. Macroalgae were almost absent on the location in Disko Fjord where sea urchins were abundant. Assessment of the entire data set showed a clear negative correlation between the abundance of sea urchins and total macroalgae cover (Fig. 5).

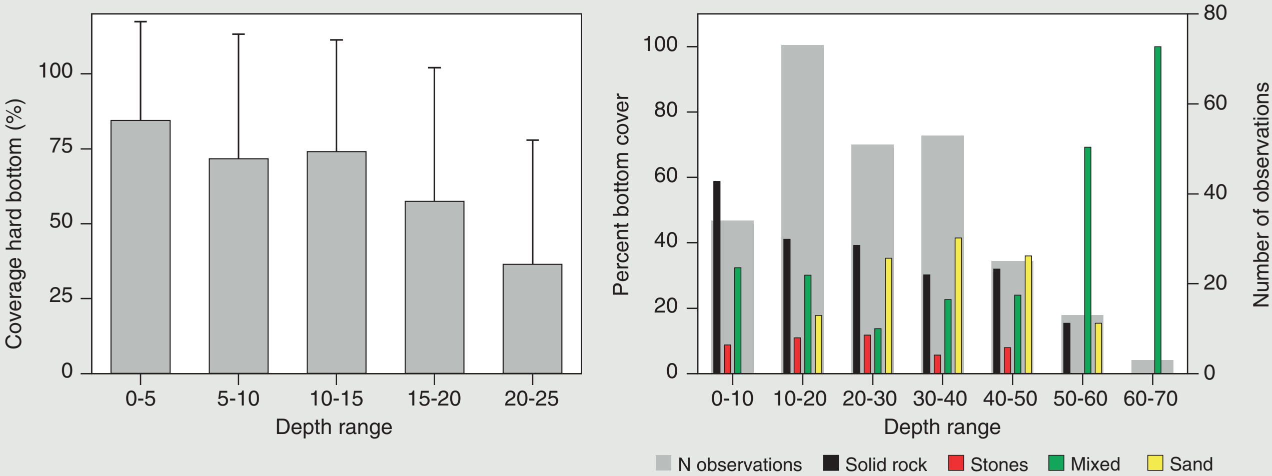


Figure 3. Distribution of substrate versus depth. Upper panel: hard bottom (%) recorded by divers in the 0–20 depth range. Hard bottoms include solid rock and stones. Lower panel: relative distribution (%) of bottom types versus depth assessed from video recordings: Rock (black), stones (red), mixed bottoms (green) and sandy bottoms (yellow). Grey columns in the background indicate number of observations.

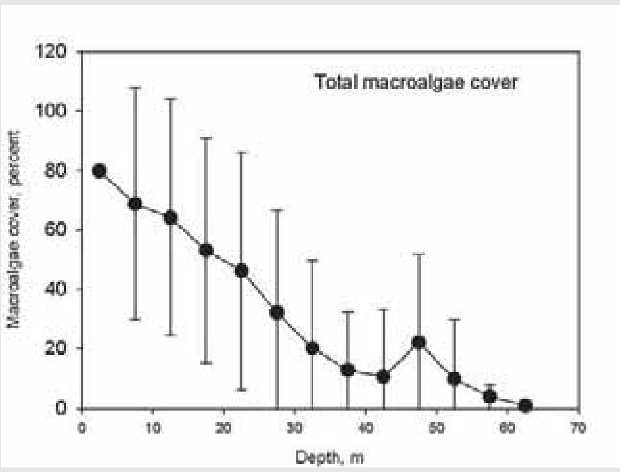


Figure 4. Average macroalgae cover (%) versus water depth based on all video recorded transects, including all types of substrate. Error bars show standard deviation across the studied transects.

The combined effect of sea urchins and the availability of suitable substrate on the macroalgae coverage are shown in Fig. 6. In areas with no sea urchins, macroalgae coverage amounted to up to 100 % at depth <20 m and 40-50 % down to 55 m (Fig. 7). All of the habitats observe below 55 m were influenced by either unstable substrate or sea urchins. Habitats with unstable substrates showed a decline in macroalgae coverage already below 10 m depth. The total macroalgae cover on bottoms with sea urchin was reduced by 60 % relative to bottoms without sea urchins. The combination of unstable substrate and sea urchins showed that the coverage was reduced to less than 25 % of that of bottoms with stable substrates and without sea urchins even at depth less than 10 m.

The average total number of species (S) at all stations was 66±10 (SD) with a tendency towards an increase of species in the most northern stations (Fig. 8). The Shannon-Wiener diversity index (H'), at each depth transect at all stations showed an overall decrease in biodiversity with increasing depth, most pronounced at the northern stations (Fig. 9). The number of specimens as well as the sampling effort (diver time etc.) was fairly uniform across the study area and the diversity and species richness indices are comparable.

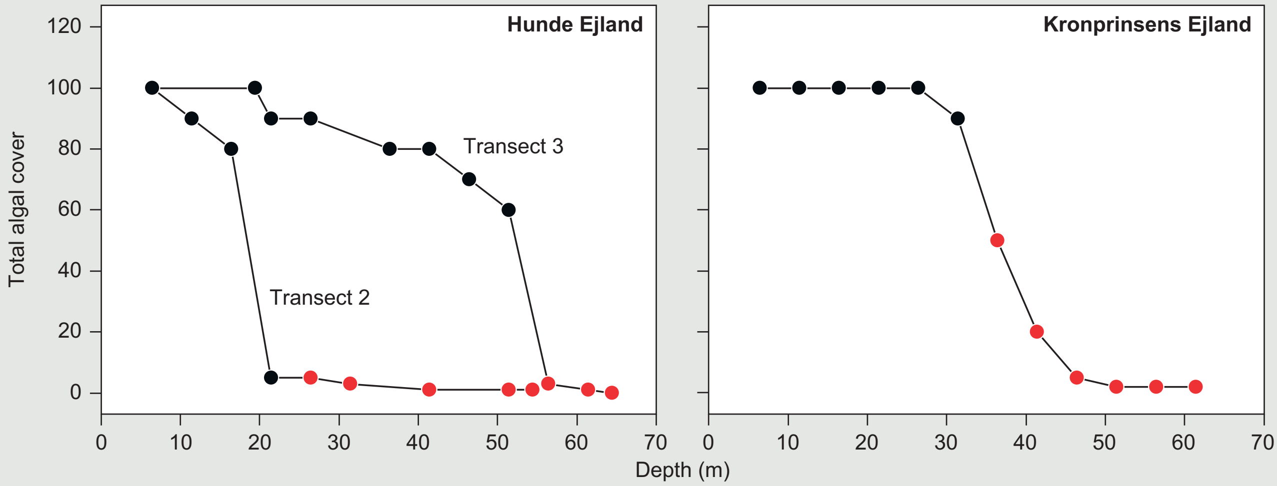


Figure 5. Total macroalgae cover (%) at individual transects versus depth. Solid substrate (solid rock or large boulders) are indicated by black symbols; unstable substrate (sand, gravel, stones) are shown with red symbols. Left: Two transect from the coast of Hunde Island in the Disko Bay. Right: transect at the location Kronprinsens Ejland.

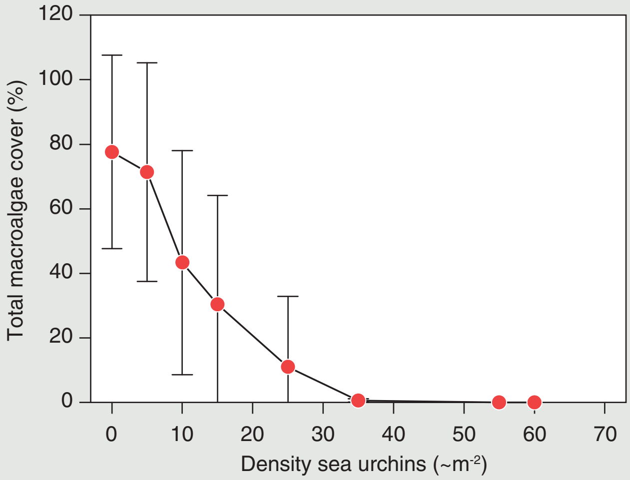


Figure 6. Average total macroalgae cover (%) versus the abundance of sea urchins *Strongylocentrotus*-type.

Red calcified algae were abundant in all depth groups (Fig. 10). In the 0 m depth group, brown algae dominated with species such as *Chordaria flagelliformis, Alaria esculenta* and *Fucus evanescens*. The 5 m depth group differed from the 0 m depth group, due to presence of other brown algal species, mainly *Agarum clathratum* and juvenile *Laminaria longicruris*. Deeper down at 10 m water depths, species dominance did not change much, apart from increased contribution of *A. clathratum* and red algae. The 15 m depth group was mainly characterised by the brown algae *A. clathratum* and red calcified algae. The 20 m depth group was characterised by *A. clathratum* and red calcified algae showed the same abundance.

The present study documents the dense macroalgae cover in hard substrate habitats. The macroalgae cover extended as deep as 60 m. This depth limit is remarkable compared to depth distributions recorded elsewhere in boreal regions. The only comparable observations of depth limits in the Arctic are from Svalbard where 60 m is given as the maximum depth distribution limit for foliose red algae that often occurs deeper than the larger brown algae kelp species. In contrast, the present study documents the presence of larger *Agarum* and *Laminaria* specimens around and below 60 m. The potential depth limit of the vegetation may be even deeper to what has been observed in this study, often coincided with lack of suitable substrate below 50 m. The potential of the large brown algae genera (*Laminaria* and *Agarum*) to maintain populations as deep as 60 m is particularly inter-

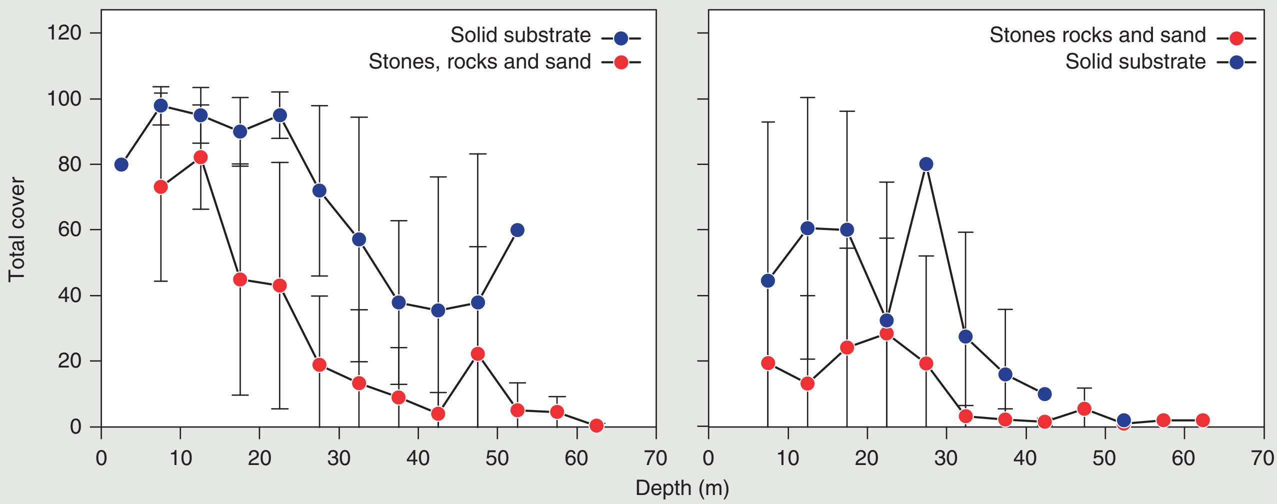


Figure 7. Total macroalgae cover of individual transect versus depth in relation to substrate and presence (left panel) or absence (right panel) of sea urchins. Red symbols: solid substrate (solid rock or large boulders); blue symbols: unstable substrate (sand, gravel, stones).

esting for the Disko West area (and West Greenland in general), because the large offshore Bank (Store Hellefiskebanke) is shallower than the depth limit of the large kelp forming brown algae. It is possible that the absence of stable substrate and/or grazing have prevented the establishment of foliose macroalgae vegetation on the offshore bank.

The population of sea urchins is negatively correlated with the macroalgae cover due to grazing and thus probably controls the macroalgae distribution which means, the vegetated habitats could be threatened by sea urchins. The sea urchin population, on the other hand, can maintain population even in the absence of macroalgae and thereby prevent re-colonization of the macroalgae.

The macroalgae community is completely dominated by large species of brown algae also seen in other parts of the Arctic such as Svalbard, the Russian Arctic coast and in the Canadian Baffin Bay area. However, beside these dominant species a highly diverse community of brown, red and green algae (as well as crustaceous red algae not included in this study) has been documented.

In summary, the survey revealed 79 species of algae at 11 stations and 54 transects. For comparison the total number of species found in the entire coast and fjord of Svalbard was 70 even though this figure represents the sum of several studies. Canadian studies performed in the high Arctic represent 55 species. This emphasise that the macroalgae diversity is very high in the Disko west area. One new species was found, which was not previously described

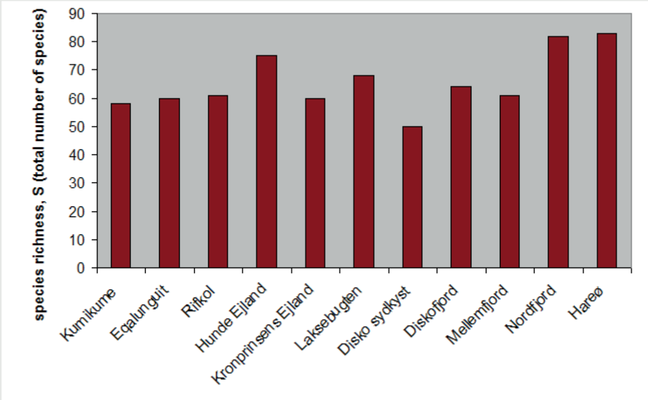


Figure 8. Species richness expressed as total number of species at each sampling station. Stations are plotted from south to north.

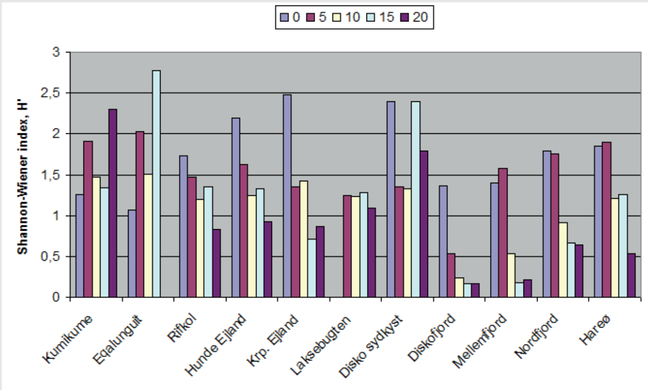


Figure 9. Shannon-Wiener diversity index in various depths transects at the different sampling stations.

Conclusions

The present study shows that a dense macroalgae vegetation is present in the coastal zone of the assessment are wherever there is suitable substrates present; macroalgae cover extents to a water depth of >60 m.

Locally in Disko Fjord sea urchin play a role in controlling the macroalgae vegetation.

The coastal macroalgae vegetation constitutes an important habitat for invertebrate fauna and as nursery area for fish.

Any oil pollution events involving oil drifting to the shore or sinking in shallow areas threats the coastal vegetated habitats.

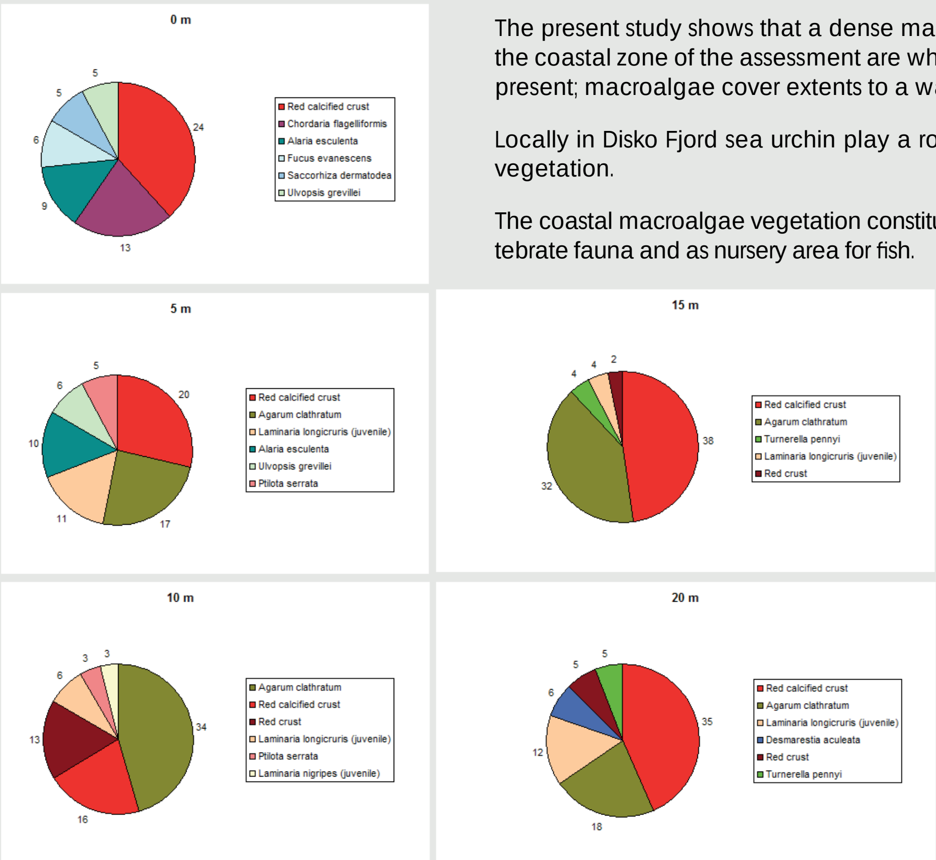


Figure 10. Species composition in relation to depth. Pie charts show the contribution (%) of the six most dominant algae species.

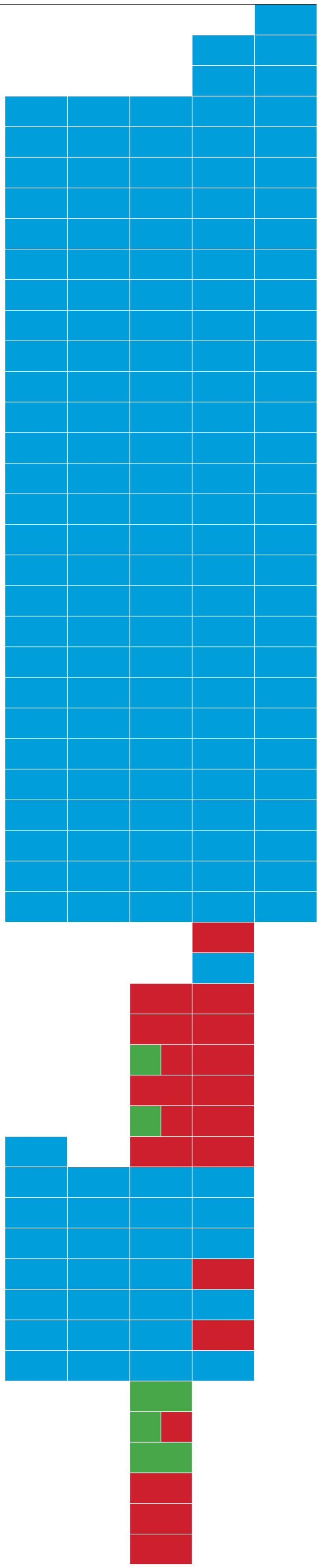
A recent study assessed the extension and production of kelp belts along Greenland's west coast, from Nuuk to north of Qaanaaq (Krause-Jensen et al. 2011a). Predominant species of the tidal zone was mainly *Fucus* spp. and in the upper sub-tidal zone species like *Agarum clathratum*, *Alaria esculenta*, *Laminaria* spp. and *Saccharina longicruris* were recorded as far north as 78° N (Pedersen 1976, 2011, Wegeberg et al. 2005, Krause-Jensen et al. 2011a).

Table 2. Distribution of the macroalgae species in the assessment area in relation to latitude. Based on ■Pedersen (1978), ■Hansen & Schlütter (1992), ■Records from the macroalgal investigation presented in Box 2.

Latitude (°N)	67	68	69	70	71
Cyanophyta					
Aphanothece sp.					blue
Calothrix scopulorum	blue	blue	blue	blue	blue
Rivularia atra	blue	blue	blue		
Rhodophyta					
Bangia fuscopupurea	blue	blue	blue	blue	blue
Clathromorphum compactum	blue	blue	blue	blue	blue
Coccotylus truncatus	blue	blue	blue	blue	blue
Devaleraea ramentacea	blue	blue	blue	blue	blue
Euthora cristata	blue	blue	blue	blue	blue
Fimbrifolium dichotomum	blue	blue	blue	blue	blue
Hildenbrandia rubra	blue	blue	blue	blue	blue
Lithothmanion glaciale	blue	blue	blue	blue	blue
Lithothamnion tophiforme	blue	blue	blue	blue	blue
Meiodiscus spetsbergensis	blue	blue	blue	blue	blue
Palmaria palmata	blue	blue	blue	blue	blue
Pantoneura fabriciana	blue	blue	blue	blue	blue
Peyssonellia rosenvingii	blue	blue	blue	blue	blue
Phycodrys rubens	blue	blue	blue	blue	blue
Phymatolithon tenue	blue	blue	blue	blue	blue
Polysiphonia arctica	blue	blue	blue	blue	blue
Polysiphonia stricta	blue	blue	blue	blue	blue
Wildemania miniata	blue	blue	blue	blue	blue
Ptilota serrata	blue	blue	blue	blue	blue
Rhodocorton purpureum	blue	blue	blue	blue	blue
Rhodomela lycopodioides	blue	blue	blue	blue	blue
Turnerella pennyi	blue	blue	blue	blue	blue
Scagelia pylaisaei	blue	blue	blue	blue	blue
Polysiphonia fucoides				blue	
Acrochaetium microscopicum			blue	red	
Rubrointrusa membranacea			red	red	
Scagelothamnion pusillum			red	red	
Membranoptera denticulata	blue	blue	blue	red	
Harveyella mirabilis			blue		
Polysiphonia elongate f. schuebeleri			blue		
Porphyra umbilicalis	blue		red		
Ceramium virgatum	blue	blue	blue		
Rhodophysema elegans	blue				

Phaeophyceae

Dermatocelis laminariae
Coelocladia arctica
Symphyocarpus strangulans
Agarum clathratum
Alaria pylaiei
Ascophyllum nodosum
Battersia arctica
Chaetopteris plumosa
Chorda filum
Chordaria flagelliformis
Delamarea attenuata
Desmarestia aculeata
Desmarestia viridis
Dictyosiphon foeniculaceus
Ectocarpus siliculosus
Elachista fusicola
Eudesme virescens
Fucus evanescens
Fucus vesiculosus
Laminaria nigripes
Laminaria solidungula
Leptonematella fasciculata
Petroderma maculiforme
Pleurocladia lacustris
Punctaria plantaginea
Pylaiella littoralis
Saccharina longicruris
Scytosiphon lomentaria
Sorapion kjellmanii
Stictyosiphon tortilis
Coilodesme bulligera
Petalonia zosterifolia
Alaria esculenta
Chordaria chordaeformis
Pylaiella varia
Saundersella simplex
Scytosiphon complanatus?
Ectocarpus fasciculatus
Halosiphon tomentosus
Laminariocolax tomentosoides
Lithosiphon filiformis
Papenfusiella callitricha
Petalonia fascia
Saccharina latissima
Saccorhiza dermatodea
Haplospora globosa
Hincksia ovata
Laminaria digitata
Microspongium alariae
Microspongium globosum
Phaeostroma longisetum



Phaeostroma pustulosum
Protohalopteris radicans
Symphyocarpus strangulans
Laminariocolax aecidioides
Stragularia clavata
Streblonema stilophorae
Isthmoplea sphaerophora
Rafsia fungiformis
Chlorophyta
Ochlochaete hystrix
Acrosiphonia arcta
Acrosiphonia sonderi
Chaetomorpha melagonium
Chaetomorpha capillaris
Gomontia polyrhiza
Ostreobium quekettii
Rhizoclonium riparium
Spongomorpha aeruginosa as Chlorochytrium inclusum
Ulva prolifera
Urospora penicilliformis
Ulvaria splendens
Chlorochytrium dermatocolax
Monostroma grevillei
Pseudopringsheimia confluens
Ulothrix flacca
Ulvaria obscura
Acrochaete repens
Blidingia minima
Bolbocoleon piliferum
Pseudendoclonium fucicola
Ulothrix subflaccida
Cladophora flexuosa?
Ulva intestinalis
Chlorochytrium cohnii
Cladophora rupestris
Kornmannia leptoderma
Percusaria percursa
Pseudothrix groenlandica
Ulothrix speciosa
Ulva compressa
Ulva lactuca
Prasiola stipitata
Pringsheimiella scutata
Protomonostroma undulatum
Urospora wormskioldii

In general, knowledge concerning the marine benthic flora in the Disko West assessment area is still scarce, but floristic studies, particularly around Qeqertarsuaq (Hansen & Schlütter 1992), and a study on *Fucus* spp. and associated fauna in the littoral zone (Hansen 1999) have been conducted. In addition, in 2009 a larger study was carried out including estimations of macroalgal coverage and depth ranges (Box 2).

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

The kelp production can be used as an estimate of kelp-derived carbon being available for the next trophic levels in the ecosystems. The annual production of kelp species in Northeast Greenland and the Beaufort Sea, Alaska, has been estimated as increase in length during the growth season and showed an annual length increase of *Saccharina latissima* of approx. 55-88 cm depending on depth (Dunton & Schell 1987, Borum et al. 2002).

In the Arctic, the length of the ice-free period is an important controller of the light reaching the sea floor. The depth range of the kelp belt along the west coast of Greenland increases towards the south in parallel to the increase in length of the ice free period (Krause-Jensen et al. 2011b). In North Greenland, a relatively dense macroalgal flora can only be found down to water depths of about 20 m (Krause-Jensen et al. 2011b), whereas macroalgae occur at water depths of 50 m in South Greenland and around Disko Island (Wegeberg et al. 2005) (See Box 2).

Sea-ice also has a high physical impact on the macroalgal vegetation because of ice scouring. The mechanical scouring of floating ice floes prevent especially perennial fucoid species to establish and grow in the littoral, the zone which is mostly influenced by ice dynamics. At such ice scoured localities, often also quite wind exposed, communities of opportunistic macroalgae, like the filamentous green algae of the genera *Ulothrix* and *Urospora* and the smaller leafy species *Blidingia minima*, develop quickly during the summer months due to the available substratum and to the life history of these algae, i.e. microstages not detached by ice. This was observed at the North Star Bay by Andersen et al. (2005), and at Ydre Kitsissut (Wegeberg, unpubl. data), areas north and south of the assessment area, respectively.

Perennial species living in the littoral zone do tolerate freezing and survive to be frozen into the ice foot if the ice melts gradually without being disrupted. In this case, the macroalgal vegetation remains intact, which is the case in more sheltered areas as demonstrated in the fjord Qaamarujuk, close to Uummannaq, just north of the assessment area (Johansen et al. 2001b). For *Fucus evanescens* from Spitsbergen it was shown that the species was able to halt the photosynthetic activities at subzero temperatures and resume almost completely when being unfrozen again (Becker et al. 2009).

Low salinity or fresh water may influence the macroalgal vegetation especially in the intertidal zone when exposed to rain and snow during low tide or when sea water mix with fresh and melt water during seasons with high water runoff from land. Low tolerance to such hypo-saline conditions may result in increased mortality or bleaching (strong loss of pigments), which suggests that hypo-salinity also has an impact on the photosynthetic apparatus, as shown for kelp species on Spitsbergen (Karsten 2007).

Substratum characteristics are also important for the distribution and abundance of the macroalgal vegetation; only hard and stable substratum can serve as base for a rich community of marine, benthic macroalgae. However, some macroalgal species are commonly attached to shells, small stones or are loose-lying in localities with a soft, muddy bottom. The phenomenon of loose-lying individuals of brown and green algae was observed and described by Christensen (1981) along the coasts of the sheltered fjords around Nuuk, south of the assessment area. Naturally occurring loose-lying macroalgae tend to be depauperate (i.e. a poorer development of the thallus), probably due to poor light and nutrient conditions.

Seabed areas dominated by encrusting coralline red algae as well as loose lying rhodoliths are reported from a single locality in the assessment area; in the Disko Fjord. Here relatively large rhodoliths with diameters of up to 13 cm are accumulated on a soft and muddy bottom (Düwel & Wegeberg 1990, Thormar 2006).

Sea urchins (*Strongylocentrotus droebachiensis*) are the most forceful grazers on kelp forests. A high density of sea urchins can result in grazing down of kelp forests leaving 'barren grounds' (also known as the phenomenon of 'iso-yake' – Japanese: sea dessert) on stones, boulders and rocks. As a result of the grazing these 'barren grounds' could be covered by coralline red algae only. If caused 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 connection with a study on the macroalgal species zonation in the littoral zone of the west coast of Disko Island, barren grounds with a relatively high number of sea urchins and grazed kelp forest have been reported (Hansen & Schlütter 1992).

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

Climate change will probably affect the macroalgal vegetation, primarily due to a longer season with less ice and thereby a longer season for growth. A change in northward distribution of species is therefore an scenario expected to be coupled to oceanic warming (Müller et al. 2009). Furthermore, a study of climate forcing on benthic vegetation in Greenland (Krause-Jensen et al. 2011) suggests that depth range, abundance and growth of subtidal vegetation belts will expand in correlation to a warmer climate; but the study also concluded that those species with the most northern distribution responded negatively to warming. In addition, melting of inland ice caps leads to an increase in freshwater runoff, which may result in lowered salinity and increasing water turbidity (Borum et al. 2002, Rysgaard & Glud 2007), having a negative impact on the local macroalgae vegetation.

4.3.3 Knowledge gaps

In general, the knowledge of macroalgal diversity and extent in the assessment area has been improved, e.g. due to the studies described in Box 2. However, knowledge on macroalgal biomass and production is still limited. It is thus recommended to perform investigations that in particular will provide 1) quantitative data on macroalgal and associated faunal biomass and/or number, and 2) information on macroalgal primary production. In addition, investigating and mapping trophic cascades is highly desirable.

Obtaining such data would provide a base for mapping and modelling littoral and sub-littoral ecology of the coasts in the Disko West area, and additionally provide information for optimizing advising and prioritizing shoreline protection and clean-up, as well as evaluation of subsequent rehabilitation of an oil impacted coast.

4.4 Benthic fauna

J.L.S. Hansen, M. Sejr, A.B. Josefson, P. Batty, M. Hjort and S. Rysgaard

The benthic macrofauna is a key element in the functioning of marine ecosystems, including the Arctic. It processes a major fraction of the organic material settling from the water column to the sea bottom, thereby exerting an important link between primary production and overall ecosystem services. Benthic organisms also provide a vital food source for higher trophic levels. In particular, in the Arctic benthic macrofauna serves as valuable food for demersal fish (e.g. Greenland halibut), seabirds and marine mammals. Some macrofaunal species are also of commercial value such as scallops, shrimps and crabs.

Although a lack of data from Greenland waters is apparent, enough data is available to suggest that species diversity in West Greenland to be in the high end compared to other ecoregions in the Arctic (Piepenburg et al. 2010) and the benthic community is often extremely heterogeneous on both local and regional scales.

The majority of the benthic invertebrate species are relatively stationary in their adult life stage and consequently particular sensitive to natural and anthropogenic environmental impacts, including physical disturbance, hypoxia, or hazardous substances. Benthic species and communities are therefore suitable indicators of environmental impacts or changes occurring on a temporal scale from years to decades.

Compared to land, oil spills in the sea often affects large areas because of spreading with water currents. Effects of oil spills have been described from a number of serious/major ship accidents including the Arctic (*Exxon Valdez*). Owing to the relative low temperature in the Arctic, growth of benthic fauna is often slow (Blicher et al. 2010, Sejr & Christensen 2007) and therefore recovery from oil pollution is likely to take long time.

Before the studies carried out as a part of background study program initiated in relation to this SEIA, only a few surveys have been carried out, e.g. a study of the macrobenthic fauna composition in the Holsteinsborg Dyb and the Store Hellefiskebanke (63-68°N) in the 1970s (Anon 1978).

As part of a larger benthic study a ship based survey was carried out in May 2009 to study the composition of the benthic fauna in the assessment area (Box 3).

A specific taxon that is receiving increasing attention is cold-water corals. These corals are widespread in large parts of the north Atlantic where they create a unique habitat that is inhabited by a specific fauna (Mortensen & Buhl-Mortensen 2004, Bryan & Metaxas 2006). Cold water corals have been found in the western part of the Davis Strait (Edinger et al. 2007). In Greenland waters knowledge of coral distribution and abundance has not been systematically studied. However, during trawl surveys conducted in Greenland waters, corals have been found at many locations along the continental slope of Southwest- and Southeast Greenland (ICES 2010). Recently, a ban against trawling in two areas south of Maniitsoq (64°N) was suggested due to the observations of high abundance of corals.

4.5 Sea-ice community

Susse Wegeberg

Arctic sea-ice is home to a specialised ecosystem consisting of bacteria, microalgae and microfauna living in cavities, brine channels and on the underside of the ice. But also large species are associated this ecosystem, such as polar cod. This ecosystem is highly dynamic and adapted to the seasonality of the seaice and to the variation in temperature, salinity and nutrient availability. These variations lead to high degree of horizontal patchiness in microbial sea-ice communities. Furthermore, the microbial sea-ice community in the Arctic is highly diverse, and one of the most important structural parameters for the community is the age of ice (first-year ice vs. multiyear ice) (Quillfeldt et al. 2009).

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

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

The sea-ice-algal production in the Arctic range from 5-15 g C m^{-2} $year^{-1}$ depending on sea-ice cover season (Mikkelsen et al. 2008). Irwin (1990) estimates an annual production of 4.4 g C m^{-2} off Labrador just west of the assessment area,

Box 3. Benthic invertebrate fauna in the Disko West area with focus on Store Hellefiskebanke

J.L.S. Hansen, M. Sejr, A.B. Josefson, P. Batty, M. Hjorth and S. Rysgaard

Knowledge concerning the benthic fauna in the Disko West assessment area has been very limited. In order to assess any potential impacts due to oil exploration or other activities, there is a strong need for establishing a baseline in regard to the occurrence and distribution of the benthic fauna in the Disko West area.

In May 2009, a ship based survey was carried out to document diversity and composition of the benthic macrofauna in the Disko West assessment area. A number of stations were sampled, including the soft bottom habitats on Store Hellefiskebanke (Fig. 1). The benthic infauna was sampled using Haps and Van Veen grabs and photographs were taken to describe the epifauna. In addition sediment composition, sediment pigment content and sediment respiration was measured (results are not shown). The results of this study together with data from a previous investigation in 1976/1977 have been used to update our present knowledge concerning the benthic macrofaunal community in the assessment area.

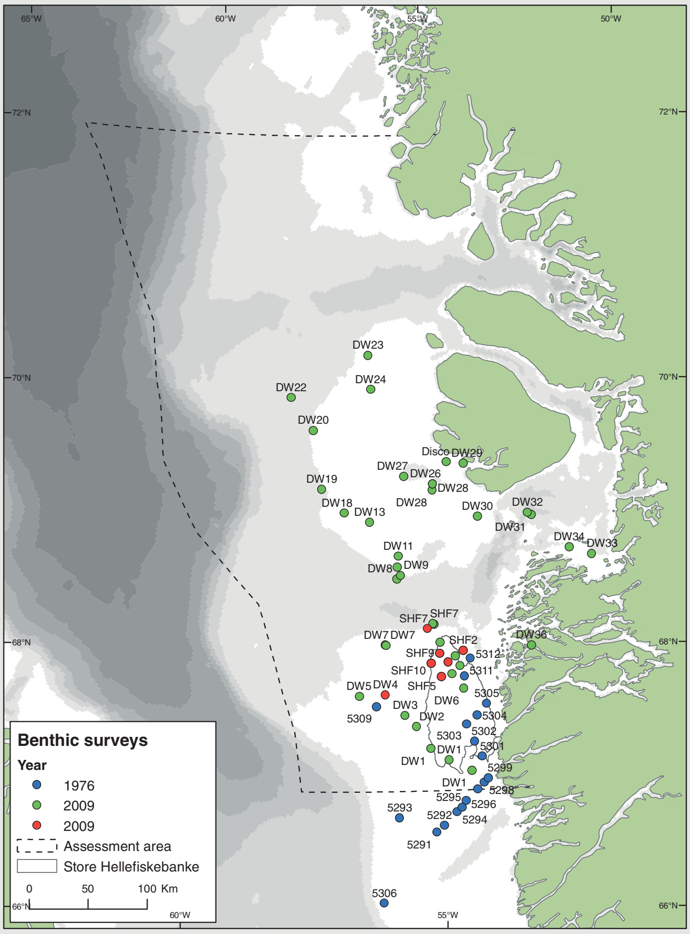


Figure 1. Stations sampled during the 2009 survey qualitatively and quantitatively (red and green symbols). Previous sampling (1976) is marked with blue symbols.

The benthic habitats in the Disko West area

Major parts of the area covered by the survey can be characterised as hard bottom habitats especially in the shallow parts (water depths <100 m). Such habitats include solid rocks and areas covered with boulders, gravel and shells, making a quantitative sampling sometimes impossible. Drop stones, i.e. stones originating from melting icebergs, are another typical feature, occurring on all sediment types at depth <200 m. The surface of the drop stones was often covered with epifauna (Fig. 2), indicating that the stone were on top of the sediment and exposed to epibiotic colonisation.

Figure 2. Typical drop stones covered with epifauna sampled on muddy bottoms at 170 m water depths.

The sediment composition was related to water depth. The shallowest locations (<30 m) were covered with well sorted sand whereas soft sediments (mud, silt and clay) were found at depths below 200 m. Depth between 150 and 200 represent a mixture of soft and hard bottoms.

Most of the shallow stations were located within or close to the Store Hellefiskebanke. Therefore the observations is not balanced in the assessment area and it is not possible to state if the distribution of soft/hard bottom is characteristically only for the Store Hellefiskebanke area or if in the relatively shallow areas (100-150 m) west of Disko Island the same mixture of sediment types occur.

The analyses of the sampled infauna and the photos of the epifauna document that the community composition followed the distribution of habitats along the depth gradient. The highest biomasses were found in the 50-100 m depth range with average values of ~500 g wet weight (ww) m^{-2} and about 300 g ww m^{-2} in the 100-150 depth range (Fig. 3). In the shallow waters (<50 m) and down to 150 m the total macrofaunal biomass was considerable lower, i.e. about one tenth or 30-50 g ww m^{-2}. The total abundance followed the same pattern, although less pronounced.

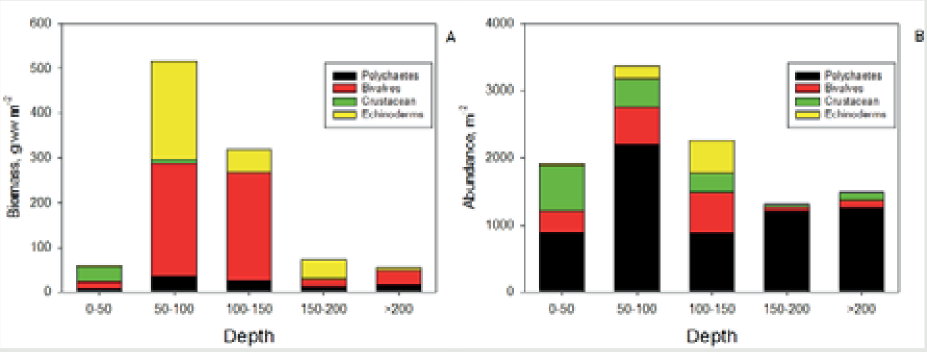


Figure 3. A) Distribution of benthic biomasses among major taxa in 50 m water depth intervals; **B**) Distribution of corresponding taxa in terms of abundance.

The average abundance in the samples between 50-100 m depth ranges was about 3000 indvs m^{-2} whereas the total abundance in the samples covering the other depth ranges varied between 1400-2200 indvs m^{-2}.

In most of the sampled area the biomass of the benthic fauna was only about one tenth of that found on the margins of the Store Hellefiskebanke. However, molluscs and echinoderms contain a relatively high amount of inorganic shell structures and as these two groups were most abundant on the bank this biases the comparison somewhat. In terms of ash free dry weight (AFDW) the biomass was about 5-8 times higher in the 50-150 m depth range compared to the rest of the area. The abundance was more evenly distributed in the area due to a relatively higher abundance of small taxa (e.g. polychaetes, crustaceans) at the deep stations which were characterised by soft sediments.

Crustaceans were most abundant at the shallowest stations (<50 m) with about 40 g ww m^{-2} (30% of the total biomass). Echinoderms were most abundant in the 50-100 m range with average biomasses of 200 g ww m^{-2} corresponding to 20% of the total biomass. However, in relative terms the echinoderms were most abundant in the 100-150 m depth range and their biomass contributed most significantly (40%) to the total biomass in the 150-200 m depth range. Molluscs dominated the biomass (50-80% of the total biomass) in the shallow waters (<150 m), whereas at the deepest stations their share in the overall biomass was about 30%.

Abundances and biomass of the polychaetes were more or less constant with depth. Thereby they contributed most significantly with 85% to the total abundance and 45% to the total biomass at the deepest stations (>200 m; Fig. 3). In the shallow waters (<150 m) their contribution to the abundance was smaller at depth less than 150 m. At the deepest stations (>200 m) the polychaetes contributed with 85% of the total abundance and about 45% of the biomass (Fig. 3).

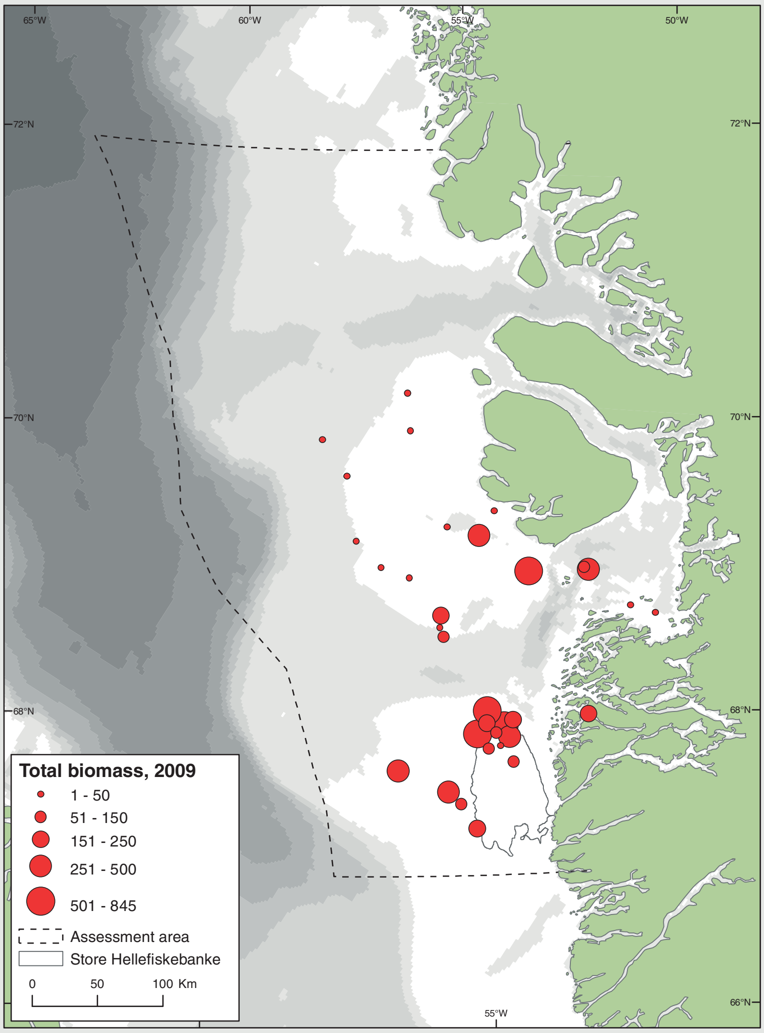


Figure 4. Distribution of benthic macrofauna biomass in the Disko West area May 2009.

As stated before, the very shallow stations (<50 m) were all located on the Store Hellefiskebanke and the total biomass of benthic macrofauna was in average only about 100 g wet weight m^{-2} (Fig. 4). On the margins of the bank, the biomass was about 500 g ww m^{-2} due to both mollusc and echinoderms. The soft-shelled clam, *Mya*, was also very abundant in this area. The photographs suggest a biomass of about 200 g ww m^{-2} of this clam. However, the clams were located too deep in the sediment to be collected during the sampling. When including this species into the calculation, it can be estimated that invertebrate faunal biomass might be about 700 g ww m^{-2} on the margins of Store Hellefiskebanke and maybe also in the 50-100 m depth range west of Disko Island which was not covered by the sampling.

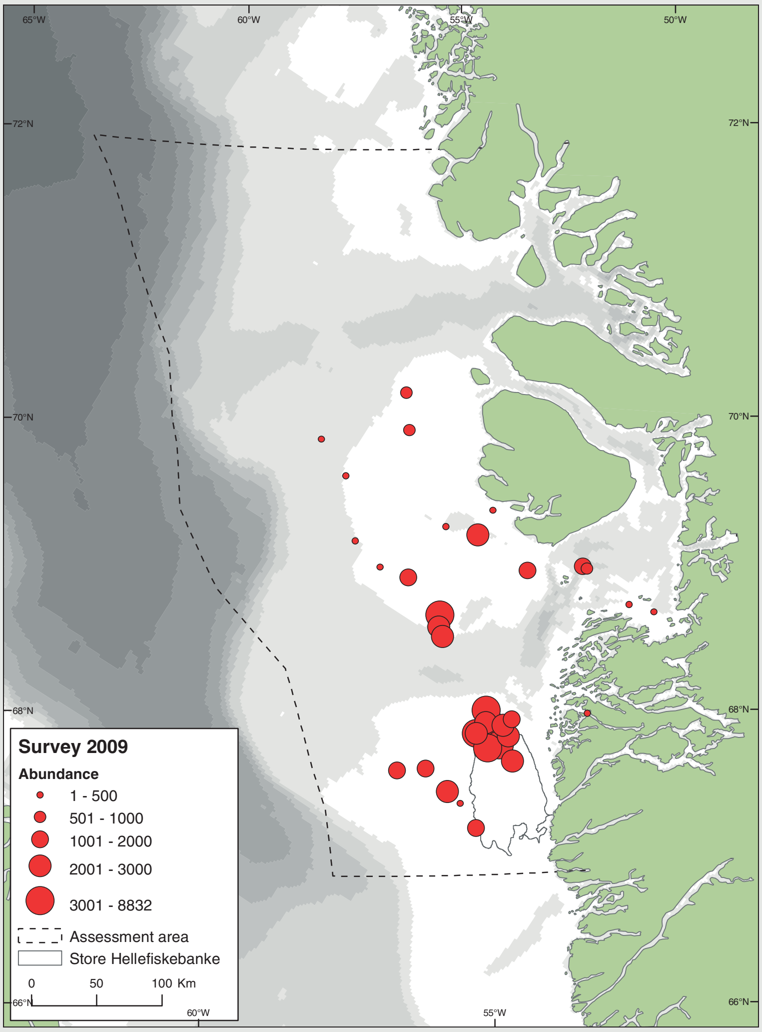


Figure 5. Abundance m^{-2} of benthic macrofauna in the Disko West area in May 2009.

Bathymetry, and in particular depth can be seen as a major factor for the distribution of the macrofauna communities in the Disko West area (Fig. 5 and 6). The shallow community is characterised by high abundances of crustaceans (amphipods), large bivalves (such as the soft-shell clam *Mya*) and sea urchins and covered about 4100 km^2 of the central Store Hellefiskebanke. The biomass of the communities on the margins of the bank (50-150 m), covering about 11600 km^2 and smaller areas west of Disko, were dominated by the presence of sea urchins and *Mya*, which in particular covered the rest of the entire Bank area at greater depth (>100 m). The area in the 150 to 200 m depth range is characterised by brittle stars (echinoderms) and bivalves which cover the outer margins west of the Bank (5300 km^2) and areas west of Disko and in Disko Bay. The deepest stations (>200 m) constitute a major part of the sampled area with soft bottom sediment and a benthic community dominated by polychaetes, but relatively low biomasses. Some of these areas should potentially be regarded as sedimentation basins with enhanced organic content in the sediment and higher macrofaunal biomass.

Macrofaunal diversity and species richness

The diversity data include in principle only animals associated with soft sediments (e.g. sediment types where it was possible to retrieve quantitative samples). However, due to the presence of drop stones, some organisms that are normally associated with hard substrates occur frequently in the samples. Examination of the epifaunal communities on the drop stones showed that these differ markedly from the species composition of the surrounding bottoms and thereby contribute significantly to the total biodiversity of the bottoms.

This data from a previous study in 1976, consisting of observations from 16 stations and a total of 104 Van Veen grab samples is comparable to the 2009 survey. A total of about 630 species were recorded at the 16 stations, including bryozoans and polyps from scyphozoans that are not always included in macrofaunal surveys. The four major taxa present in 1976 were polychaetes, molluscs, echinoderms and crustaceans which contributed with about 360 species to the overall diversity. The polychaetes contributed with most species (145). Some of the stations in the 1976 survey were located more southerly than in the 2009 survey. Only 51 samples were taken in the same area as in 2009, and there the total species richness present was about 460 and about 279 within the four major taxa. The average number of species found in one 0.1 m^2 Van Veen sample was 61 in 1976 in the entire area. On average 34 species of the major taxa were found in the 51 samples taken directly on the bank. In some samples a very high number of species, exceeding 100 species per 0.1 m^2 was found. There was no clear correlation between diversity and depth on the Bank. The distribution of species among samples in this restricted area was the same in 1976 as during the 2009 survey, showing almost identical species area curves (Fig. 7).

A comparison of the species richness during the 1976 and 2009 survey based on the four major taxa present in single 0.1 m^2 Van Veen samples showed that for a sampling effort of 41 samples the expected number of species was 291 in 1976 and 248 during the 2009 cruise.

However, by including only stations in the same part of the bank the species area curves are almost identical. The estimate shows that sampling one more Van Veen sample (from 41 to 42) would increase the total species number by 2 and sampling of one more station would add 10 species. For a sampling effort of 104 samples covering a larger area (blue curve, Fig. 8) it is expected to find 369 species of four major taxa. One more sample would add 1 species to the list. If the same kind of estimate is applied to all species identified in 1976 (635 in total) it could be expected to find 1-2 more species when taking one more sample. One more station would increase the number by 7-8 species. Considering the smaller area of the central Store Hellefiskebanke, the species number will increase from 459 to 462 by sampling 55 instead of 54 samples.

Opposed to the other three major groups (bivalves, echinoderms and crustaceans) the distribution of polychaete species richness did not differ much between Store Hellefiskebanke and the remaining Disko West area, since the bank is not in particular richer in polychaetes than the rest of the investigated area.

Habitat distribution

The benthic soft bottom habitats in the Disko West area are similar to what is found elsewhere at continental shelves at comparable depth; the softest sediment types (mud and clay) are distributed in the deepest parts where the finest organic and inorganic particles can settle. However, the presence of drop stones originating from the melting icebergs over centuries is a special feature that influences the benthic habitat by increasing the small-scale structural heterogeneity of the sediment surface leading to a high diversity (alpha and beta diversity) of the benthic communities. In addition to the presence of drop stones, a generally higher heterogeneity was found, except in water depth more than 300 m. It is unknown to what extend this heterogeneity relates to reworking of the sediment by iceberg scouring.

As found elsewhere, the benthic ecosystem in the aphotic zone in the Disko West area is fuelled by the sedimentary flux of organic particles from the productive surface layers. The organic particles are partly re-mineralised while sinking through the water column being exposed to pelagic heterotrophic processes. Therefore, the total input of organic material to the benthos not only depends on the local water column productivity but also on water depth. The deeper the water column the more material will be re-mineralised and the less is available for the benthic community. This pattern fits with the observation during the 2009 survey.

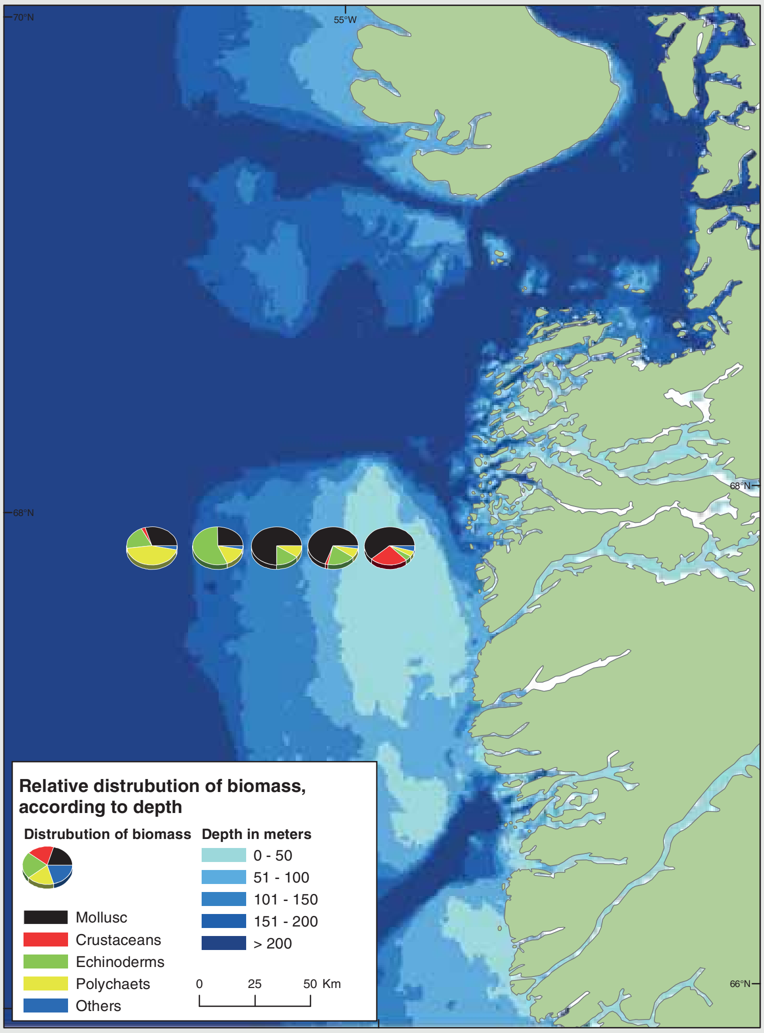


Figure 6. Distribution of benthic macrofauna communities during the survey in May 2009 in terms of biomass in different depth intervals <50 m, 50-100 m, 100-150 m, 150-200 m and depth >200 m.

Diversity of benthic fauna in the Disko West area

The study in 2009 also documented the presence of a highly diverse macrofauna community at all locations visited. A total of about 270 species of the four major taxa has so far been identified in the samples, but further analysis will increase this number and some species are new to science. As indicated by the species-area curves (Fig. 7 and 8), these numbers may only represents a fraction of the total diversity of the invertebrate fauna. During the 1976- investigation about 700 species were documented in about 150 samples.

The distribution of polychaetes species among stations, for example, showed markedly differences in the communities although the stations were situated in a relatively small area. The distribution of species among stations suggests that in sampling one more station the species list would increase by 5-6 new polychaete species alone and about 14 more species if all taxa are included. Data from 1976 showed almost exactly the same patterns and it is likely that the number of species in 2009 also would reach about 600-700 if all groups were included. Many species occur only in one of these two data sets, and although merging of the two data sets is not straightforward this suggests that the 'real number' of species in the area could well be considerably higher maybe exceeding 1000.

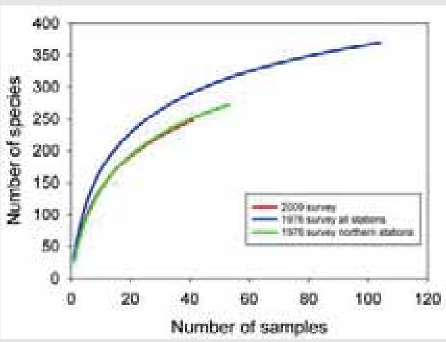
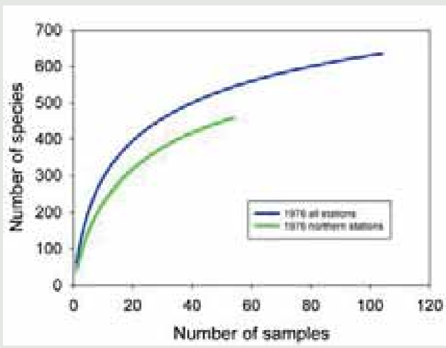


Figure 7. Randomised species accumulation curves showing cumulated number of species vs. number of Van Veen samples on the Store Hellefiskebanke in 1976 (blue line) and 2009 (red line). The green line shows the distribution of species at the stations in the northern part of the 1976 survey.

Figure 8 Distribution of species richness on the Store Hellefiskebanke in 1976 (data represents average number of species per 0.1 m² (Van Veen samples).



Potentially there are several new species to science among the sampled specimens and so far one polychaete species is confirmed to be a new species belonging to the genus "*Asclerocheilus*".

Biodiversity 'hotspot' Store Hellefiskebanke

From the studies performed in 2009 and 1976 it can be concluded that species diversity is very high on the Store Hellefiskebanke and the surrounding area. Despite the limited number of observations it is clear that the diversity is very high also when compared with other temperate regions, e.g. in western Europe and other parts of the West Greenland seas. In order to gain a more complete picture of the species richness more studies are required including sea bottoms dominated by gravel and other types of mixed sediment which are difficult to sample.

Within the studied area, the Store Hellefiskebanke can be considered as a biodiversity "hotspot" and an area with a strong bentho-pelagic coupling. With more than 600 documented benthic species in total and a point diversity up to 100 species found in one single 0.1 m^2 sample, this emphasise the importance of the Store Hellefiskebanke for the total benthic diversity of West Greenland.

The biomass found on here (ca. 700-800 g m^{-2}) is about 10-fold higher on the banks margins (in the 50-150 depth range) compared to the rest of the investigated area. In particular, bivalves (e.g. *Mya*) and echinoderms contribute to these enhanced biomasses with up to 400-500 g ww m^{-2}. Another characteristic is the very high abundances of amphipods (crustaceans), a high quality food source for juvenile fish, in the shallowest part.

Secondary production is presumably high on the Store Hellefiskebanke and this may be due to the shallowness in combinations with the offshore location. The surface mixed layer probably extends all the way to the bottom of the bank. This means that the filter feeders have direct access to the primary production in the illuminated surface layer, resulting in a very efficient pelago-benthic coupling allowing sustaining enhanced biomasses of the benthic community. The shallow depth also suggests that wave energy can penetrate to the sea floor. The coarse and well oxygenated sediments on the top of the bank are probably also maintained by frequent sediment re-suspension thereby transporting the finer particles away from the area thus favouring species such as the sandeel (Box 4).

The benthos of the Store Hellefiskebanke is available for higher trophic levels, i.e. seabirds and marine mammals. Large bivalves are valuable food items for king eiders as well as walruses. The shallowness of the bank makes these food resources easily accessible. Large aggregations of king eiders are seen in the area during winter (Box 5) and suggest an efficient utilization of the benthic macrofauna although any quantitative measurements of the significance of the predation are missing. The walruses occur in winter on the outer margins of the Store Hellefiskebanke (Section 4.8.5) where suitable size classes of bivalves have their highest densities. The benthic community in the area provides also a diverse food source to benthic foraging fish and predatory macrobenthos thereby sustaining their diversity.

The present data coverage is too sparse to determine whether similar productive benthic habitats exist in other parts of the Disko West area.

Conclusions

The quality of future effect studies on benthic fauna in relation to oil exploration activities in Greenlandic waters depends to a large extent on availability of relevant taxonomic knowledge and reference material of the macrozoobenthic community. It is therefore recommended to construct a reference collection based on the presented and other studies for quality assurance of future investigations (incl. site surveys) and for general documentation of the biodiversity.

It is recommended to develop equipment and techniques to sample gravel bottoms and bottoms with drop stones quantitatively.

Techniques for a more precise positioning of soft bottoms sampling in relation to small-scale properties of bottom surface morphology such as iceberg scours etc. will lead to a better understanding of small-scale habitat heterogeneity and thereby opening the possibility of developing better BACI-designed (**B**efore **A**fter **C**ontrol **I**mpact) macrofauna effect studies.

The Store Hellefiskebanke should be nominated as a highly vulnerable area due to the high diversity and ecosystem service. The uniqueness, however, depends on whether or not similar habitats exists in the Disko West area and whether or not such areas could serve as alternative foraging areas for key species like walruses, seals, eider ducks and sandeels.

and <1 g C m^{-2} $year^{-1}$ has been reported from Kangerluarsunnguaq (Mikkelsen et al. 2008) and in Young Sound, Northeast Greenland (Rysgaard et al. 2001).

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

The annual productions of the ice algae communities in the assessment area and relevant Arctic seas are presented in Table 3.

Mikkelsen et al. (2008) tested if the ice algae acted as inocula for initiating the spring bloom of phytoplankton by algal seeding, but had, however, not conclusive results. Michel et al. (2002) concluded that ice algal species released into the water column did not appear to play an important role for phytoplankton development. The ice algal community was dominated by pennate diatoms species by up to 85 %, and the phytoplankton bloom was very strongly dominated by pelagic species of centric diatoms not present in the ice algal community in the North Water Polynya. Also Booth (1984) found that species composition in the sea-ice differed significantly from that of the phytoplankton. These findings suggest therefore that the sea-ice algae constitute a unique and separate community compared to the pelagic living phytoplankton.

The inside ice microfauna was found to be dominated by ciliates and heterotrophic dinoflagellates and the bottom-ice meiofauna by nematodes in the North Water Polynya (Michel et al. 2002). This fauna community corresponds to observations in the Greenland Sea, where also crustaceans, though, were considered important (Gradinger et al. 1999). Gradinger et al. (1999) calculated a potential ingestion rate of the meiofauna, which levelled the estimated annual sea-ice primary production, and therefore they presumed that grazing could control biomass accumulation. However, Rysgaard et al. (2001) considered that the low ice algal production they found in Young Sound did not seem to be caused by high grazing pressure, since the biomass of grazers was not exceptionally high. In addition, Michel et al. (2002) concluded that very little ice algal production was channelled through the meio- and microfauna within the ice in the North Water Polynya, due to suboptimal prey size for predators.

Table 3. Ice algal annual production (g C m^{-2} $year^{-1}$) in different areas of the Arctic. *Integrated over 7 months; November to June. It might therefore be an underestimate of the annual production. **Calculated from an ice algal contribution averaging 57 % of the entire primary production (15 g C m^{-2} $year^{-1}$).

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

Buck et al. (1998) described a special spring sea-ice phenomenon from the Disko-area, termed an infiltration community. It is well-known from Antarctica, but had not earlier been described for the Arctic. The infiltration layer is created when a load of snow depresses the sea-ice below sea level and the snow-ice interface become flooded. Off Disko, in some of these flooded, refrozen regions, assemblages of infiltrated phyto-and zooplankton developed, which showed a relatively lower, but similar, algal biomass than in the well-developed bottom ice community. The communities were dominated by pennate diatoms, heterotrophic dinoflagellates, other flagellates and ciliates.

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

The production of the ice community may be of great importance at times of the year where the pelagic and benthic productions are relatively low, especially just before spring bloom of phytoplankton, and for example to spawning fish species as polar cod and Arctic cod. In addition, the sea-ice community is expected to be very vulnerable to oil spills as the ice may catch and accumulate oil in the interface between ice and water as well as the oil may penetrate the ice through brine channels, all of which are the spaces occupied by sea-ice communities.

The present information on sea-ice production, biomass and community structure in the assessment and other areas is very heterogeneous, at times even contradicting, and thus important or critical areas in the assessment area cannot be identified on the available information. Further studies are recommended to fully appreciate the role of sea-ice communities in the Baffin Bay marine ecosystem and to support identification of potential important or critical areas of sea-ice production in the assessment area.

4.6 Fish and shellfish

A. Burmeister, H. Siegstad and A. Retzel

Our present knowledge concerning the fish fauna in West Greenland (including the assessment area) is mainly based on information obtained during early Danish expeditions and follow-up analysis (Jensen 1926, 1935, 1939), as well as on more recent studies on single fish species including the description of new species (Nielsen & Fosså 1993, Møller & Jørgensen 2000, Møller 2001) and fisheries related research activities and assessments (Gutt 1995, Munk et al. 2000, 2003, Pedersen 2005, and references therein, Simonsen et al. 2006, Bergström & Vilhjalmarsson 2007).

Greenland waters are now surveyed annually by the Greenland Institute of Natural Resources (GINR) and the German Federal Research Centre for Fisheries. The survey catch data are occasionally used for fish assemblage studies (Rätz 1999, Jørgensen et al. 2005). New species are added to the Greenland fish fauna each year, but presently it is not known whether this is due to increasing temperatures or just the result of the increasing amount of surveys and sampling activities in deep waters (400-1500 m).

Presently, the total number of fish species known from the Greenland Exclusive Economic Zone (EEZ) is 269, representing 80 families in total. About 80 of these species spawn in Greenlandic waters. The biology for many of the other species is poorly studied and therefore it is not clear whether they spawn in Greenland or not.

The fish diversity is highest off Southwest (226 species) and Southeast (182 species) Greenland and lowest in Northeast (47) and Northwest (79) Greenlandic waters. It is well known that the submarine sills between Canada/Greenland and Greenland/Iceland are effective barriers especially for deep water species and that they have a strong impact on the water masses and the fish assemblages (Møller et al. 2010). The higher diversity in West Greenland regions are probably a result of both higher temperatures, south to north directed currents, but also more knowledge on occurrence and distribution gained in relation to fishing and other surveys and the biogeographical history of the various fish families.

The International Polar Year 2007-08 (IPY) was used to prepare an updated checklist of the fish species currently known for Greenland waters and to analyse whether new species have arrived recently as a result of increasing temperatures (Møller et al. 2010).

Since the latest publication covering all known Greenland fish species (Nielsen & Bertelsen 1992), fifty-seven species have been added. Nineteen of these are reported for the first time. Twenty-nine were added on the basis of taxonomic revisions and/or identification of specimens caught before 1992, whereas 28 species have been caught in Greenland waters for the first time since 1992. Ten species were new to science. Only five of the added species are Arctic – i.e. mainly caught north of the Davis and Denmark Straits (Møller et al. 2010).

Many of the different fish species occurring in the assessment area (Table 4) are demersal, i.e. live near the seabed (Pedersen & Kanneworff 1995). A relatively low number of species are of relevance for the commercial fishery in Greenland. Among them is Greenland halibut which is of great importance in terms of economic value (see also Section 5.1). Several other species are caught in small scale commercial or subsistence fishery including capelin, Arctic char, redfish, spotted wolffish and Atlantic halibut (Mosbech et al. 1998).

Several shellfish species are also common in the assessment area such as snow crab or northern shrimp. They are not only of great economic importance (see also Section 5.1) but also for the marine ecosystem in general.

4.6.1 Selected species

Greenland halibut (*Reinhardtius hippoglossoides*)

Greenland halibut is a slow growing deep-water flatfish widely distributed in the north Atlantic including Baffin Bay, Davis Strait and Labrador Sea.

The main spawning ground is assumed to be located in the central part of the Davis Strait south of the sill between Greenland and Baffin Island to the south of the assessment area. Spawning takes place here in early winter (Jørgensen 1997a, Gundersen et al. 2010) probably around 62° 30’N-63° 30’N and at water depths greater than 1500 m.

Store Hellefiskebanke, Disko Bay and Disko Bank west of Disko Island are well documented settling and nursery areas (Smidt 1969, Gundersen et al. 2010, Stenberg 2007) for Greenland halibut but larvae are also brought into the Baffin Bay via the West Greenland Current (Bowering & Chumakov 1989). The Greenland halibut populations in the Davis Strait, Baffin Bay, inshore areas in Northwest Greenland and the east coast of Canada area are hence believed to be recruited from the spawning stock in the Davis Strait.

Greenland halibut gradually migrates towards greater depth and towards the presumed spawning area as they grow to reach the spawning area as adults (Boje 2002 and GINR unpubl. data). Young halibut, i.e. 1 – and to some extend 2 year old fish feed on zooplankton while older fish feed on shrimps, fish and squids at the sea bottom or during irregular feeding trips into the water column (Jørgensen 1997b).

Greenland halibut is an important food source for narwhals. During winter 50,000 narwhals distributed at two wintering grounds in the central part of Baffin Bay were estimated to consume about 790 t of this fish per day assuming a diet consisting of 50 % of Greenland halibut (Laidre et al. 2004).

Table 4. Overview of selected fish and shellfish species occurring in the assessment area.

Species	Main habitat	Spawning area	Spawning period	Exploitation	Importance of assessment area to population
Blue mussel	subtidal, rocky coast	subtidal, rocky coast	–	local	low
Iceland scallop	inshore and on the banks with high current velocity, at 20-60 m depth	same as main habitat	–	commercial and local	medium
Northern shrimp	mainly offshore, at 100-600 m depth	larvae released at relatively shallow depth (100-200 m)	March-May in southern part, August in northern	commercial and very important	high
Snow crab	coastal and fjords, at 180-400 depth	same as main habitat	April-June	commercial	medium
Polar cod	pelagic	–	–	–	medium
Atlantic cod	fjords	pelagic eggs and larvae in upper water column	February-May	local	low
Greenland cod	inshore / fjords	inshore / fjords, demersal eggs, pelagic larvae	February-March	commercial and local	medium
Sandeel	on the banks at depths between 10 and 80 m	on the banks, demersal eggs, pelagic larvae	July-August	important prey item	medium
Spotted wolffish	inshore and offshore	hard bottom, demersal eggs	peaks in September	local	medium
Arctic char	coastal waters, fjords	freshwater rivers	in autumn	local	medium
Capelin	coastal	beach, demersal eggs	April-June	local, important prey item	medium
Atlantic halibut	offshore and inshore, deep water,	pelagic eggs and larvae, deep water	Spring	local	low
Greenland halibut	deep water, in fjords and offshore	south of assessment area	Winter	important, both local and commercial	high
Redfish	offshore and in fjords, 150-600 m depth	spawn outside area	–	local	medium
Lumpsucker	pelagic	coastal, demersal eggs	May-June	commercial and local	medium

Atlantic cod (*Gadus morhua*)

Abundance and distribution of Atlantic cod has varied greatly in West Greenland waters in the past decades. Potential offshore spawning areas have been identified usually located between 60° and 66° N in waters of both East and West Greenland (Wieland & Hovgaard 2002).

Until the late 1980s, Atlantic cod was numerous on the banks, predominantly in the southern part of the assessment area, and fished intensively until the offshore stock crashed. Today, Atlantic cod occur only in low numbers in inshore waters (local stocks) (Hovgaard & Christensen 1990, Horsted 2000). In recent years an increasing number of juvenile Atlantic cod (age 1-2 yrs) have been registered on Store Hellefiskbanke between 66° N-69° N which suggest that this area is an important nursing area for the Atlantic cod stock in West Greenland. A recovery of the offshore Atlantic cod stocks is expected due to the increasing water temperatures recorded in recent years (see also chapter on climate change).

Another cod species common in the assessment area, is Greenland cod (*Gadus oqac*) – but it is considered of minor importance for the commercial fisheries compared with Atlantic cod, though it has some subsistence importance (Mosbech et al. 1998).

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. Known differences in maximum length, progressive spawning and well separated fjord systems suggest that individual fjord systems contain separate capelin stocks (Sørensen & Simonsen 1988, Hedeholm et al. 2010).

Sometime during autumn to spring capelin migrates to the fjords, where they form dense schools prior to spawning. Spawning takes place in shallow water (<10 m), 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). However, dense concentrations are sometimes also found in deeper waters down to 600 m (Huse 1998, Friis-Rødel & Kanneworff 2002).

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 chains, 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, Vilhjalmsson 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 assessment area.

Lumpsucker (*Cyclopterus lumpus*)

The common lumpsucker is distributed throughout the assessment area. Lumpsuckers spend most of the year in deep offshore waters, but in spring and early summer they seek shallow coastal waters to spawn (Muus & Nielsen 1998). After spawning the female leaves the spawning ground and the approximately 100,000-350,000 eggs are guarded by the male throughout the whole embryo period (Muus & Nielsen 1998, Sunnanå 2005). Based on Norwegian data, it seems that the offspring probably spend the first two years in the near shore kelp forests. The lumpsucker has increasing commercial importance because of its roe, and the fish is harvested by gill net fishery from small boats (Mosbech et al. 1998, Olsvig & Mosbech 2003).

The feeding behaviour of Greenland lumpsucker is unknown, but due to their poor swimming capabilities it is most likely restricted to jellyfish and other slow moving organisms (Muus & Nielsen 1998). Lumpsucker may constitute a significant prey resource to sperm whales in the area as seen elsewhere (Kapel 1979, Martin & Clarke 1986). Since little is known on lumpsucker migrations and dependency on other ecosystem components, it is unclear how the species might response to climatic changes.

Two other fish species are also potential key species in the marine food web at least in part of the assessment area: sandeel (*Ammodytes* spp.) and polar cod (*Boreogadus saida*). Both are important food sources for seabirds and marine mammals (see also Box 4 – Sandeel and Box 1 – Sept survey 2009).

Sandeel (*Ammodytes dubius*)
The sandeel is a pelagic foraging fish that spend part of the time hiding from pelagic predators in the seabed sediment. The sandeel plays an important role in the marine food web, e.g. as important food item for certain fish, marine mammals and seabirds.

Sandeel occur mainly in shallow water on the banks and often in large schools. The sandeel is one of the few fish species in the assessment area which spawn during the summer (Kapel 1979, Larsen & Kapel 1981, Andersen 1985) and they are largely stationary after larvae settlement. They feed on zooplankton (e.g. *Calanus* spp.) and small fish.

Sandeel occur in high numbers particular in the southern part of the assessment area, e.g. Store Hellefiskebanke and play an important role in the food web, (for more details see Box 4).

Polar cod (*Boreogadus saida*)
Polar cod is a pelagic or semi-pelagic species with a circumpolar distribution in cold Arctic waters. It may form large aggregations and schools in some areas, often in the deeper part of the water column or close to the bottom in shelf waters. It occurs in coastal waters and is often associated with sea-ice, where it may seek shelter in crevices and holes in the ice. Spawning takes place in late winter and the eggs float and assemble under the ice. The larvae hatch in spring when the ice melts and the ice algae has initiated the spring production.

Polar cod mainly feed on zooplankton such as copepods and pelagic amphipods (Panasenko & Sobolova 1980, Ajiad & Gjøsætter 1990). As growing larger they also feed on small fish. In coastal waters their diet consists of epibenthic mysids (Cohen et al. 1990) and in the ice covered areas they feed on ice-associated amphipods (Hop et al. 2000).

Polar cod plays a key role in the Arctic marine food webs as 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.

From studies performed in relation to diving depths of narwhals by Laidre et al. (2003) it was concluded that polar cod could be an important food sources also for narwhals in the northern wintering ground.

Knowledge on the ecology and abundance of polar cod in the assessment area is poor. As part of a study performed in September 2009, distribution of juvenile polar cod was studied in relation to zooplankton distribution (Box 1).

Arctic char (*Salvelinus alpinus*)
Arctic char is the most northern ranging freshwater fish and has a circumpolar distribution. It is widespread in Greenland including the most northern areas (Muus 1990).

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

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. Anadromous char mature at a size of 35-40 cm (Muus 1990), corresponding to an age of 5-7 years and they constitute an important resource for local consumption and play a significant role in the subsistence fishery in Greenland (Rigét & Böcher 1998).

The young char called ‘parr’ remain in fresh water for several years before their first migration to the sea, i.e. at a length of 12-15 cm, corresponding to an age of 3 to 6 years depending on growth conditions, (Riget & Böcher 1998). They undergo morphological and physiological changes allowing them to live in saltwater. The seaward migration generally coincides with the spring freshet, which occurs in May-June, depending on the latitude.

At sea, Arctic char mainly stay in coastal areas not far from the river (approx. up to 25 km) they derived from (Muus 1990). Tagging experiments carried out in Southwest Greenland showed that char populations from different rivers mix largely at sea.

In coastal areas char feeds intensively on small fish, fish larvae, zooplankton and crustaceans. During this part of their life the main growth occurs. The growth rate is also considerably faster than for lake resident populations.

In June-September, both spawners and non-spawners migrate back to freshwater, i.e., rivers and lakes, 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.

Northern Shrimp (*Pandalus borealis*)
Northern shrimp has a circumpolar distribution and it is a dominant species in Greenlandic waters. In West Greenland it is distributed along the entire coastline at depths ranging from 9-1,450 meter, with highest densities between 150 and 600 m. (Hortsed 1978, Bergström 2000). The preferred habitat is muddy bottom, and the bottom water temperature optimum in Greenland waters is between 2 °C and 4 °C (Bergström 2000). Spawning occurs during April in inshore shallow waters (Horsted 1978).

Box 4. Abundance of sandeel (*Ammodytes dubius*) in the Store Hellefiskebanke area

J.L.S. Hansen and M. Hjorth

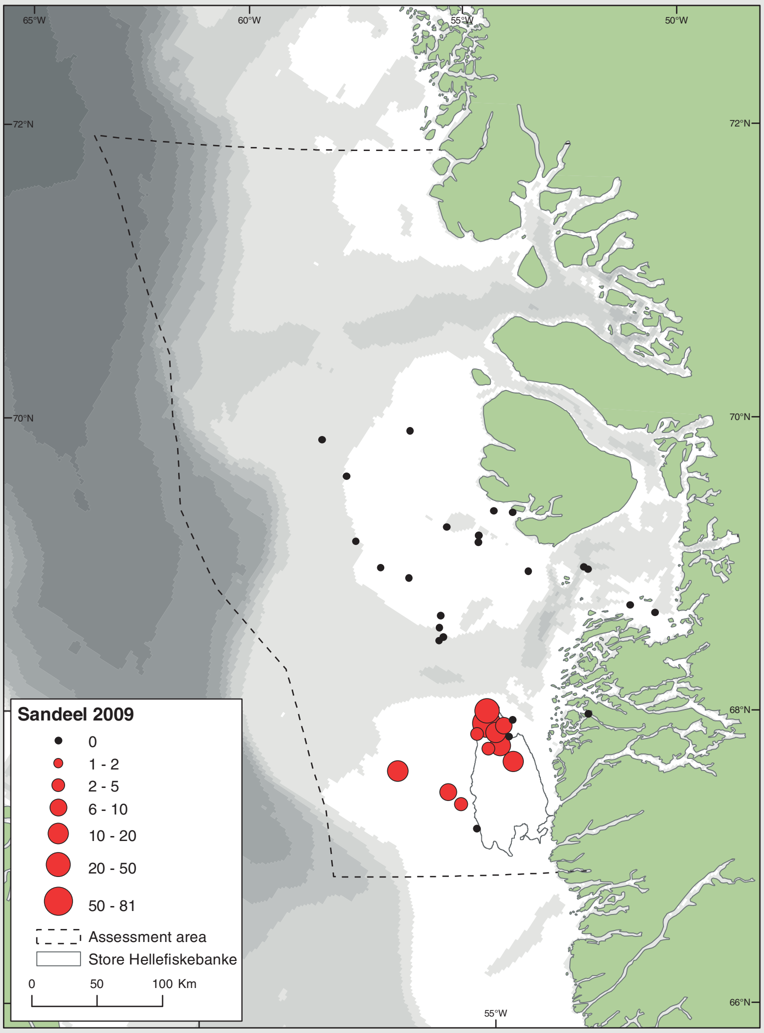


Figure 1. Distribution of sandeels in May 2009.

During the study of benthic fauna in the assessment area in 2009 (Box 3), sandeel specimens were observed in several samples. A total of 81 individuals were recorded in the Store Hellefiskebanke area (Fig. 1). The fish had an average length of 7.67 ± 1.46 cm (SD, N = 71) and the weight was on average 890 mg ± 640 mg (SD, N = 71).

In particular, in the 25-75 depth range, sandeels were very abundant whereas very few specimens were found at stations deeper than 150 m (Fig. 1). The distribution of sandeels correlates with the distribution of sandy sediments (Fig. 2) and almost all specimens were found on the Store Hellefiskebanke (Fig. 1).

Sandeels are specialized in living on sandy bottoms and spend most of the time partially buried in the sediment. In temperate regions this is typically during daytime; however it has not been possible to elucidate the diurnal rhythm at higher latitudes from the literature.

This diurnal rhythm has to be taken into account when estimating the size of the population associated with the Store Hellefiskebanke, as the sediment samples with sandeels were taken at both day and night time.

The distribution of sandeel was clearly correlated with depth (Fig. 3) and with coarse and well oxygenated sediments present on the Store Hellefiskebanke. Sandeels depend on coarse sediment in order to ventilate their gills. This may explain why this species was almost exclusively found on the Store Hellefiskebanke where these sediments are covering most of the area. It is possible that similar sediments occur in the shallow areas west of Disko Island. However, this has not yet been documented except from one single observation. Therefore, it seems not very likely that sediment dwelling populations of the same sizes as those associated with the Store Hellefiskebanke exist in other parts of the assessment area.

A rough estimate of the population size, based on the abundances in the different depth ranges, suggests an average abundance of 9 individuals m^{-2} over an area of 15,000 km^2. The population estimate is very likely an underestimate because it includes samples taken during the night time and the fact that sampling efficiency is not 100 % and probably does not include all year-classes. The sizes of the specimens suggest that the majority of the caught sandeels in this study were in the 2-year class (Fig. 4) whereas Andersen (1985) found up to 20 year old individuals. The ratio between

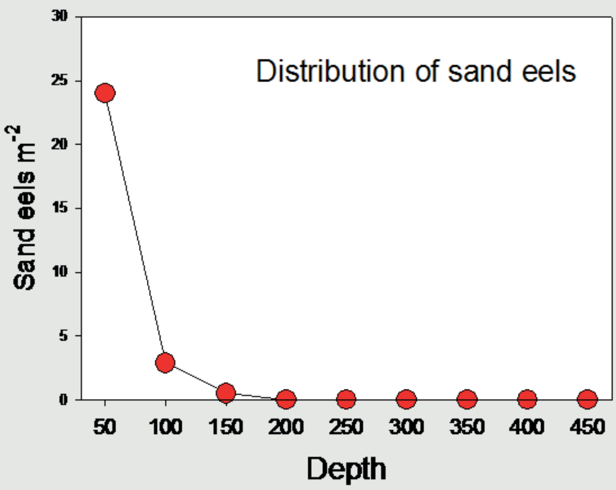


Figure 2. Distribution of sandeels versus depth in the Disko West area in May 2009.

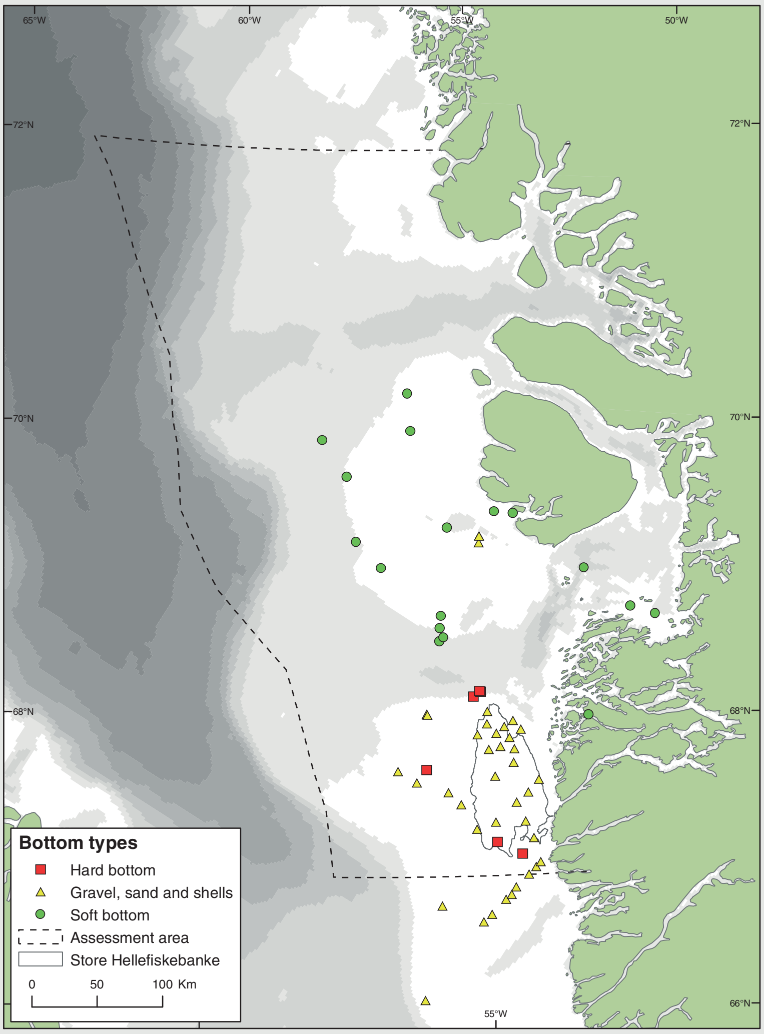


Figure 3. Distribution of sediment types: Hard bottom (red), bottoms with shells, gravel, stones and sand (yellow) and soft clay and mud (green).

log weight and log length being 3.24 fits with what has been found for sandeel communities at Georges Bank in the NW Atlantic by Nelson & Ross (1991), who found a relation of 3.26 in autumn surveys (N = 377). The fish in the George Bank study were longer and older than what these data suggests.

Sandeels are sensitive to oil, because oil pollution is critical for their preferred habitat (i.e. well oxygenated coarse sediment). The burial time in sand has been reported to decrease if the sand is contaminated with oil. The fish may try to move into clean adjacent areas or into deeper waters.

Conclusions

Sandeels are probably a key species in the pelagic ecosystem of the entire Disko west area. However, while hiding in the sediment their distribution is restricted to habitats typical for the Store Hellefiskebanke. At present, the data coverage is too sparse to determine whether or not similar habitats as on the Store Hellefiskebanke exist in other parts of the Disko West area. Sandeels from the Store Hellefiskebanke are available for higher trophic levels in the aquatic food web of West Greenland including birds, seals and fish like Atlantic cod. The present study emphasises the potential importance and vulnerability of sandeels in the assessment area. However, much more detailed knowledge is needed concerning their ecology and food web interactions and how this species might be affected by oil pollution.

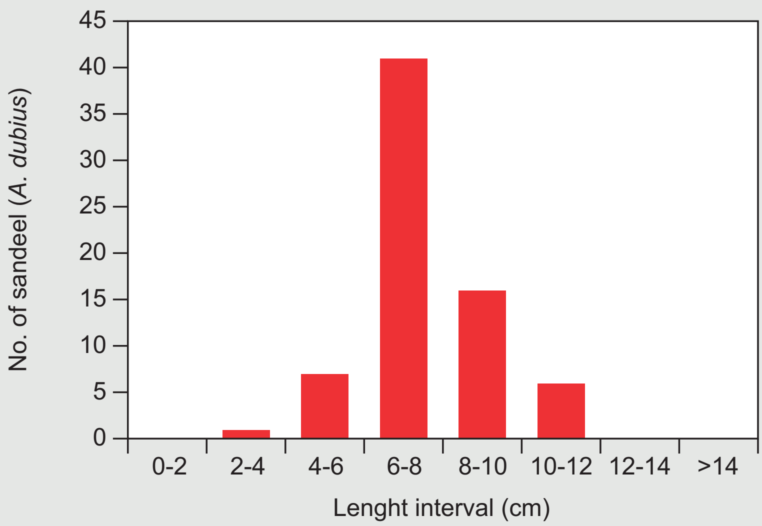


Figure 4. Frequency distribution of body length of the captured sandeels in the Disko West studies 2009.

Northern shrimps are highly mobile both horizontally and vertically, showing a diurnal migration, i.e. foraging at the bottom during daytime and in the water column during the night (Horsted & Smidth 1956, Bergström 2000).

Northern shrimp are omnivores and predates on worms, dead organic material, algae and zooplankton (Horsted & Smidth 1956), and serve as food for large fish such as cod and Greenland halibut (Parsons 2005).

Northern shrimp is a protandric hermaphrodite. In West Greenland waters, the juveniles mature as males at about 3 years of age. It functions as a male for 2-3 years, and then undergoes a transition to female at an age of 5 to 6 years (Horsted & Smidth 1956, Wieland 2004). The maximum age for Northern shrimp is more than 8 years (Savard et al. 1994).

Mating and spawning occur during July to September, the egg-bearing period lasts 8 to 10 months, depending on the temperature in the bottom water. The larvae hatch in April to June of the following year (Shumway et al. 1985), Bergström 2000, Horsted 1978). When the hatching time approaches, the female migrates to relatively shallow water (< 150 meters). The newly hatched larvae live freely in the upper part of the water column. During spring and summer, the larvae pass through six planktonic stages over a period of three to four months. In the last larval stages, the larvae settle on the bottom and become immature (juvenile) shrimps (Shumway et al. 1985, Bergström 2000, Storm & Pedersen 2003).

Hatching are believed to be distributed along the entire coast of West Greenland (Storm & Pedersen 2003) and ovigerous females are found along the entire coast (Data GINR).

Due to the northbound West Greenland current which dominates the West Greenland shelf (Ribergaard et al. 2004) larval drift from hatch areas to settling areas can cover distances of up to 500 km (Storm & Pedersen 2003). The shelf banks north of 64° N and Disko Bay is considered to be important areas for larvae development and juvenile shrimps (Storm & Pedersen 2003, Ribergaard et al. 2004, Wieland 2005).

In 2003 the highest biomass of Northern shrimp in West Greenland waters was estimated at 600 kt. Since then the biomass has declined owing to a decrease in the biomass in the offshore areas. The total biomass of Northern shrimp in West Greenland waters was estimated to 190 kt in 2012 (Kingsley et al. 2012).

Since 1988 more than half of the total biomass of Northern shrimp in West Greenland waters has been concentrated in the inshore (Disko Bay) and offshore areas north of 67° N. In the last decade the distribution area for Northern shrimp has moved northwards and the main biomass (80 % to 90 %) is now concentrated north of 67° N (including Disko Bay) (Ziemer et al. 2010, Kingsley et al. 2012).

Since 1999 the biomass in Disko Bay has been averaging 23 % of the total biomass in West Greenland waters. The mean density of Northern shrimp in Disko Bay is significantly higher than in the offshore areas. In 2011 and 2012 respectively 35 % and 48 % of the total shrimp biomass in West Greenland waters was found in the Disko Bay area (Kingsley et al. 2012).

Snow crab (*Chionoecetes opilio*)
The snow crab is a subarctic species, distributed in the Bering Sea (North Pacific) and the north-western Atlantic, including Canada and West Greenland between 60° N and 74° N in both offshore and inshore (fjords) locations (Burmeister 2002). It pre-

dominantly inhabits mud or sand-mud substrate at depths between 100 and 800 m and at bottom 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. The larvae proceed through three planktonic stages before settling on the bottom during autumn, where it preys on fish, clams, polychaetes, brittle stars, shrimp, other crabs and its own congeners (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 understood for the assessment area. The population in the assessment area is declining due to years of high fishing pressure.

4.7 Seabirds

D. Boertmann

Seabirds is an important component in the marine ecosystem of the Disko West assessment area. Many species primarily consume fish, in particular schooling species (capelin, sandeel and polar cod). Some species live on or supplement their fish diet with large zooplankton (copepods, krill), and others feed primarily on benthic invertebrates (e.g. bivalves) (Falk & Durinck 1993, Merkel et al. 2007). The species utilise the common resources by means of different feeding strategies. Some for example, are deep-diving foragers while others take their food from the water surface. Many seabird species tend to aggregate at breeding or foraging sites, and very high concentrations may occur in the assessment area. A single flock of king eiders was for example estimated to hold up to 30,000 birds, which may represent as much as 6 % of the total population wintering in Greenland. Other examples are the large breeding colonies where up to 50,000 pairs of northern fulmar breed. An overview of the seabird species occurring in the assessment area is given in Table 5.

Most of the seabirds in the assessment area are colonial breeders and numerous breeding colonies are found dispersed along the coast of the assessment area (Figure 13). The size of the colonies range from a few pairs to more than 50,000 individuals and vary in species composition, from a single to up to 10 different species. The breeding seabirds utilise the waters near the breeding site; thick-billed murres and fulmars may fly more than 100 km to find their food, but most feed within a much shorter range (Falk et al. 2000). However, numerous seabirds also utilise the waters much further away from the coasts and these comprise non-breeding individuals from breeding populations all over the North Atlantic – mainly black-legged kittiwakes and northern fulmars – which spend the summer in the food rich waters off West Greenland (Mosbech et al. 1998). Great shearwaters (*Puffinus gravis*), breeding in the southern hemisphere, occasionally also occur offshore in the region. Another non-breeding seabird segment utilises the region in summer. Seaducks arrive from breeding sites in Canada and inland Greenland and assemble to moult in remote bays and fjords (Figure 14). King eiders are numerous in the fjords of Disko Island, harlequin ducks (*Histrionicus histrionicus*) stay at remote rocky islands, and long-tailed ducks (*Clangula hyemalis*) and red-breasted mergansers (*Mergus serrator*) are found in shallow fjords and bays (Frimer 1993, Mosbech & Boertmann 1999, Boertmann & Mosbech 2002). A few species occur only as migrant visitors during spring and autumn, e.g. two species of phalaropes, Sabine's gull (*Larus sabini*) and the rare and threatened ivory gull (*Pagophila eburnea*) (Boertmann 1994).

Table 5. Overview of selected seabird species occurring in the Disko West assessment area. b = breeding, s = summering, w = wintering, mi = migrant visitor, c = coastal, o = offshore. Importance of study area to population (conservation value) indicates the significance of the population found in the assessment area in a national and international context as defined by Anker-Nilssen (1987). * indicate that they are colonial breeders in the assessment area.

Species	Occurrence		Distribution	Red-list status in Greenland	Importance of study area to population
Fulmar*	b/s/w	year round	c & o	least concern (LC)	High
Great cormorant*	b/s/w	year round	c	least concern (LC)	High
Brent goose	mi	spring and autumn	c	least concern (LC)	Medium
Common eider*	b/s/m/w	year round	c	vulnerable (VU)	High
King eider	m	Aug.-Sep.	c	not evaluated	High
	w	Oct.-May	c & shallow banks		
Long-tailed duck	b/m/w	year round	c	least concern (LC)	Medium
Red-breasted merganser	b/m/w	year round	c	least concern (LC)	Medium
Harlequin duck	m	Jul-Aug.	c (rocky shores)	near threatened (NT)	Medium
Red-necked phalarope	mi, (b)	spring and autumn	o	least concern (LC)	Low
Grey phalarope	mi, (b)	spring and autumn	o	least concern (LC)	Low
Arctic skua	b	summer	c	least concern (LC)	Low
Black-legged kittiwake*	b/s	year round	c & o	vulnerable (VU)	High
Glaucous gull*	b/s/w	year round	c & o	least concern (LC)	Medium
Iceland gull*	b/s/w	year round	c & o	least concern (LC)	Medium
Great black-backed gull*	b/s/w	year round	c & o	least concern (LC)	Medium
Sabine’s gull	b	very localised		near threatened (NT)	Low
	mi	Aug. and May/Jun	o		
Ross’ gull	b	very localised	c	vulnerable (VU)	Low
Ivory gull	w, mi	Nov.-May	o	vulnerable (VU)	Medium
Arctic tern*	b	May-Sep.	c	near threatened (NT)	High
Thick-billed. murre*	b/s/w	year-round	c & o	vulnerable (VU)	High
Razorbill*	b/w	year-round	c & o	least concern (LC)	High
Atlantic puffin*	b/w	year-round	c & o	neat threatened (NT)	High
Black guillemot*	b/w	summer	c	least concern (LC)	High
		winter	c & o		
Little auk*	b	May-Aug.	c & o	least concern (LC)	High
	w	Sep.-May	o		
White-tailed eagle	b/w	year round	c, rare in southern part	vulnerable (VU)	Low

Sixteen species of seabirds breed in the assessment area (Boertmann et al. 1996). The most widespread is the black guillemot (*Cepphus grylle*), breeding along almost all rocky coasts. Northern fulmar (*Fulmarus glacialis*) is found in immense numbers in a few breeding colonies in Disko Bay and Uummannaq Fjord. There is only a single colony of thick-billed murre (*Uria lomvia*) in the region (Box 6). Numbers here are declining, primarily due to unsustainable harvest. Although the closed season was prolonged in 2001, so the spring hunt is now banned, the decline continues. Black-legged kittiwake (*Rissa tridactyla*) breeds in several colonies within the region, and especially the interior parts of Disko Bay is a stronghold for the species in Greenland (Labansen et al. 2010). These colonies have declined in recent decades (Boertmann 2006, Labansen et al. 2010). However, the shorter hunting season has had significant positive impact on the breeding common eiders (*Somateria mollissima*) (Merkel 2008, 2010). Arctic tern (*Sterna paradisaea*) breeds also in several colonies within the region, e.g. the largest Arctic tern colony in Greenland is on Grønne Ejland (Egevang & Boertmann 2003, Egevang et al.

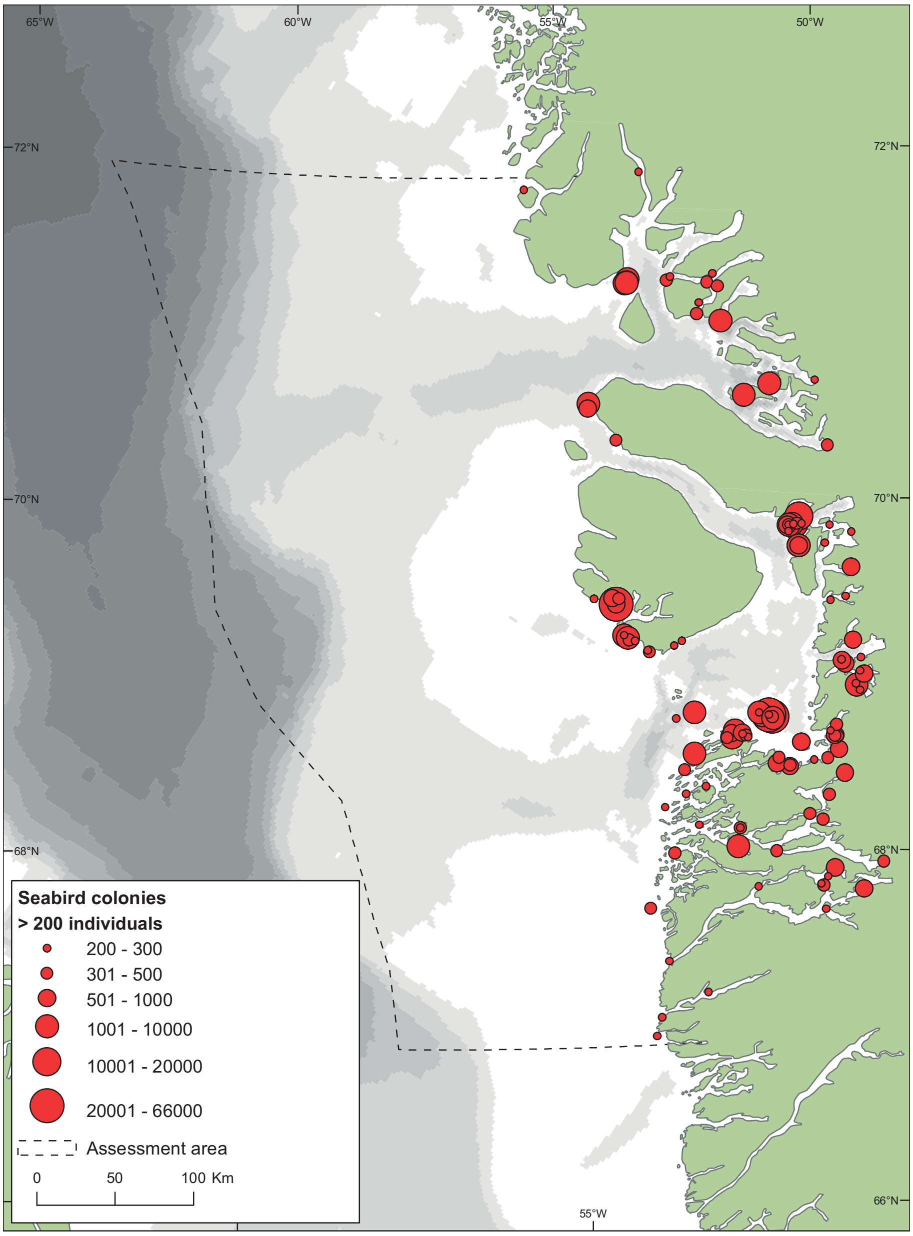
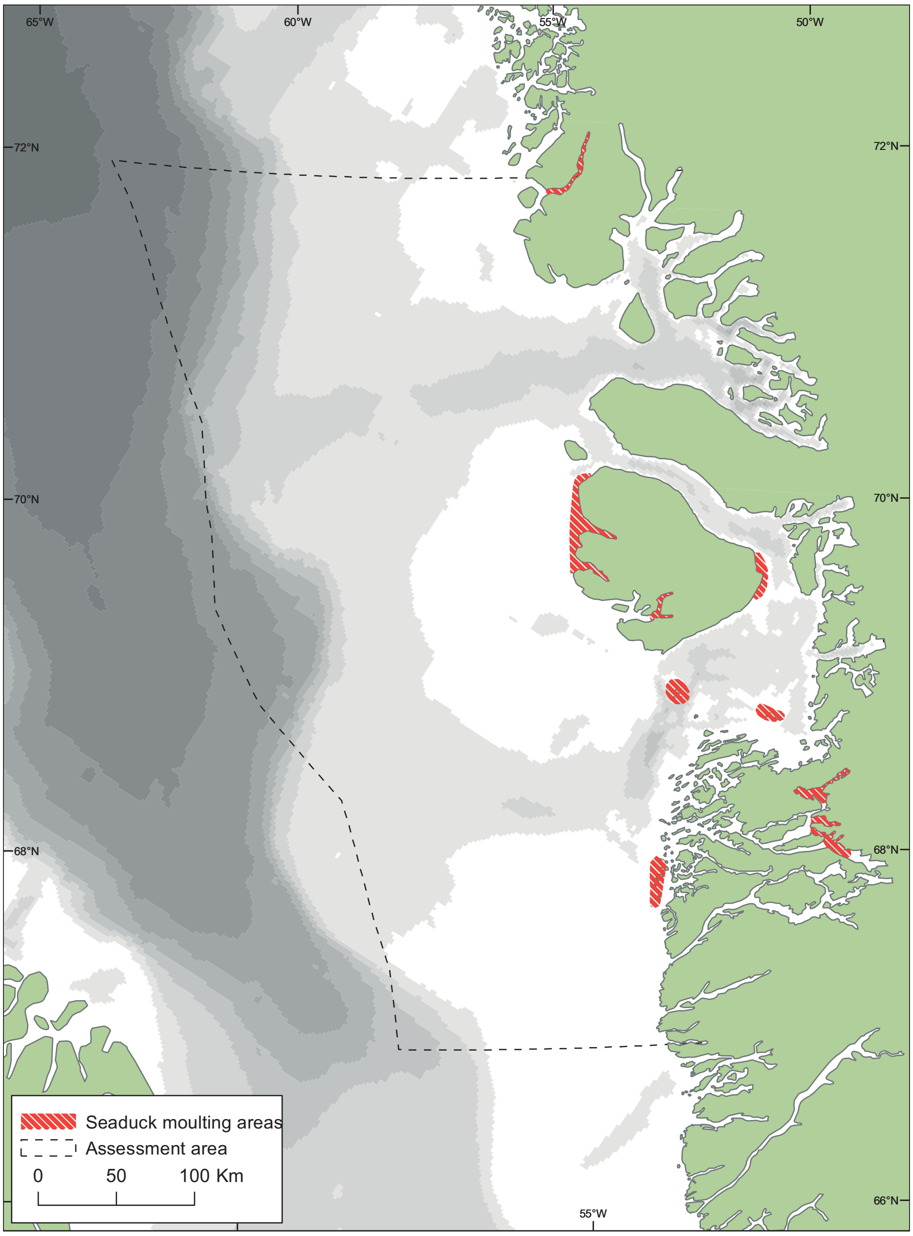


Figure 13. Distribution of seabird breeding colonies in the study area. Colonies with less than 200 individuals not shown (Greenland Seabird Colony Register).

2005). Scarcer breeding species include Atlantic puffin (*Fratercula arctica*) and little auk (*Alle alle*) while Ross's gull (*Rhodostethia rosea*) and Sabine's gull (*Larus sabini*) are very rare breeding very locally in the region (Egevang & Boertmann 2008, 2012).

During autumn large numbers of seabirds begin to assemble in the waters off the West Greenland coast (See Box 7). Some are under way to wintering sites outside Greenland waters, but many and probably the major part will stay throughout the winter, mainly south of the assessment area (Boertmann et al. 2006). However, especially in the southern part of the assessment area many wintering seabirds occur where the ice is loose or where tidal currents keep waters ice free. At such sites, extremely high numbers of wintering seabirds are often found. These are not only of local origin, but arrive from breeding sites in Canada, Iceland and Svalbard, making the Greenland wintering sites of high international importance. The most numerous species in winter are common eider, king eider, thick-billed murre and the large gull species.

Figure 14. Important areas for moulting seaducks, mainly king eiders; also common eiders, harlequin ducks and red-breasted merganser are among the moulting ducks. The moulting period is July to September. (Map based on Mosbech & Boertmann (1999) and Boertmann & Mosbech (2001, 2002).



The distribution of the wintering seabirds has been surveyed in the coastal area of West Greenland (Merkel et al. 2002, Boertmann et al. 2004). It is estimated that more than 3.5 million birds winter along the entire coast of Southwest Greenland. To this figure an unknown but probably very high number (several million) of little auks should be added (Boertmann et al. 2006). They occur mainly in offshore waters, where they are difficult to survey. Also large numbers of thick-billed murres occur in the offshore area in spring and autumn. The knowledge of the habitat use of the wintering seabirds and the factors governing their distribution is generally poor. Despite the unknowns it is evident that, seen in a North Atlantic perspective, the waters of West Greenland are very important for seabirds (Barrett et al. 2006).

A number of studies of king eiders have been conducted in recent years (Box 5) and it is evident that the assessment area is very important for the king eider population breeding in eastern Arctic Canada.

Thick-billed murre abundance and distribution have been surveyed from aircraft in spring, and some significant concentrations were observed in the assessment area (Figure 15 and 16) (Merkel et al. 2002).

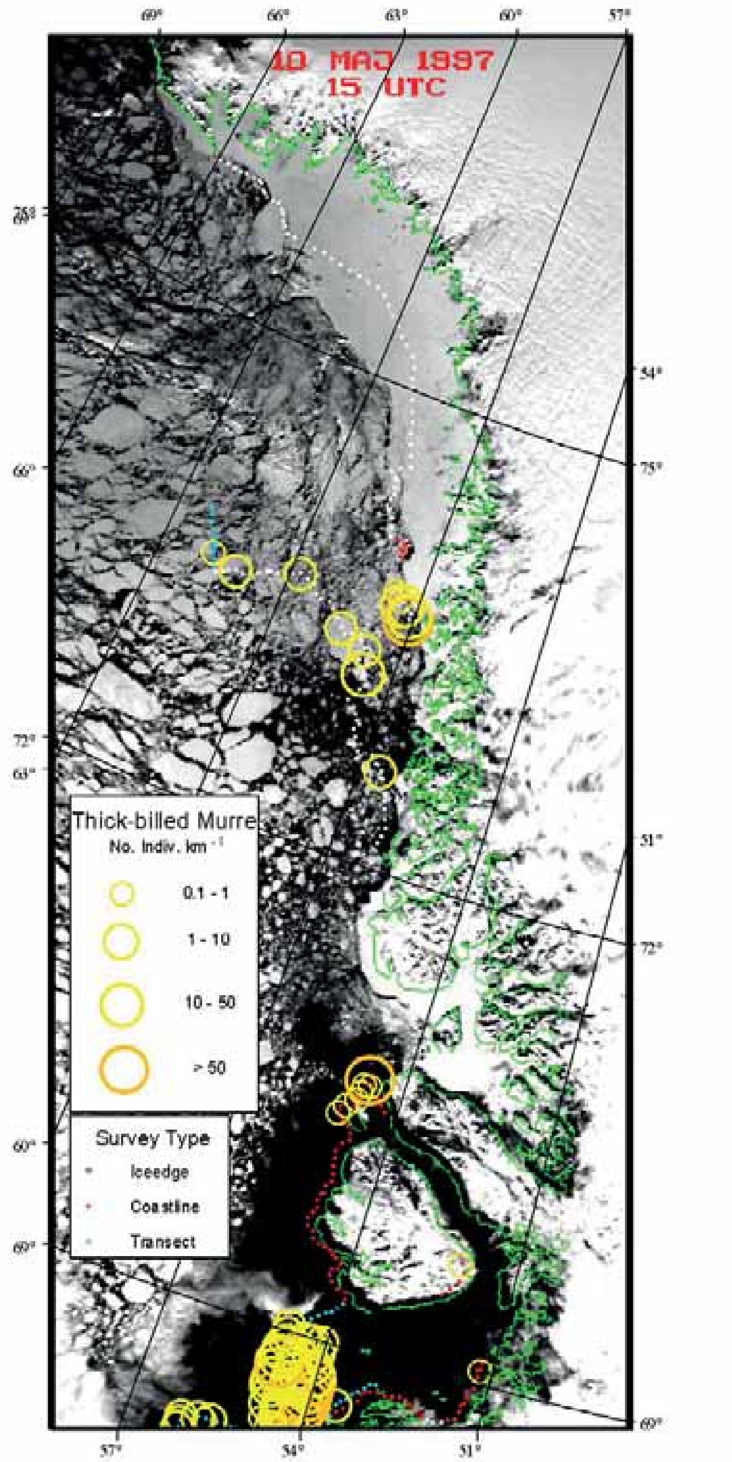


Figure 15. Distribution of thick-billed murres in May 1997, based on airborne surveys. Results are superimposed on a synoptic image of the ice distribution. A large concentration of birds is seen southwest of Disko Bay (DCE unpublished).

Another study initiated in 2005 focused on the post-breeding migration of the thick-billed murres from the breeding colony in Disko Bay. The three-week old chicks leave the colony and initiate a swimming migration together with one of the parent birds which then moult flight feathers and become unable to fly for a three-week period. The temporal and spatial distribution of this swimming migration was unknown until birds were satellite tracked (Mosbech et al. 2009). These birds moved through Vaigat, and dispersed in the waters west of Disko (Box 6).

The marginal ice zone project in April and May 2006 (Frederiksen et al. 2008) revealed large concentrations of thick-billed murres present in the assessment area and confirmed earlier studies (Figure 15 and 16), although the murres were much more widespread in the area and many were found even in dense drift ice near the Canadian border (Figure 16). In total about 400,000 thick-billed murres were estimated to be present in the assessment area during the survey, and significant concentration areas were located (Figure 16).

In autumn 2009, an extensive study of biological oceanography including seabirds was carried out from both ship and aircraft in the assessment area between the Greenland and the Canadian coasts (See Box 1). This revealed that high numbers of little auks were found widespread outside the shelf areas in the deep water parts, while the thick-billed murres were found more patchily on the Greenland side in an area were also high densities of small polar cod were found in depths accessible to the murres. Stomach analysis of both little auks and thick-billed murres sampled in deep off shelf waters indicated that especially the hyperid amphipod *Themisto* was an important prey.

Although not seabirds, geese should also be mentioned in this context, because they often utilise saltmarshes within the assessment area. These saltmarshes are very low and occasionally become inundated at high water levels. Particularly the Greenland white-fronted goose (*Anser albifrons flavirostris*) is vulnerable, because the population is seriously decreasing (Fox et al. 2006). 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 2001a).

Box 5. King Eider satellite tracking

A. Mosbech , F. Merkel and C. Sonne

The Disko West assessment area is very important for the king eider (*Somateria spectabilis*) population breeding in eastern Arctic Canada. Satellite tracking and surveys of concentration areas have been conducted in recent years to identify key areas, delineate populations and estimate the population size.

Thirty-six king eiders were tracked from their breeding and moulting sites by means of satellite transmitters on their migration to the wintering grounds on the fishing banks off West Greenland (Mosbech et al. 2004c, Mosbech et al. 2006a). The results showed that regardless of the locality where the birds were caught and implanted with a transmitter (eastern Canada or West Greenland), almost half of the tracked birds wintered at Store Hellefiskebanke and the adjacent coast. A single bird was followed for two years where it performed a clockwise migration around Baffin Island on the migration between moulting, wintering and breeding areas (Fig. 1).

On Store Hellefiskebanke most birds were found in areas with water depths less than 50 m and up to 70 km from the coast (Fig. 2). Previous surveys had shown that up to 300,000 king eiders could be wintering in this area in March (Mosbech & Johnson 1999). An aerial survey carried out in late April 2006, as a part of the marginal ice zone project (Frederiksen et al. 2008), resulted in an estimate of about 400,000 king eiders (75% confidence intervals:

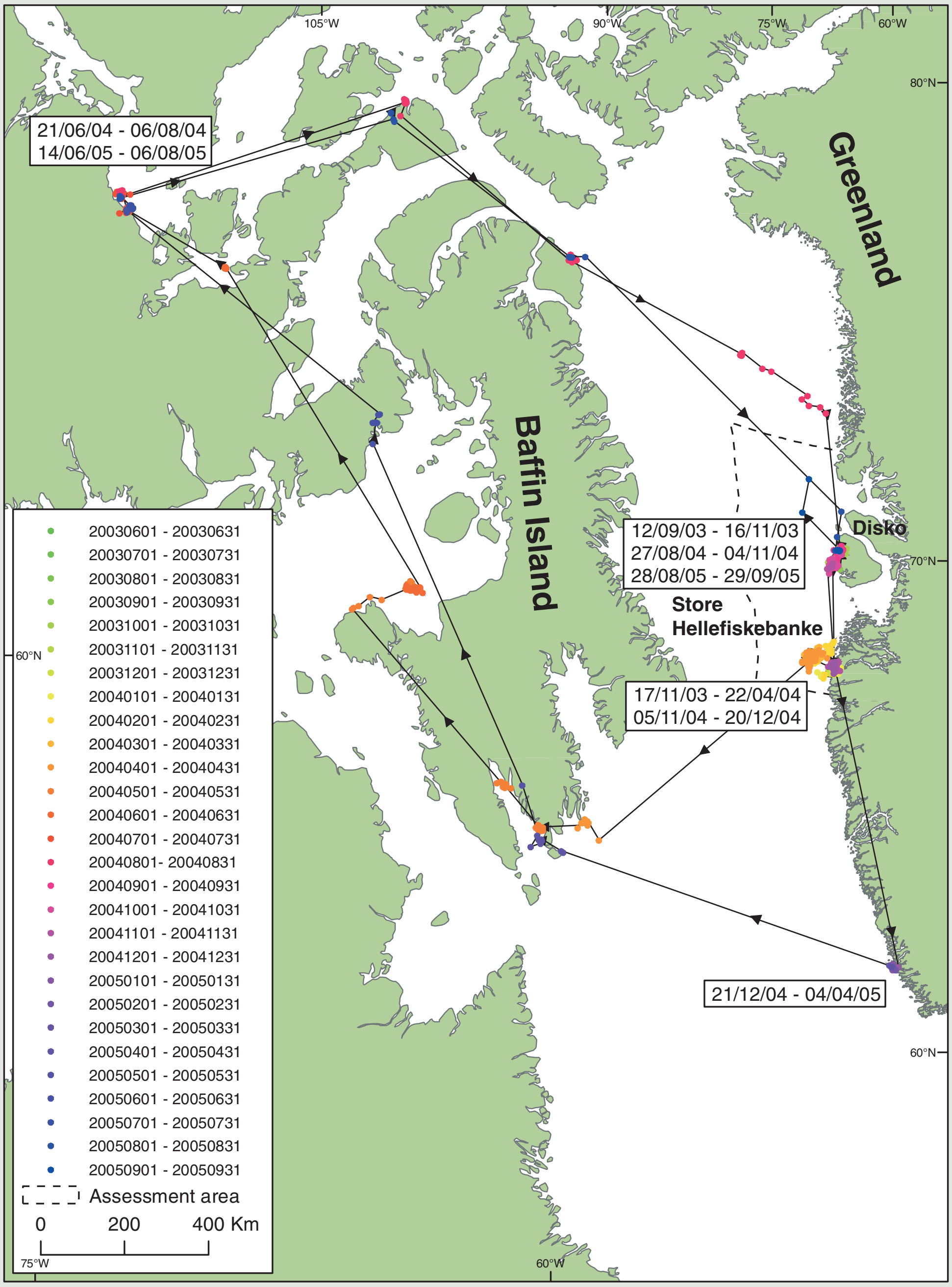


Figure 1. A single king eider tracked with satellite transmitter (No. e41195) from the moulting area at Disko Island in September 2003 and the following two years through two full migration cycles to the breeding grounds in Arctic Canada. Two sites in the assessment areas were of particular importance to this bird: the waters west of Disko Island and the shallow part of Store Hellefiskebanke. Based on DCE/GINR data, Mosbech et al. (2006c).

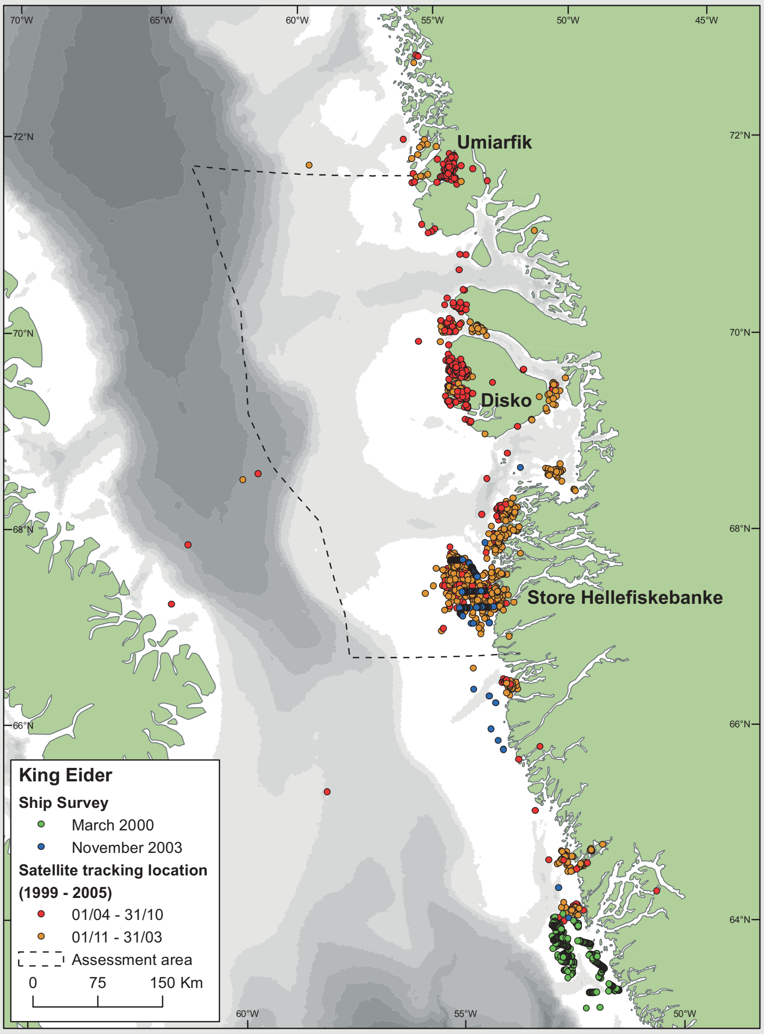


Figure 2. King eider satellite tracking locations from year round tracking of birds implanted at moulting localities in Umiarfik and the fjords at the west coast of Disko and at a breeding locality in Arctic Canada (outside the map). The scattered dots in the central Baffin Bay and on Baffin Island are from bird migrating to and from breeding localities in Arctic Canada west of the map border. Observations from two ship based surveys (March 2000 and November 2003) are also indicated on the map. The importance of the waters west of Disko Island and on Store Hellefiskebanke (at c. 68° N) is apparent. Based on DCE/GINR data, Mosbech et al. (2006a).

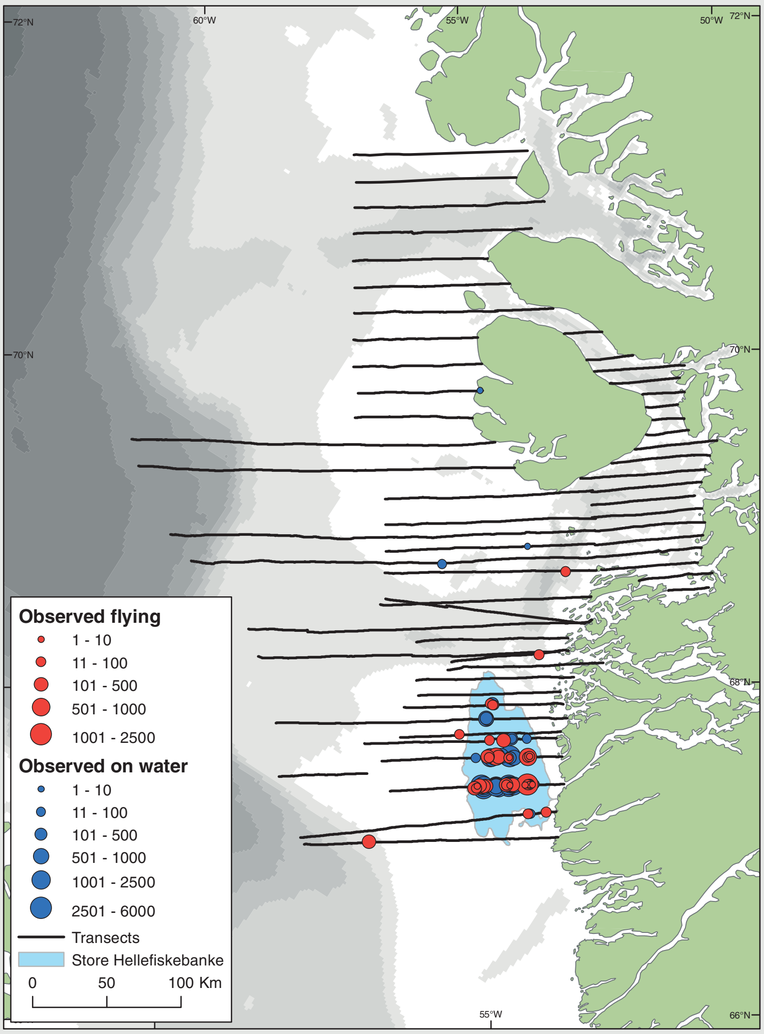


Figure 3. Distribution of king eiders (n = 57100) observed on aerial transects in April and May 2006. Their estimated abundance is based on the blue area corresponding to the 50 m isobath of Store Hellefiskebanke, see text for further information.

227,000 – 709,000) staging in the shallow parts of Store Hellefiskebanke (Fig. 3). Based on a ship survey in November 2003 an abundance of 500,000 king eiders (75% confidence intervals: 529,000 – 1,083,000) was estimated for the Store Hellefiskebanke in November (Mosbech et al. 2007). This probably encompass the entire population of king eiders wintering in West Greenland, and this fact makes this shallow part of Store Hellefiskebanke extremely sensitive to oil spills.

A tracked king eider equipped with a depth transducer recorded 43 m as maximum dive depth and it showed a diurnal diving pattern with preference for diving during daylight, even in midwinter, with only a few hours of twilight (Fig. 4) (Mosbech et al. 2006a), indicating the importance of these few hours for foraging. It also indicates that there are plenty of benthic mussels at the site, since the birds are able to find sufficient food during these few hours.

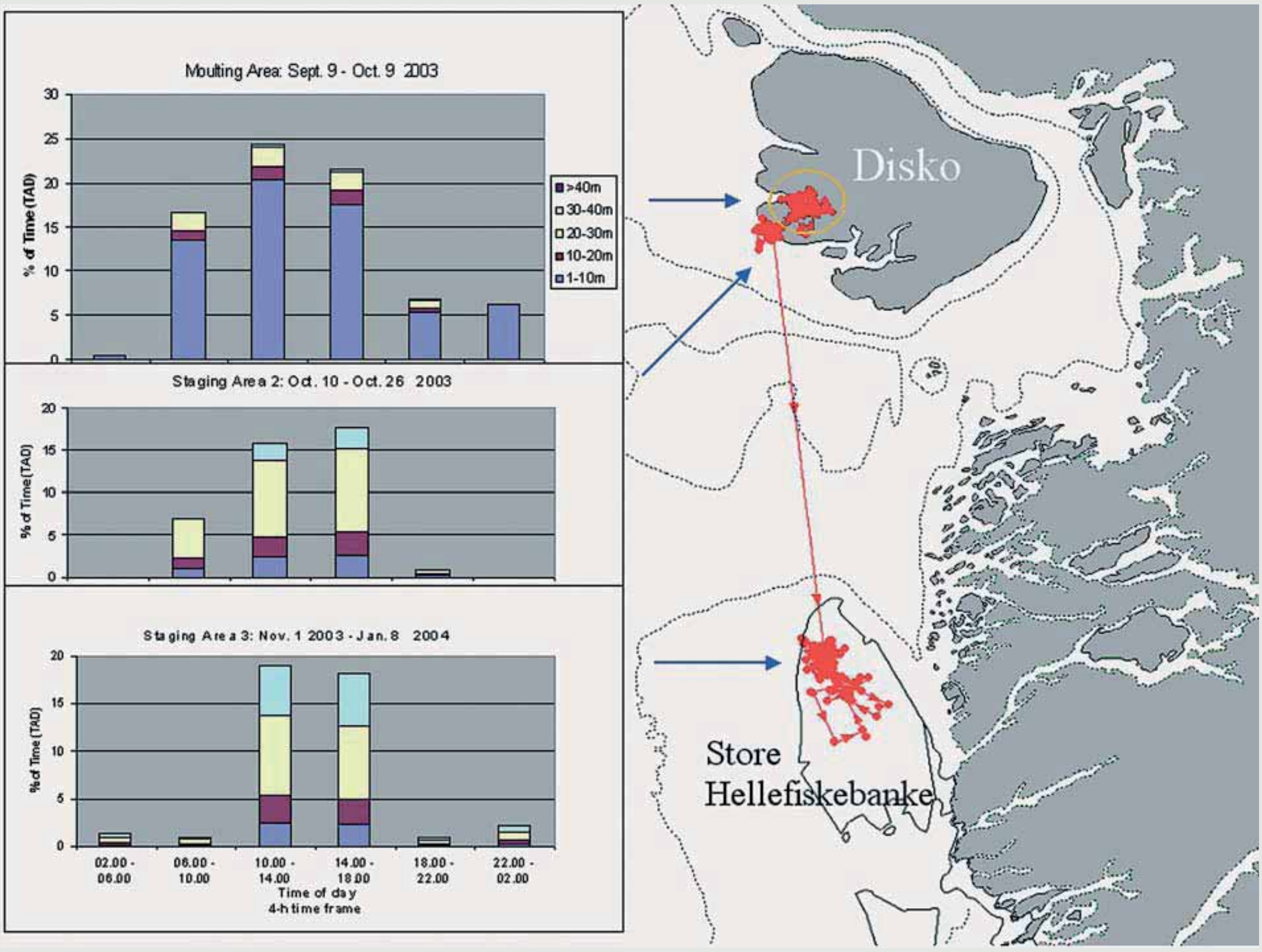


Figure 4. Satellite tracked locations and track-line for a female king eider using three distinct staging areas from 7 September to 8 January and diurnal diving behaviour in these three areas. The columns show the time spent in different depth intervals (Time At Depth, TAD) as percentage of the time in each four-hour time frame and averaged for the staging period. The diving data covered 75 %, 79 % and 54 % of the time spent in the three staging areas, respectively (reproduced from Mosbech et al. 2006b).

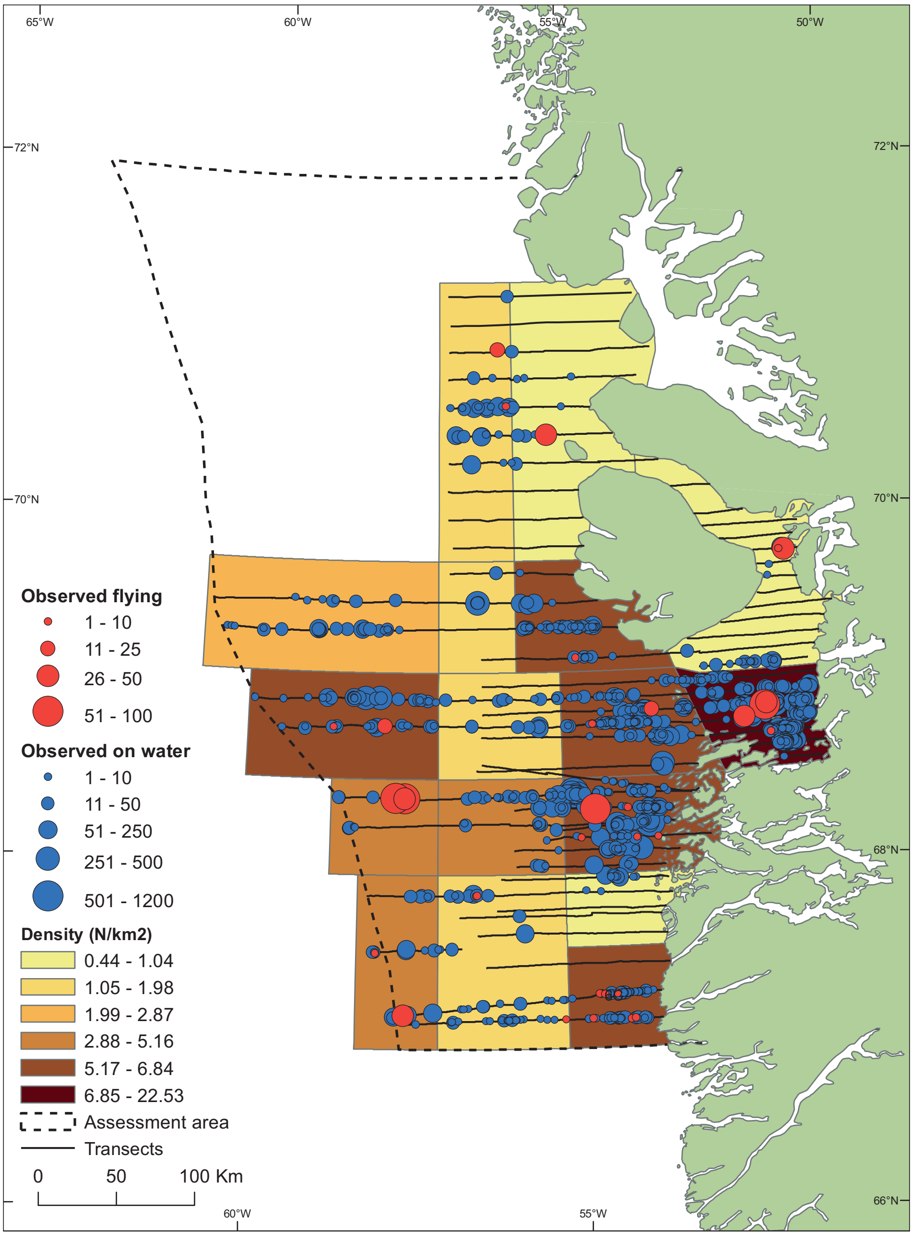


Figure 16. Densities of thick-billed murres in the spring 2006 survey area. Based on the numbers observed from aircraft during the marginal ice zone project in April and May 2006 it was estimated that about 430,000 (CV 11%) thick-billed murres reside in the area (Frederiksen et al. 2008). Especially high concentrations were found in southern Disko Bay (ice free) and relatively high concentrations were found northwest, west and southwest of the entrance to the bay in areas with both open water and quite dense ice cover. Surprisingly high concentrations were found far offshore near the Canadian border in areas with dense ice cover. This is presumably birds crossing directly over the central Davis Strait and Baffin Bay on their way to the large breeding colonies in Arctic Canada (Frederiksen et al. 2008).

4.8 Marine mammals

The marine mammals is another important element of the ecosystem in the Disko West assessment area. Besides polar bear and walrus, there are at least 14 species of whales and five species of seals, (Table 7).

Some of the marine mammals listed in Table 7 have been studied more intensively within the assessment area during the past years thus allowing a more detailed description.

4.8.1 Polar bear (*Ursus maritimus*)

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

The polar bears occurring in the Disko West assessment area belong to two different populations which differ genetically (Paetkau et al. 1999). Satellite telemetry data collected during the 1990s indicated little spatial overlap between them, and they are referred to as the Baffin Bay and the Davis Strait subpopulations (Taylor et al. 2001) (Figure 17). These studies also documented that the greater majority of polar bears that occur in the Disko West assessment area belong to the Baffin Bay subpopulation (Taylor et al. 2001).

Box 6. Thick-billed murre studies in the Ritenbenk/Innaq colony in Disko Bay

A. Mosbech and F. Merkel

The thick-billed murre colony at Ritenbenk (Innaq) is the last remaining thick-billed murre colony in Disko Bay. It has been declining for more than 50 years from about 46,000 to only 1300 birds in 2012. As part of the background study program, studies of thick-billed murre were carried out in the colony in 2005 and 2006 (Mosbech et al. 2009) and again in 2011. The overall aim has been to gain a better understanding of the population development, the causes for the decline as well as the potential for increase, and to identify important areas for the birds especially during the swimming migration.

The thick-billed murre is the most important hunted bird species in Greenland and it is also very vulnerable to marine oil spills. The hunting season and the hunting bag have been effectively reduced with new legislation in 2001 (Merkel & Christensen 2008). However, oil activity in the Disko West Area is a new challenge to the thick-billed murre population and makes it important to identify migration routes and important habitats.

The project has included studies of colony attendance, population estimates, population modelling, sustainable harvest modelling, chick feeding and foraging activities, and migration based on ringing recoveries and satellite telemetry.

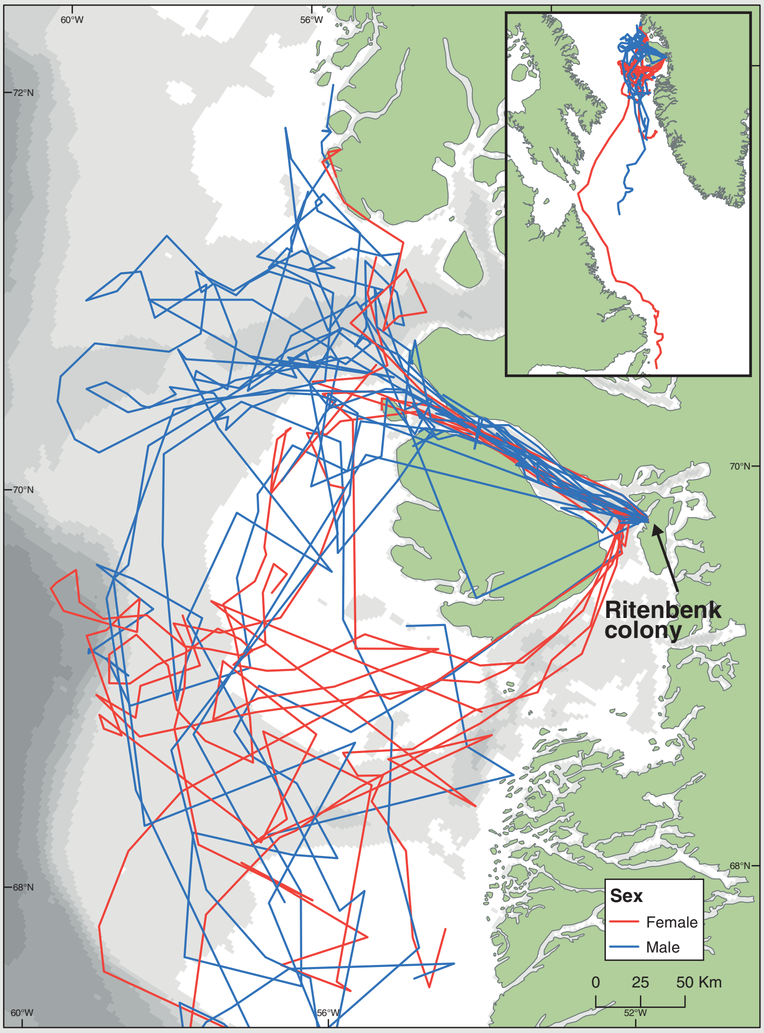


Figure 1. Tracking routes of 27 thick-billed murres from the Ritenbenk colony in 2005 and 2006. Blue lines = males, red lines = females.

Population trend

The entire colony was counted both directly and from digital photos. In order to correct the total counts for diurnal as well as day-to-day variation in murre numbers, repeated counts of study plots were carried out. The most reliable count was 2,447 individuals, based on a total direct count on 19 July 2006 and corrected for diurnal and day-to-day variation. Taking colony attendance into account, this is estimated to correspond to 1,835 breeding pairs.

The most recent previous count of the Ritenbenk colony was in 1998, when a comparable survey method provided an estimate of 3,415 individuals. This corresponds to a decline of 28 % or 4 % per year.

Both the total counts and the repeated counts of study plots indicate an increase in the number of birds present from 2005 to 2006. However, this positive result should not be overemphasized, since considerable year-to-year variations in attendance may mean that the negative trend in colony size has not been reversed. And indeed the results from the counts in 2011 and 2012 indicate a further decline in the thick-billed murre population (direct count in 2011: 1480 birds, and direct count in 2012: 1315 birds; none of these corrected for diurnal variation).

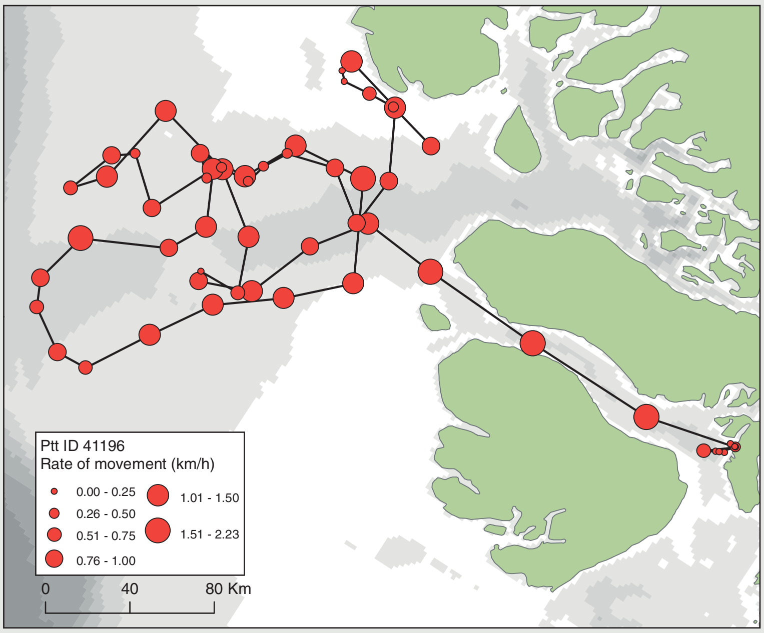


Figure 2. The route tracked for a male thick-billed murre using a subcutaneous satellite transmitter. The male took up parental care on the breeding ledge and later left the ledge with the chick and started swimming migration. Average rate of movement is calculated between the best quality locations in consecutive transmission periods (Best Pick location in each of 56 28 hour cycles).

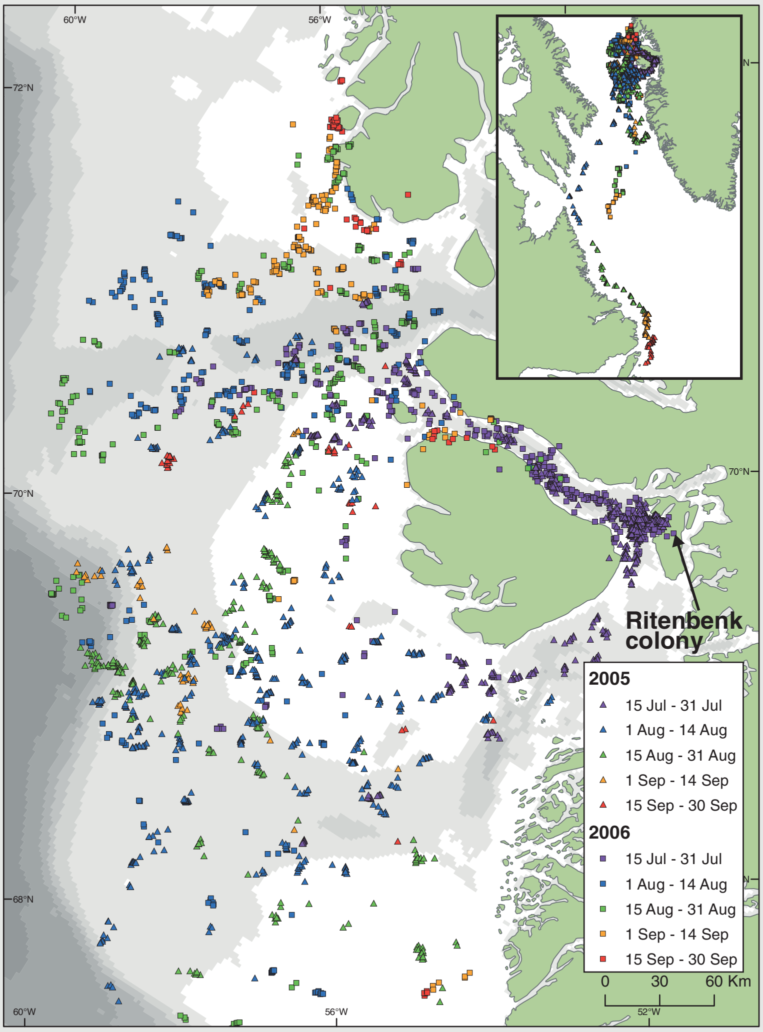


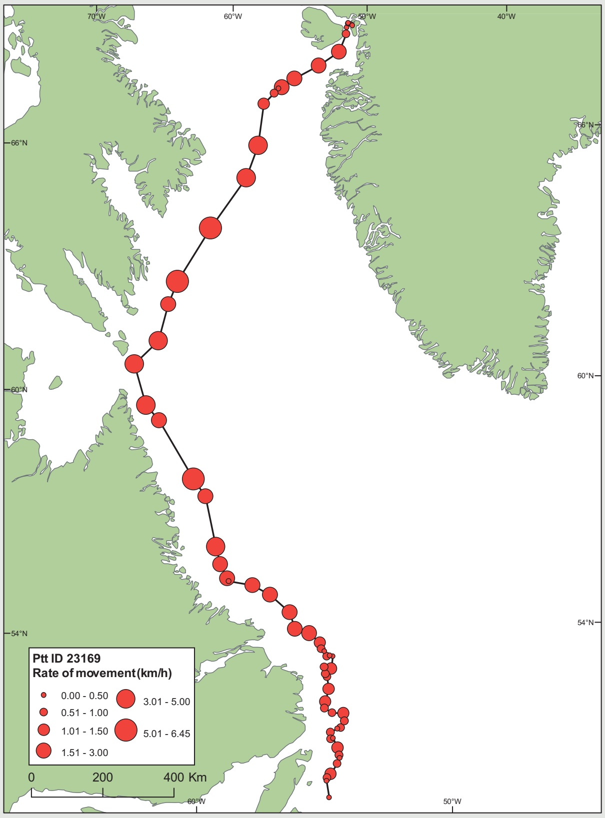
Figure 3. Temporal and spatial distribution of locations from 27 thick-billed murres tracked from the Ritenbenk colony.

Population model

In order to investigate the mechanisms behind the population decline a simple matrix model of the thick-billed murre population at Ritenbenk was constructed. The model estimates the maximum sustainable harvest based on a number of assumptions. Model results were compared to the reported numbers of birds shot available from the official harvest statistics (*Piniarneq*). Harvest statistics show that the *Annual Hunting Bag* in Ilulissat municipality in 1993-2001 was between 100 and 206 birds (except 40 in 1998). These birds were presumably mainly adult breeders, since few immatures occur near the colonies at this time of year. A comparison with results of the harvest model indicates that shooting of adult breeders is the most likely cause for the decline in the size of the colony until 2001, when summer hunting was banned. The model indicates that, if this ban is respected and winter hunting pressure remains constant, there is a chance that the population will stabilise.

Moult and autumn migration

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 male adult, which during the first weeks of the swimming migration moults its flying feathers and becomes flightless. The female typically continues 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 Innaq/Ritenbenk twenty-seven murres were equipped with satellite transmitters in July (26 g pressure proof implantable Microwave satellite transmitter (PTT Platform Terminal Transmitter)). Murres with chicks were selected and were tracked for up to 112 days. The obtained tracks showed that 15 out of 16 males left Disko Bay through Vaigat (swimming), whereas females used routes N and S of Disko Island equally (Fig. 1 and 2).

Later in August and September most tracked murres occurred dispersed in southeast Baffin Bay (Fig. 3). While most birds thus moult their flight feathers in Baffin Bay, two of the birds migrated SW towards Labrador and Newfoundland (Fig. 4). It is concluded that a large part of the population migrate through Vaigat and past Hareø around 1 August, during this time they will be very sensitive to an oil spill in this area. Similarly, the population will be very sensitive to oil spills in Disko Bay when they arrive in May.

Figure 4. The route of a female thick-billed murre (#4137507) tracked from Ritenbenk and arriving in northern Newfoundland in the first half of August 2005. The average rate of movement was calculated between the best quality locations in consecutive transmission periods ('best pick' locations). At the coast of Labrador the average rate of movement fell below 3 km/h indicating that wing moult started here.

Figure 5. Data logger attached to a metal tarsus band on a thick-billed murre.

Figure 6. Thick-billed murre arriving at nesting ledge with capelin for its chick at Ritenbenk, July 2005.

Foraging behaviour and feeding conditions

Foraging behaviour (dive activity and chick feeding) was studied in 2006 to investigate whether food limitation during the breeding season might affect chick survival and thus population growth. Dive activity was recorded using miniature leg-mounted data loggers (Fig. 5), whereas chick feeding frequencies were observed directly. Capelin was an important food item in 2006 (Fig. 6), feeding trips were relatively short, and the proportion of time birds spent diving was relatively low (<10 %) (Fig. 7). The overall impression was that food availability was sufficient in 2006 and preliminary results indicate that this was also the case in 2011. Most likely the cause for the continued decline in the colony should be found outside the breeding season or from illegal hunt in the summer period.

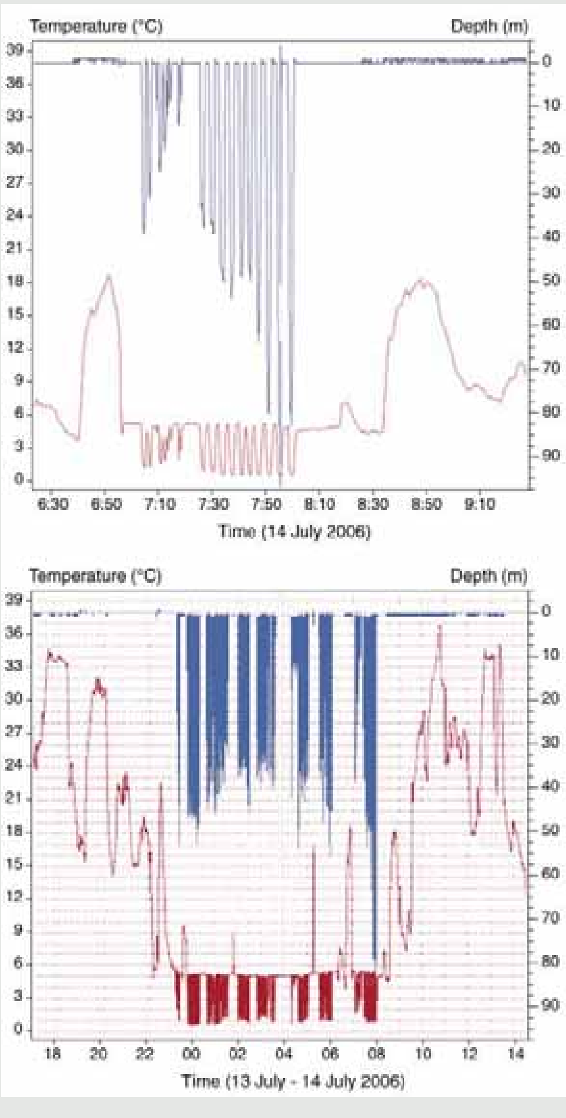


Figure 7. A) Diving behaviour recorded with Time-Depth Recorder (TDR) for a thick-billed murre on a foraging trip the night between 13 and 14 July 2006. Between 11 PM and 8 AM the murre made 9 feeding bouts. Most dives (blue) went to about 40 m, but in the last feeding bout dives exceeded 80 m depth. The temperature (red)at the sea surface was ca. 5 °C, decreasing to ca. 1 °C at 40 m and remaining at that level down to 80 m. **B**) Enlargement of the last feeding bout in Figure A.

On the basis of the results from a large-scale mark-recapture population study from 1994 to 1997, Taylor et al. (2005) estimated that the Baffin Bay subpopulation numbered 2074 (95% CI 1544-2604 bears) polar bears in 1997.

A demographic study of the Davis Strait population completed in 2009 estimated the size of the population to be 2142 (95% CI 1811-2534; Obbard et al. 2010). Recovery in central West Greenland of a few polar bears that were tagged in the Davis Strait area indicates that polar bears from the Davis Strait population occasionally occur in the Disko West assessment area.

Table 7. Overview of marine mammals occurring in the Disko West assessment area. Importance of study area to population (Conservation value) indicates the significance of the population occurring within the assessment area in a national and international context as defined by Anker-Nilssen (1987).

Species	Period of occurrence	Main habitat	Distribution and abundance in assessment area	Protection/ exploitation	Greenland Red List status	Importance of assessment area to population	VEC
Polar bear	Winter	Drift ice and ice edges	Relatively common and mainly when ice is present	Hunting regulated	Vulnerable (VU)	High	+
Walrus	Winter	Polynyas, MIZ, shallow water	West of Disko Island and Store Hellefiskebanke	Hunting regulated	Endangered (EN)	High	+
Hooded seal	Jun.-Oct.	Mainly deep waters	Common	Hunting unregulated	Least Concern (LC)	Medium	
Bearded seal	Whole year	Waters with ice	Widespread and abundant	Hunting unregulated	Data Deficient (DD)	Medium	+
Harp seal	Jun.-Feb.	Whole area	Numerous	Hunting unregulated	Least Concern (LC)	Medium	
Ringed seal	Whole year	Waters with ice	Common and widespread	Hunting unregulated	Least Concern (LC)	High	+
Harbour seal	Summer	Coastal waters	Very rare today	Hunting regulated	Critically endangered (CR)	Low	
Bowhead whale	Winter (Feb.-Jun.)	Pack ice/marginal ice zone	Locally abundant migrant and winter visitor	Hunting regulated	Near Threatened (NT)	Medium	+
Minke whale	Summer (Apr.-Nov.)	Coastal waters and banks	Rather common mainly in southern part	Hunting regulated	Least Concern (LC)	Low	
Sei whale	Summer (Jun.-Oct.)	Offshore, edge of banks	Occasional in southern part	Protected (1986)	Data Deficient (DD)	Low	
Blue whale	Summer	Edge of banks	Few, and in southern part	Protected (1966)	Data Deficient (DD)	Low	
Fin whale	Summer (Jun.-Dec.)	Edge of banks, coastal waters	Abundant mainly in southern part	Hunting regulated	Least Concern (LC)	Low	
Humpback whale	Summer (Jun.-Nov.)	Edge of banks, coastal waters	Abundant mainly in southern part	Hunting regulated	Least Concern (LC)	Low	
Pilot whale	Summer (Jun.-Oct.)	Deep waters	Occasional in southern part	Hunting unregulated	Least Concern (LC)	Low	
White-beaked dolphin	Summer	Shelf waters	Occasional in southern part	Hunting unregulated	Not Applicable (NA)	Low	
Killer whale	all year, sporadical	Ubiquitous	Rare but regular	Hunting unregulated	Not Applicable (NA)	Low	
White whale	Winter (Nov.-May)	Banks	Abundant migrant	Hunting regulated	Critical Endangered (CR)	High	+
Narwhal	Winter	Edge of banks, deep waters.	Abundant summer, winter and migrant visitor	Hunting regulated	Critical Endangered (CR)	High	+
Sperm whale	Summer	Deep waters	Unknown	Protected (1985)	Not Applicable	Low	
Bottlenose whale	Summer	Deep waters	Unknown	Protected (1985)	Not Applicable	Low	
Harbour porpoise	Summer (Apr.-Nov.)	Coastal and deep waters	Only in southern part	Hunting unregulated	Least Concern (LC)	Low	

Based on the movement of polar bears with satellite transmitters, the border between the Baffin Bay and Davis Strait management units was placed at 66° N (i.e. between the entrance to Kangerlussuaq/Søndre Strømfjord in West Greenland and Cumberland Peninsula on Baffin Island) (Taylor et al. 2001).

Between 1974 and 2010 a total of 1332 polar bears were marked in the Baffin Bay including the 16 captured in West Greenland in April 2009 (Box 8). Information on cross-over of marked bears between Baffin Island (Canada) and West Greenland confirm the conclusion from satellite telemetry (Taylor et al. 2001) that polar bears have a wide range within the Baffin Bay and that bears from the Canadian sector of Baffin Bay occur in West Greenland and vice versa (Box 8).

One adult male (D7282, previously marked as X14049) was recaptured on 15 April 2009 in the Disko West assessment area from previous tagging at 73° 21' N-80° 50' W near Bylot Island, where it was marked as a 6 year old on 24 September 1994 (Box 8). This confirms that polar bears that range the western parts of Baffin Bay occur in West Greenland.

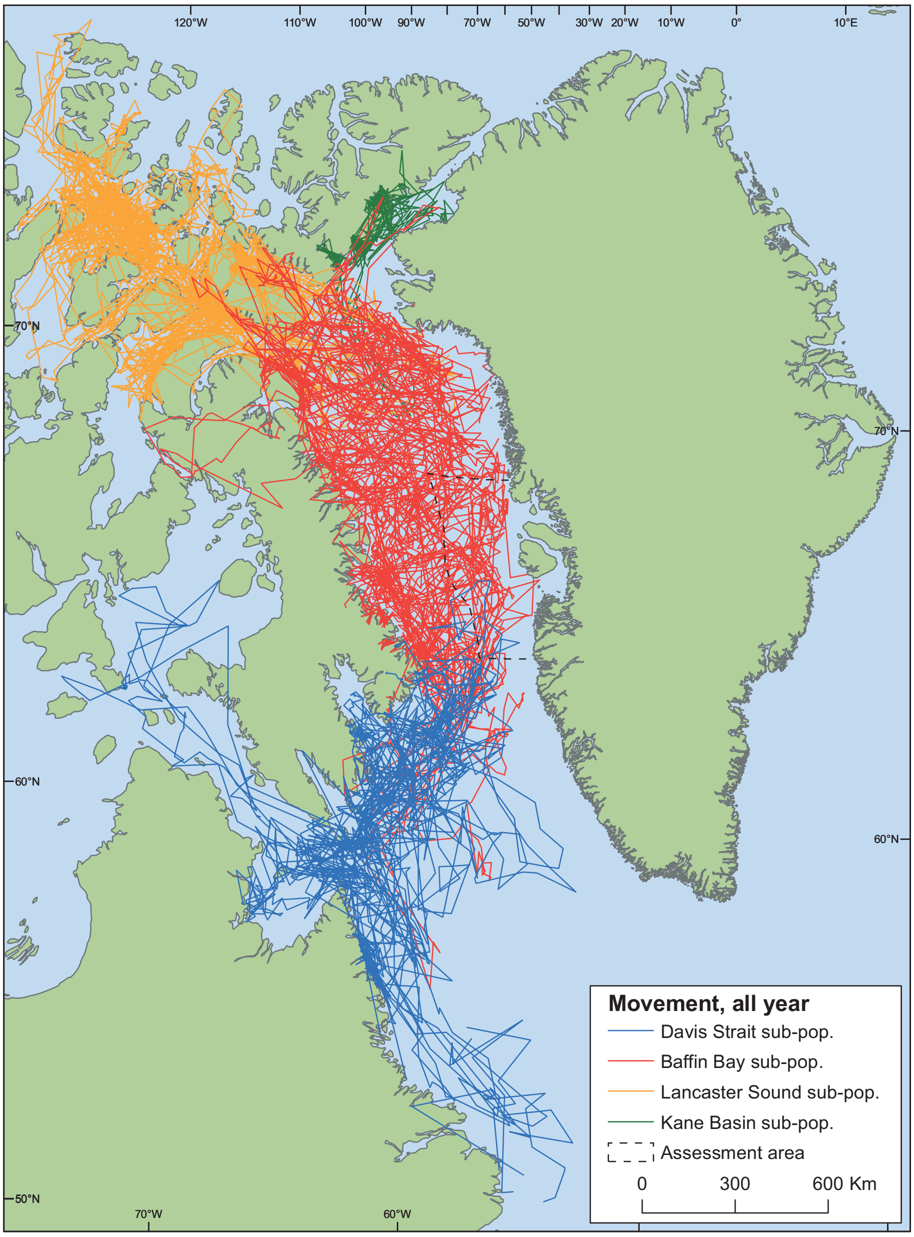


Figure 17. Track lines showing the overall movement during 1991-2001 of polar bears instrumented with satellite transmitters in the Davis Strait-Baffin Bay region and adjacent areas. A certain degree of overlap between the different subpopulations is apparent. However, Davis Strait and Baffin Bay have experienced an annual average decline in sea-ice extent of about 9% per decade between 1979 and 2006 (Perovich & Richter-Menge 2009) and therefore it cannot be excluded that the borders between the subpopulations have changed and are changing. The maps are based on unpublished data: Department of Environment Government of Nunavut (DEGN) and Greenland Institute of Natural Resources (GINR).

Box 7. Densities of seabirds-at-sea in the Disko West assessment area

A. Mosbech, K. Johansen, D. Boertmann and F. Merkel

Since the beginning of the 1990s, NERI/DCE has collected data on seabird distribution in the off-shore areas of Greenland. Both ships and aircrafts have been used as observation platforms, and the sampling methods allow calculation of densities (individuals/km²) of the different species. The surveys have been carried out by NERI/DCE, both on dedicated seabird surveys and on ships of opportunity, and also by the Marine Mammal and Seabird Observers (MMSO) on board the vessels carrying out seismic surveys in the Greenland waters. These MMSOs are instructed to sample seabird data following a standardised protocol prepared by DCE, allowing incorporating the data into the database maintained by DCE (Johansen et al. 2012). These seismic surveys have in many cases covered waters, from where no previous information on seabirds was available. The information from DCEs seabird-at-sea database is available for companies preparing environmental impact assessments (EIA) in the Greenland waters.

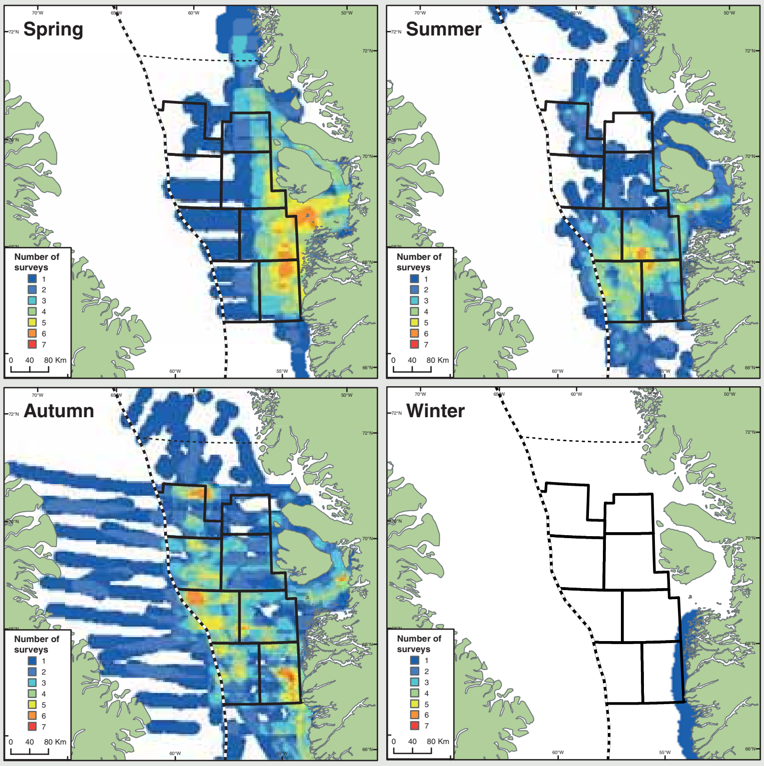


Figure 1. The seabird-at-sea survey effort in the Disko West assessment area. The distribution of survey effort is shown as the number of overlapping ship- and aerial surveys conducted during spring (Apr.-May), summer (Jun.-Aug.), autumn (Sep.-Dec.) and winter (Jan.-Mar.). White areas represent areas with no survey activity.

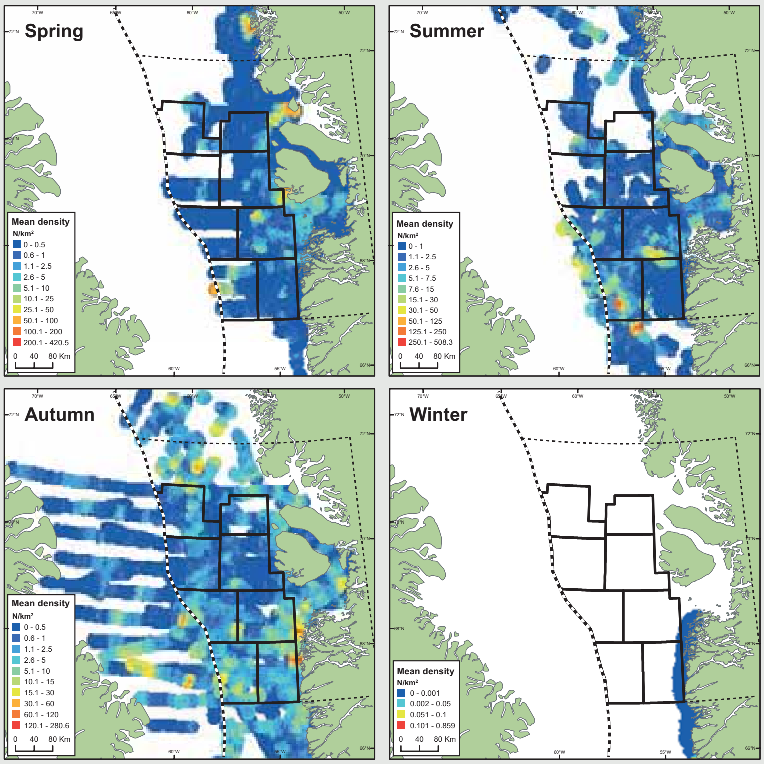


Figure 2. Distribution of northern fulmar in the assessment area during spring (Apr.-May), summer (Jun.-Aug.), autumn (Sep.-Dec.), and winter (Jan.-Mar.). Note that survey coverage and density scale varies between seasons. Fulmars are numerous and widespread in the offshore areas. Concentrations are linked to foraging areas such as upwelling areas and areas with commercial fisheries. In spring high concentrations also occur near the large colonies. Northern Fulmar usually avoids areas with high ice coverage and in the winter only a few are present in the area..

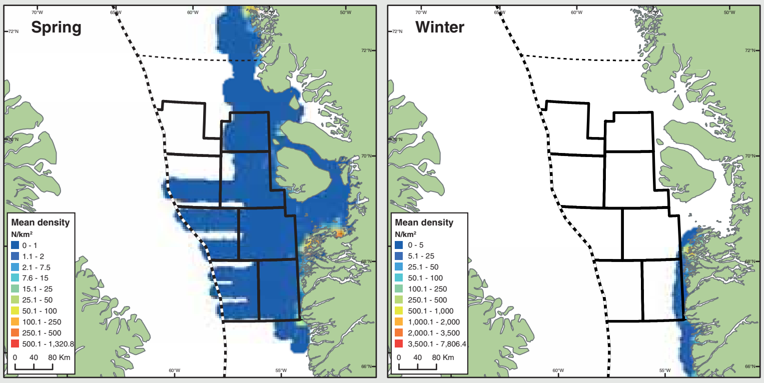


Figure 3. Distribution of common eider in the assessment area based on aerial surveys performed in spring and winter. Note that the density scale varies between seasons. Common eider winter in the coastal zone archipelago where there is open water and large numbers stage there during spring migration. Note that the scales differ between seasons.

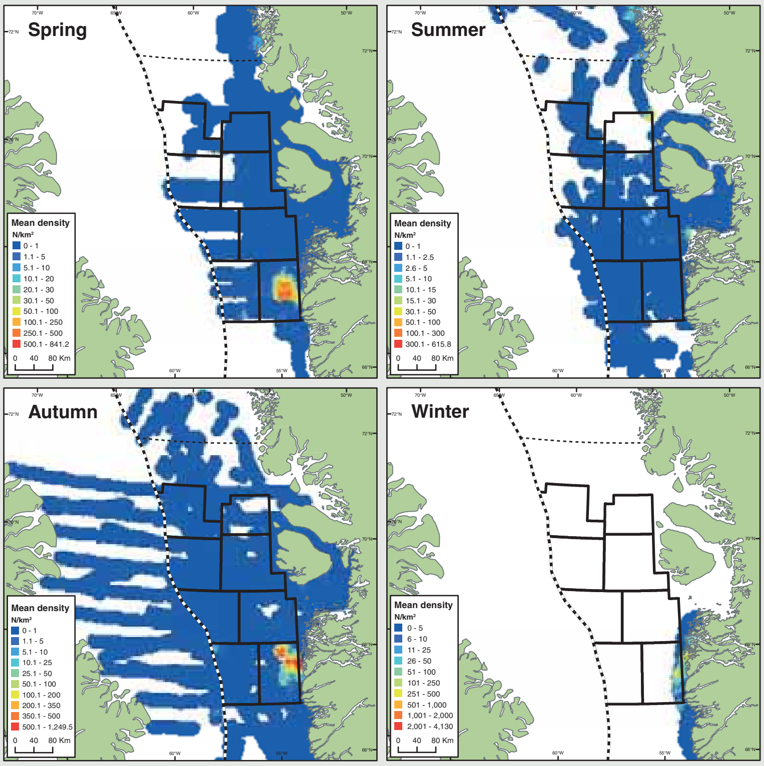


Figure 4. At-sea distribution of king eiders in the assessment area during spring (Apr-May), summer (Jun.-Aug.), autumn (Sep.-Dec.) and winter (Jan.-Mar.) based on ship survey and aerial survey data. Note that survey coverage and density scale varies between seasons. Note the high concentrations at Store Hellefiskebanke, see Box 5 for further details.

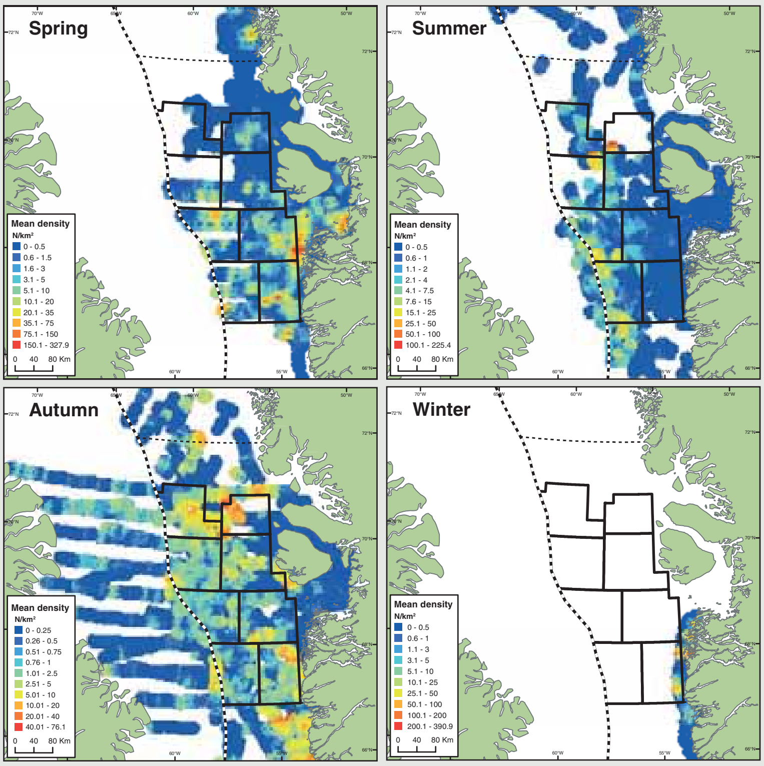


Figure 5. Densities of black-legged kittiwake in the assessment area during spring (Apr.-May), summer (Jun.-Aug.), autumn (Sep.-Dec.) and winter (Jan.-Mar.) based on combined ship survey and aerial survey data. Note that survey coverage and density scale varies between seasons. Kittiwakes are abundant in the assessment area except in winter. Concentrations occur near large breeding colonies, and also in off-shore areas where migrating birds are on their way towards north and stage in feeding areas. During summer many kittiwakes occurring offshore are non-breeding birds from populations breeding elsewhere in the North Atlantic (Lyngs 2003).

Seabird densities were calculated as follows. The original survey transects were split into 3 km segments, and for each segment a density was calculated for each species on the basis of the number of birds observed, the length of the segment, and an effective search width estimated separately for each survey and species by means of distance sampling methods (Buckland et al. 2001). For each survey the densities of each species were interpolated to 3×3 km raster grids by inverse distance weighting (power 2, radius 15 km), and the densities shown on the maps represent the mean value for all surveys in an overlay analysis of these grids for each of the four seasons. Densities were calculated only within a 15 km buffer around the survey transects. Note that the number of overlapping surveys varies markedly between seasons and areas (Fig. 1).

Figures 2 to 7 show the results for some of the numerous species.

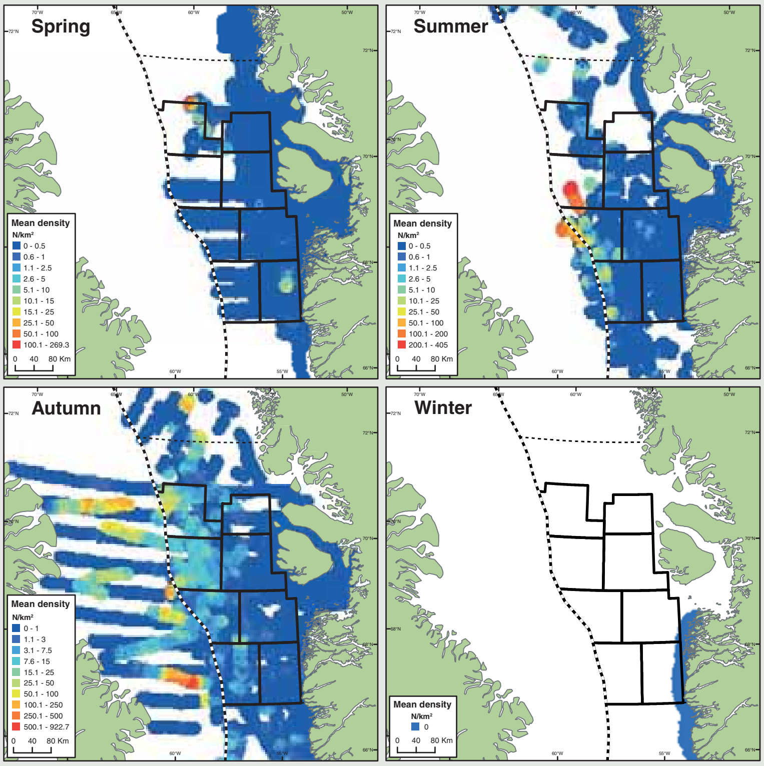


Figure 6. Densities of thick-billed murre in the assessment area during spring (Apr.-May), summer (Jun.-Aug.), autumn (Sep.-Dec.) and winter (Jan.-Mar.) based on combined ship survey and aerial survey data. Note that survey coverage and density scale varies between seasons. Thick-billed murre is abundant in the assessment area in all seasons. High concentrations occur in the ice free waters south of the assessment area during winter and at staging areas during spring migration. Note also relative high densities in summer and autumn. See Box 6 for details.

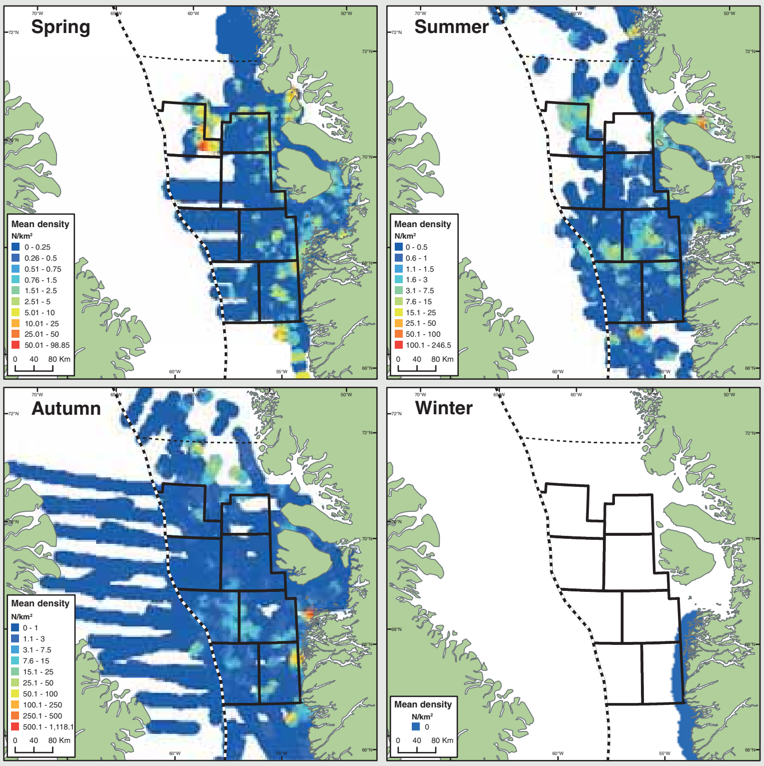


Figure 7. Density of little auk in the assessment area during spring (Apr.-May), summer (Jun.-Aug.), autumn (Sep.-Dec.) and winter (Jan.-Mar.) based on ship survey and aerial survey data. Note that survey coverage and density scale varies between seasons. Little auk is a numerous autumn visitor during migration through the western part of the assessment area.

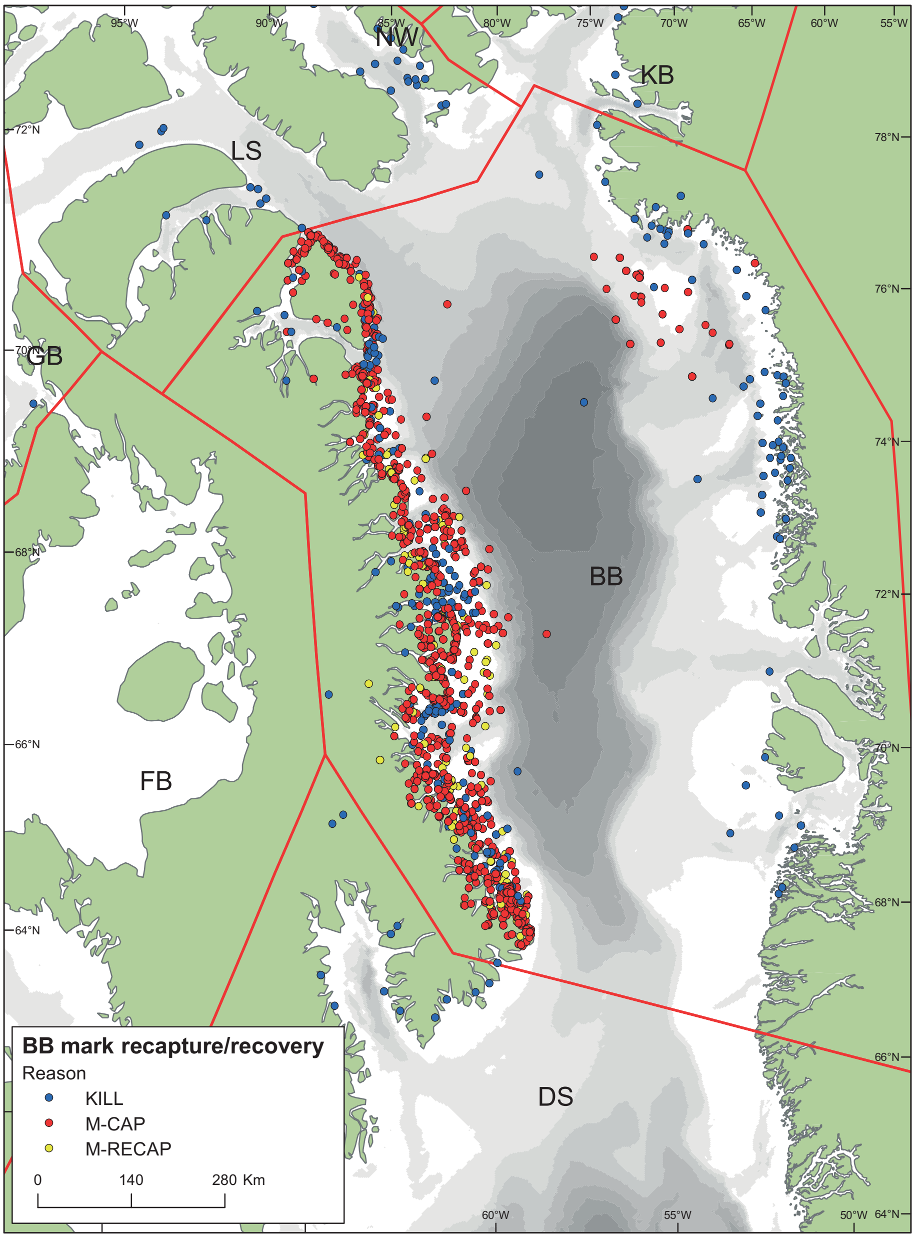


Figure 18. Map showing original tagging site (red, n = 1266 bears) and sites of re-capture during scientific studies (yellow, n = 230) and of hunter kills (blue, n = 310) of polar bears that were marked in the Baffin Bay region during 1974-2009 (DEGN and GINR unpublished data). Baffin Bay polar bears that were tagged along Baffin Island have been shot by hunters in the Disko West assessment area (between ca. 68° and ca. 71° 30' N) confirming the results of the telemetry study that polar bears range widely over the Baffin Bay region.

In addition, between 1974 and 2007 a total of 2068 polar bears were marked in the Canadian parts of the Davis Strait subpopulation (Figure 18). Of these only 1.5 % (n = 31) have been recovered in Baffin Bay north of 66° N during 1974 – 2010. These include an adult female with two 0-year-old cubs, and three young single bears that were killed in West Greenland (between 68° 10' and 69° 12' N) in 1981, 2008 and 2009 (DEGN and GINR, unpubl. data). If the family group is considered one 'bear unit' only 0.2 % of the bears tagged in Davis Strait have been recovered in the Disko West assessment area.

In 2009 a study was initiated to provide updated and supplementary information on distribution, movement and habitat use of polar bears in the Disko West assessment area. The results of this study are described in Box 8.

Conservation status

Given the recorded catch from the Baffin Bay population 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 ca. 1600 in 2004 (Anon 2007). The current size of the Baffin Bay population

Box 8. The April 2009 to April 2010 study of polar bear movements and habitat use in Northwest Greenland

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

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

During the 2009 field operation, 16 polar bears were tagged in April 2009 on the fast ice and the pack ice in the north of the Disko West assessment area between 70° 14' N and 71° 04' N (Fig. 1, Table 1). Fifteen of these bears were fitted with a satellite radio transmitter. Ten of these transmitters were small ear-tags (Born et al. 2010) which were applied to sub-adult polar bears of both sexes and adult males. Ear-tag transmitters had an expected life time of 3-6 months. Five adult female bears were fitted with satellite radio-collars with and expected life time of 2+ years.

Movements, home ranges and focal areas

One of the bears with satellite radio-collars (D7273, 6 years old) dropped her transmitter shortly after deployment and another adult female (D7276, 17 years old) was shot in NW Greenland 13 February 2010. Adult males and sub-adult bears of both sexes experienced shorter tracking durations due to ear tag attachments (mean duration of transmission: 75.7 d, SD = 45.0, range: 28-196 d, n = 10). Hence, the annual cycle of movement can be described for four adult females only and three females after February 2010.

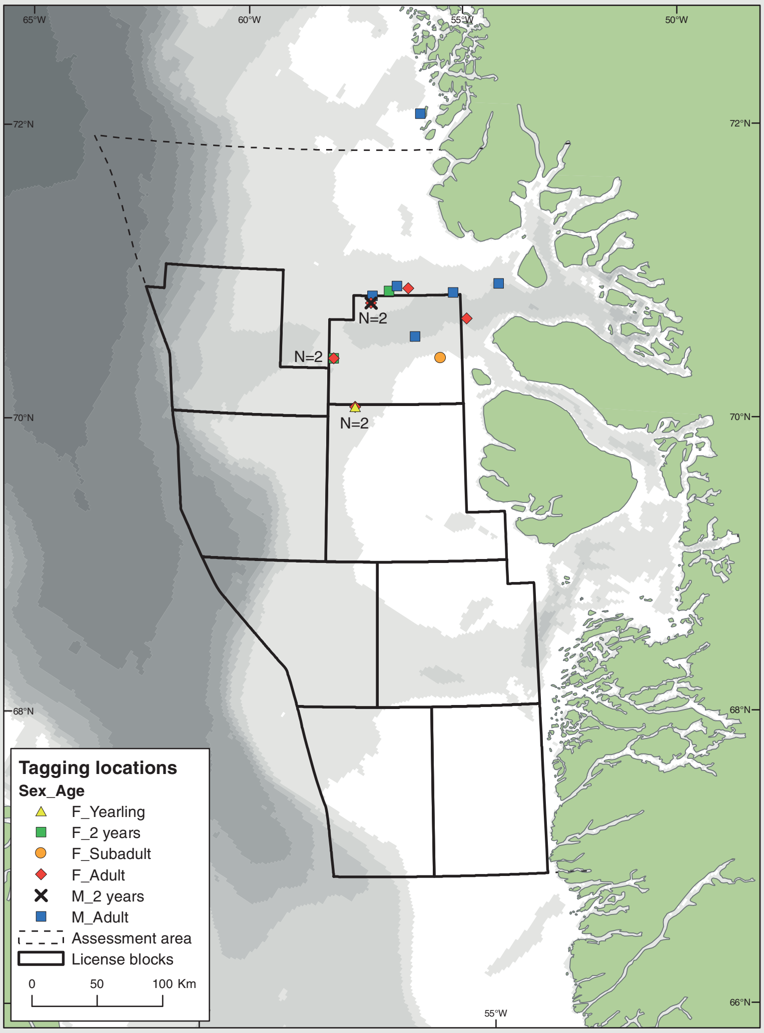


Figure 1. Disko West assessment area with borders of license blocks and locations where 16 polar bears were tagged during April 2009. Fifteen of these bears were fitted with satellite transmitters. F = femelaes, M = males.

Table 1. Polar bears tagged during the 2009 tagging operations in the Disko West region. Type of transmitter and duration of tag attachment is shown for those tags which stopped as of April 2010. Individual age was obtained from reading of tooth cementum growth layers.

ID	Sex	Category	Date tagged	Deg. N	Min	Deg. W	Min	Age	Transmitter ID	Type	Transmitter stop	Duration (days)
D7272	M	Adult	08.04.2009	71	1	55	24	4	68011	SPOT5	6/22/2009	76
D7273	F	Adult	08.04.2009	70	14	57	27	5	68006	TAW-4610H	05/03/2009	26
D7274	F	Yearling	08.04.2009	70	14	57	27	1	-	-		
D7275	M	Adult	09.04.2009	71	4	56	35	10	68012	SPOT5	06/04/2009	57
D7276	F	Adult	10.04.2009	70	34	57	54	17	68004	TAW-4610H	2/13/2010	SHOT
D7278	F	2 years	10.04.2009	70	34	57	54	2	68013	SPOT5	05/08/2009	29
D7277	F	Subadult	10.04.2009	70	34	55	42	4	68014	SPOT5	6/24/2009	76
D7280	M	Adult	11.04.2009	71	4	54	26	7	74777	SPOT5	07/06/2009	88
D7281	M	Adult	15.04.2009	70	43	56	13	7-8	74778	SPOT5	6/16/2009	63
D7282	M	Adult	15.04.2009	71	0	57	6	15	74779	SPOT5	06/12/2009	59
D7283	F	Adult	15.04.2009	70	57	57	8	13	68005	TAW-4610H	12/29/2009	transmitting
D7284	M	2 years	15.04.2009	70	57	57	8	2	74780	SPOT5	06/12/2009	59
D7285	F	Adult	16.04.2009	70	50	55	8	5	74771	TAW-4610H	1/14/2010	transmitting
D7286	M	Adult	18.04.2009	72	15	56	2	25	74781	SPOT5	10/30/2009	196
D7287	F	Adult	19.04.2009	71	3	56	21	7	74767	TAW-4610H	1/14/2010	transmitting
D7288	F	2 years	23.04.2009	71	2	56	45	2	74782	SPOT5	6/20/2009	59

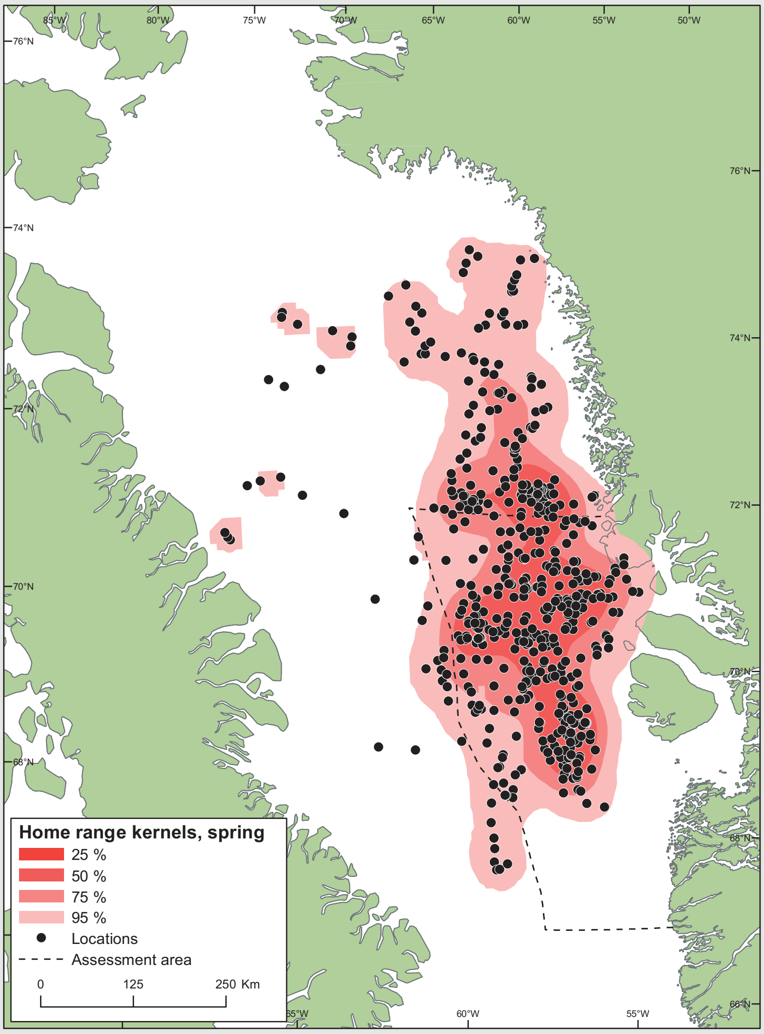


Figure 2. Home range of 16 tracked polar bears in spring (April-May) 2009. Home range calculated as kernel polygons, which show the fraction in % of the locations they include.

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

In *spring* 2009 (April-May), the polar bears (n = 15) used a large area over the annual sea-ice in Baffin Bay and were concentrated in the Baffin Bay assessment area and to the south hereof (Figure 2) from ca. 67° 30' N to offshore at ca. 75° N. The area of the 95 % kernel home range was approximately 198,400 km^2. As sea-ice receded during early summer the range of the polar bears shifted west towards Baffin Island (Fig. 2).

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

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

In *winter* 2010 (January-March), when the annual sea-ice had formed, three adult polar bears (D7283, D7285, D7287) departed from the land on eastern Baffin Island where they had spent the open water season and moved offshore. Two of these bears moved from Baffin Island during late January 2010, whereas D7283 which had been in a maternity den on Baffin Island moved onto the sea-ice sometime around 31 March 2010. Polar bears typically show fidelity to den and spring feeding areas (Wiig 1995). This tendency was confirmed by bear D7283 and bear D7285 which moved towards the West Greenland coast where they occurred in the shear zone between land fast ice and the offshore Baffin Bay pack ice between ca. 72° and ca. 76° N. D7283

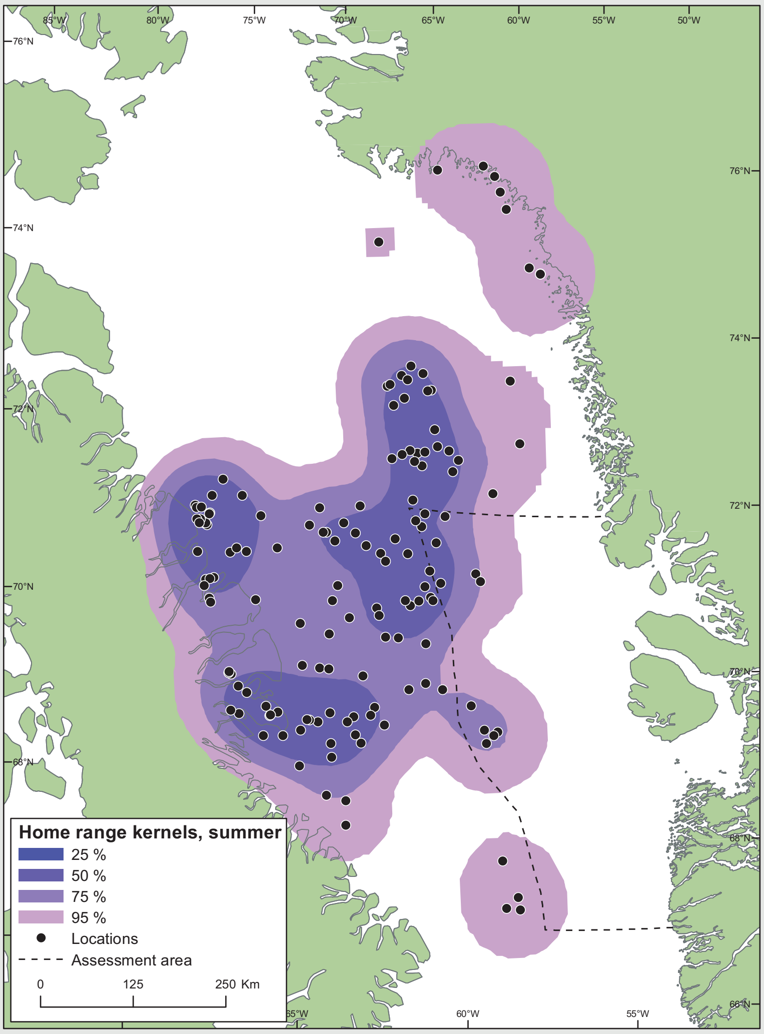


Figure 3. Home range of 13 tracked polar bears in summer (Jun.-Aug.) 2009. Home range calculated as kernel polygons, which show the fraction in % of the locations they include.

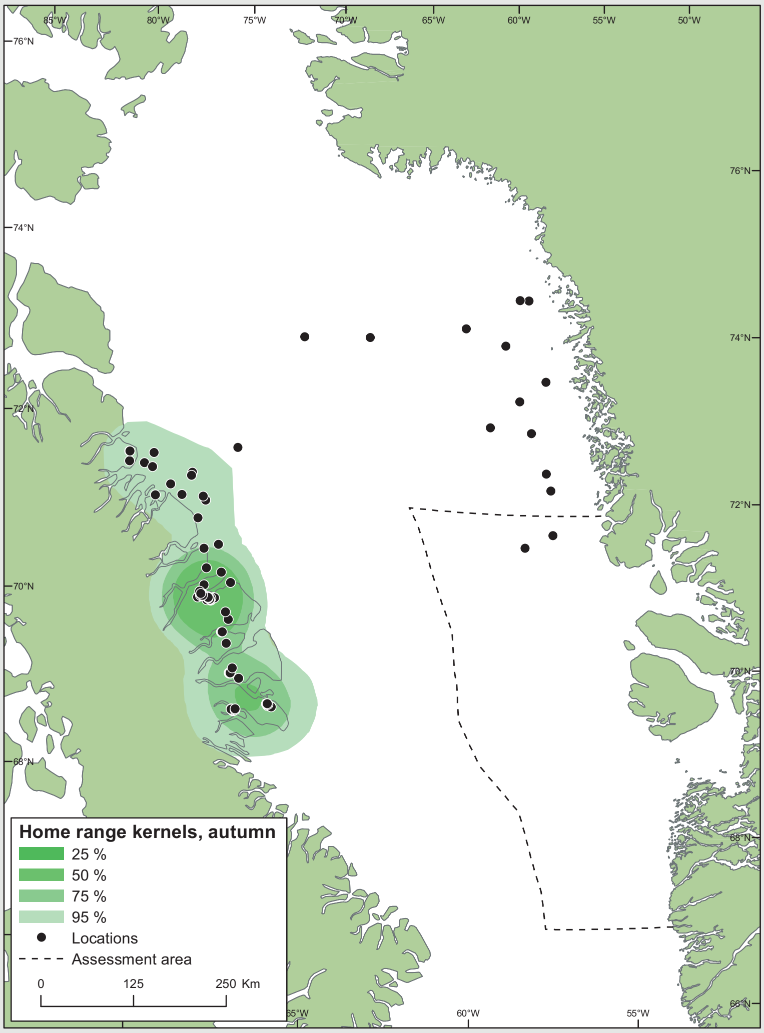
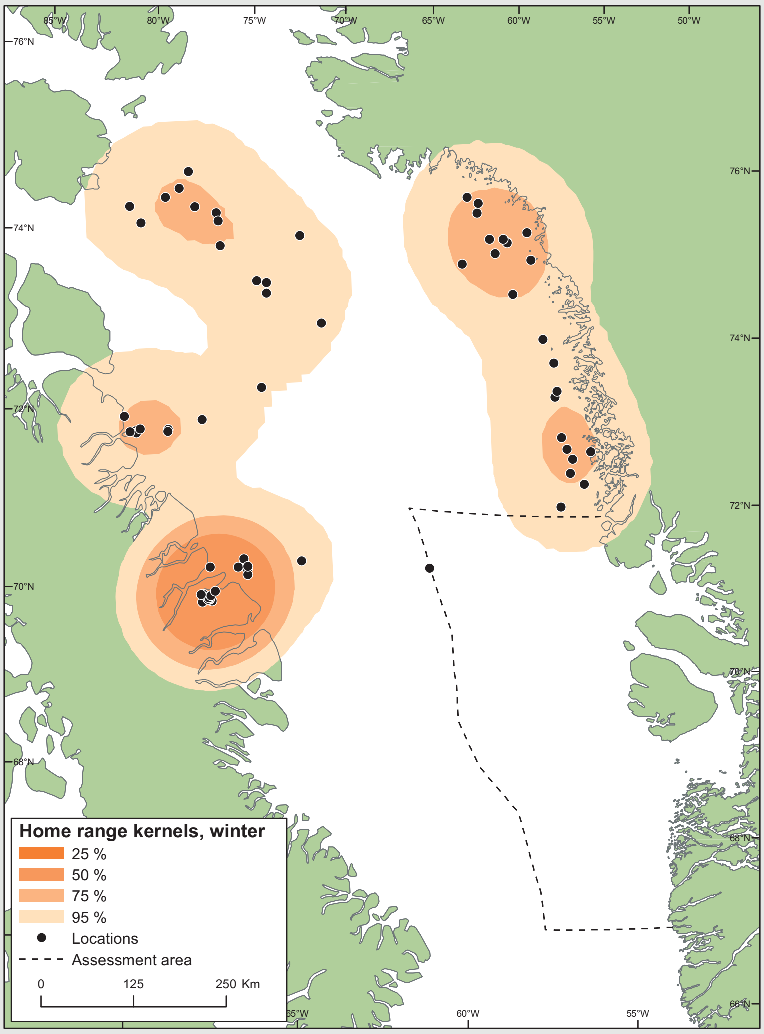


Figure 4. Home range of 5 tracked polar bears (1 male, 4 females) in autumn (Sept.-Dec.) 2009. Home range calculated as kernel polygons, which show the fraction in % of the locations they include.

was shot in Upernavik on 13 February 2010. Bear D7287 used the northern Baffin Bay in late winter (Fig. 5). However, the two other adult female polar bears (D7283; D7287) were on the ice in the west side of Baffin Bay as of April 2010 (Fig. 5).

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

Adult males and sub-adults of both sexes had shorter tracking durations due to ear tag attachments and all except bear D7286 remained on the Baffin Bay sea-ice during the period they were tracked. Similar to adult females, there was a consistent movements westward by adult males and sub-adults as the Baffin Bay sea-ice receded in late spring. Overall, the range of adult males was similar to that of adult females. Specific movement patterns were contrasted between adult male and adult female polar bears during the on-ice period in spring and early summer (Fig. 6).
The 2009-2010 study confirmed that polar bears in Baffin Bay move considerable distances during the year (Fig. 6). Satellite telemetry studies in the 1990s showed that the home range size of individual polar bears exploiting Baffin Bay averaged 192,000 km^2 being considerably larger than the home ranges of bears inhabiting areas with more consolidated ice (Ferguson et al. 1999). It was suggested that the explanation for the large home ranges of bears in Baffin Bay was that these bears explore a habitat with large seasonal flux of annual ice in which the distribution of various prey in particular ringed seals is variable and patchy.



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

Time spend on the West Greenland side

Dates on which bears moved west of 60° W longitude varied within the months of May and June (Table 2). The earliest departure date was May 6 and the latest was June 8. For the most part, dates of crossing 60° W were concentrated at the last 10 days of May. It should be noted that bears crossed

Figure 5. Home range of 4 tracked polar bears in winter (Jan.-Mar.) 2010. Home range calculated as kernel polygons, which show the fraction in % of the locations they include.

this longitude threshold however many remained in the vicinity (between 60° and 63° W) for several more weeks until the sea-ice had disappeared in central and western Baffin Bay. However, tracking of an additional number of polar bears in Baffin Bay in subsequent years and an aerial survey in September 2012 specifically dedicated to finding polar bears during the open water season have shown that a few bears spend the summer in the Melville Bay and adjacent areas (Born et al. 2012).

Table 2. Date when polar bears crossed 60° W longitude for at least one week in spring with the recession of spring Baffin Bay sea-ice.

Transmitter ID	Date crossed 60° W	Season	Deg. N	Deg. W
68004	08.06.2009	summer	71.13	-61.83
68005	27.05.2009	spring	69.10	-62.23
68011	24.05.2009	spring	72.13	-60.22
68012	24.05.2009	spring	70.51	-61.05
68013	Did not cross			
68014	22.05.2009	spring	70.70	-60.71
74767	11.05.2009	spring	70.66	-62.38
74771	27.05.2009	spring	71.80	-61.5
74777	26.05.2009	spring	70.49	-60.7
74778	Did not cross			
74779	16.05.2009	spring	72.54	-61.16
74780	23.05.2009	spring	72.24	-60.52
74781	04.06.2009	summer	73.45	-62.88
74782	06.05.2009	spring	72.05	-60.6

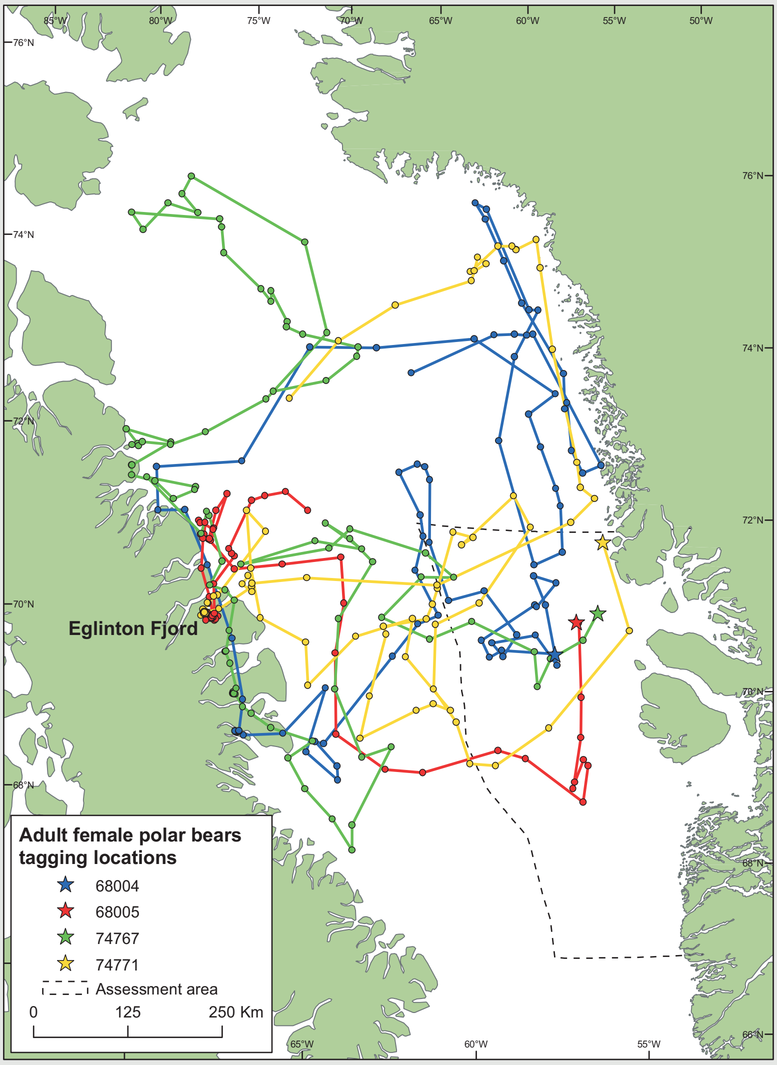


Figure 6. Tagging locations and movements of four female polar bears in 2009 and 2010.

Maternity denning sites

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

Summary and conclusions

The study was limited to only one field season and only one year of satellite tracking. Owing to these *a priori* constraints in effort only 15 polar bears were instrumented with satellite tags in 2009 of which only 3 bears *de facto* could be used for describing habitat and area use for a full annual cycle. Due to low sample size refined analyses and comparisons of habitat use and movement were not attempted. Furthermore, these constraints do not allow any final conclusions concerning the importance of the Disko West assessment area for polar bears.

Nevertheless, based on the current knowledge regarding the distribution and movements of polar bears within the Baffin Bay (Taylor et al. 2001 and this study) it may tentatively be concluded that polar bears from the Baffin Bay subpopulation range the Disko West assessment area during winter, spring and summer. Polar bears in this area follow the receding sea-ice westward towards Baffin Island during early summer. This movement commences early May. Polar bears range widely over the Baffin Bay pack ice during winter, spring, and summer. The majority of Baffin Bay polar bears spend the summer on the east coast of Baffin Island and the bears have a tendency to show fidelity to the eastern edge of the Baffin Bay pack ice including that part of the ice edge that is located in the Disko West assessment area. The Baffin Bay polar bears prefer to den on the east coast of Baffin Island. Overall, females and males seem to have the same range. Judging from recoveries in harvest in West Greenland of marked bears from the Davis Strait subpopulation, the occurrence in the assessment area of polar bears from this subpopulation seems to be low.

is not known (Anon 2010). An assessment of the number of polar bears in the Baffin Bay was initiated by DEGN and GINR in 2011. The plan involves assessment of numbers by use of a multi-year genetic mark-recapture study (Atkinson et al. 2011).

In general, it can be stated that the Baffin Bay subpopulation occurring in the assessment area currently is assumed to have an unfavourable conservation status (Obbard et al. 2010), mainly due to long-term over-exploitation (Obbard et al. 2010) and habitat degradation (Stirling & Parkinson 2006) e.g. due to climate change (see also Chapter 8).

The polar bear is listed as 'Vulnerable' (VU) on both the global red-list (IUCN 2012) and on the Greenland red-list.

Predicted future trends for polar bears in Baffin Bay

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

Since 1979 the spring break-up of the sea-ice in Baffin Bay has occurred significantly earlier in the season and the total amount of sea-ice has decreased since ca. 2000 (Stirling & Parkinson 2006).

Also of note are the significant trends in loss of sea-ice on the banks of West Greenland which are an important spring foraging habitat for polar bears. Between 1979-2010 the average sea-ice concentration on the banks of western Greenland (0-300 m) in April, May and June within the boundaries of the Baffin bay polar bear population has decreased by ca. 25% (Laidre unpubl. data).

4.8.2 Walrus (*Odobenus rosmarus*)

E.W. Born

Three populations of Atlantic walrus are distributed in Greenland, i.e. in West, Northwest, and East Greenland. The 'West Greenland' walrus population occurs from fall to spring at the edge of the Baffin Bay pack ice from c. 66° 30' N to 70° 30' N (Figure 19). Further north in Baffin Bay and Smith Sound walruses occur almost year-round in the North Water polynya and adjacent areas. They are, however, absent from the coastal areas of NW Greenland during the open water season in August–September when they summer along the eastern and southern coast of Ellesmere Island (Canada) and in the Canadian High Arctic archipelago. Walruses in these areas are referred to as 'the North Water' population. Walruses occur year-round along the eastern coast of Greenland where they mainly are distributed inside the National Park of North and Northeast Greenland north of the entrance to Scoresby Sound (c. 71°N). There is only limited exchange between walruses to the west and east of Greenland (Andersen et al. 1998, Born et al. 2001).

Information on distribution and migration as well as genetics indicates that the three Greenland walrus subpopulations represent separate population units (Witting & Born 2005). The genetic analyses (Cronin et al. 1994, Andersen et al. 1998, Andersen & Born 2000, Born 2001, Stewart 2008, Andersen et al. 2009a&b, NAMMCO 2009) also indicate that four subpopulations exist in the Baffin Bay-Davis Strait region (labelled 3, 4, 5 and 7, respectively, in Figure 19). It was found that (1) walruses in the West Greenland (4) and the northern Baffin Bay (5) subpopulations differ genetically with some likely limited male mediated gene flow between these population, (2) walruses at south-eastern Baffin Island (3) and West Greenland (4) do not differ genetically, and (3) that walruses from Hudson Strait (3) have some genetic input to this Southeast Baffin Island-West Greenland population. The genetic evidence implies a direction of migration consistent with the suggestion by Freuchen (1921) and Vibe (1950, 1956) of a large-scale counter-clockwise migration of walruses in the Baffin Bay region. A satellite telemetry study during 2005-2008 supported the notion that walruses in West Greenland and from south-eastern Baffin Island constitute the same population which is hunted in both Greenland and Nunavut (NAMMCO 2009, Dietz et al. 2010) (Figure 20).

Distribution and population size

Several systematic aerial surveys conducted during 1981-2008 (Born et al. 1994a (and references therein), Mosbech et al. 2007a, NAMMCO 2009, Heide-Jørgensen et al. 2010a) showed that winter distribution of walruses off central West Greenland is similar to that indicated by historical information with two main concentrations;

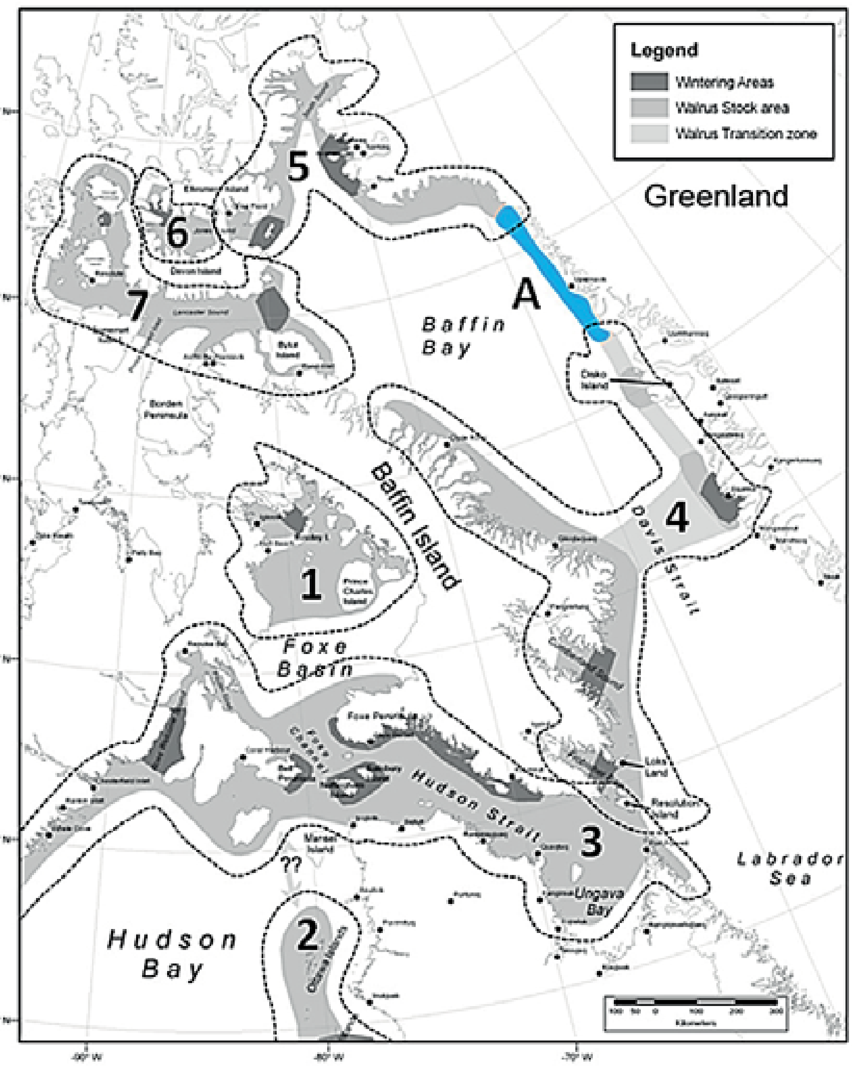
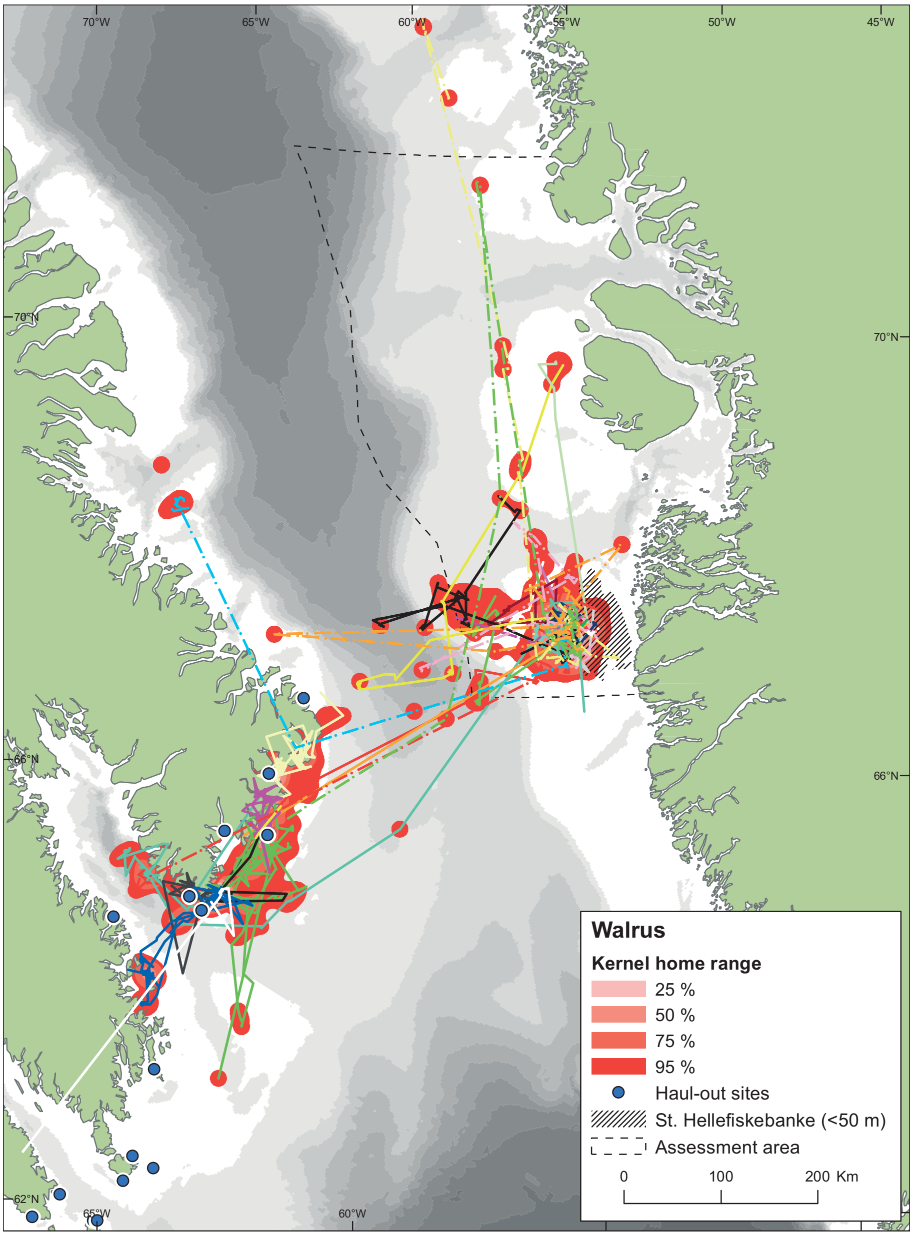


Figure 19. Distribution of seven subpopulations of Atlantic walrus in the western Atlantic Arctic (Born unpublished). The map is based on NAMMCO (2006), Stewart (2008) and courtesy of R.E.A. Stewart (DFO, Canada, unpublished). Legend: (1) Foxe Basin, (2) South and East Hudson Bay, (3) N. Hudson Bay-Hudson Strait-N. Labrador-SE Baffin Island, (4) Central West Greenland, (5) North Water/N. Baffin Bay, (6) W. Jones sound, and (7) Penny Strait-Lancaster Sound, and (A) the stock affiliation of transient walruses (blue) that occur at low density along the coast of NW Greenland has not been determined.

Figure 20. Track lines and range polygons from 31 walruses instrumented with satellite-linked transmitters at Store Hellefiskebanke during March-April 2005-2008 and at southeast Baffin Island during August-September 2008 (Dietz et al. 2010). Home ranges are calculated as kernel polygons, which show the fraction in % of the walrus locations they include.



the shallow water banks between approx. 66° 30' N and approx. 68° 15' N, and the banks along the western coast of Disko Island/Qeqertarsuaq between ca. 69° 15' and 70° 30' N (Born et al. 1994a, Mosbech et al. 2007a, Heide-Jørgensen et al. 2010a). However, during the aerial surveys in late March and April-May 2006 two small groups of walruses were observed further north at approx. 71° 10' N (Mosbech et al. 2007a) and approx. 73° N (Heide-Jørgensen et al. 2006b). The 2006 and 2008 aerial surveys that were dedicated to estimating the abundance of walruses on their central West Greenland wintering grounds resulted in weighted averages of the fully corrected estimates of abundance (2 methods for calculation and correction used) of ca. 2500 to ca. 3000 walruses in the Store Hellefiskebanke-area and 400 in the northern area off Disko Island (Heide-Jørgensen et al. 2010a).

From October-November until late-May the walruses from the West Greenland subpopulation are found on the pack ice, approx. 30 to 100 km off the coast between Sisimiut and Qeqertarssuatsiaq (Hareø). These walruses prefer areas with dense pack ice (usually more than 60 % ice cover) in water that is less than 100 m deep. Sub-adults and females with young generally occur closer to the coast than males, in areas with less dense ice and shallower water (Born et al. 1994a, Dietz et al. 2010). Although larger congregations numbering one to two hundred have occasionally been reported from this area, most walruses observed during aerial surveys were either single or in pairs (Born et al. 1994a, Dietz et al. 2010, Heide-Jørgensen et al. 2010a). Observations of new-born calves in this area are extremely rare (Born et al. 1994a, 1995, Born 2005). Recordings of underwater sounds indicate that walruses mate in central West Greenland (Born et al. 1994a).

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

There are no historical estimates of abundance of walruses in western and north-western Greenland. Catches over several decades of many hundreds of animals indicate, however, that walruses were much more abundant in these areas at the beginning of the 20th century (Born et al. 1994a, 1995, Witting & Born 2005, NAMMCO 2009).

Walruses are benthic feeders that usually forage in shallow waters with depths of less than approx. 100 m (Vibe 1950, Fay 1982, Born et al. 2003), although they occasionally make dives to at least 200-250+ m depth, both inshore and offshore (Born et al. 2005, Acquarone et al. 2006). They generally have an affinity for shallow water areas with suitable benthic food. They prefer to winter in areas where the sea-ice does not become solid (Born et al. 1995, and references therein). In western and north-western 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).

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

Movements

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

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

Miscellaneous observations offshore in Davis Strait in March-July suggest that walruses migrate across Davis Strait from western Greenland to eastern Baffin Island during spring (Born et al. 1982, Born et al. 1994a). Satellite telemetry during spring of

2005-2008 supported the notion that the majority of walruses that winter in central West Greenland move west to summer at south-eastern Baffin Island (NAMMCO 2009, Dietz et al. 2010). During spring 2005-2008, 23 walruses were fitted with satellite transmitters at their wintering grounds at Store Hellefiskebanke, in the Disko West assessment area (NAMMCO 2009, Dietz et al. 2010). Eight of these transmitters lasted long enough to document the migration from the wintering grounds in northern Davis Strait to south-eastern Baffin Island (Figure 20). The westward migration occurred between 7 April and 25 May with the routes across Davis Strait being quite similar taking place at the most shallow and the narrowest part (ca. 400 km) of the strait. The walrus birth season is protracted but peaks in late-June (Born 2001) and the satellite telemetry study therefore indicated that the walruses leave their West Greenland wintering grounds prior to the peak of calving season.

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 (i.e. at the latitude of the settlement of Nutaarmiut) before turning south again (Figure 20). One of these walruses stopped transmitting on its way south along the coast whereas the other migrated to Baffin Island. This demonstrates that an unknown proportion of the West Greenland wintering stock of walruses may occur within the assessment area for an unknown period of time during May-June (NAMMCO 2009, Dietz et al. 2010).

Important and critical areas

Within the assessment area there are two critical areas for wintering walrusses. The most important is the Store Hellefiskebanke (Figure 20) and the other is the area west of Disko Island. The numbers occurring here is reported above. In summer the walrusses wintering in the assessment area are in Canadian waters around south-eastern Baffin Island, where the population has been estimated at at least 3000 individuals (NAMMCO 2009). The recent estimates of the winter population in the assessment area indicate that a major part of the Baffin Island summer population is here in winter.

Conservation status

Walruses occurring in the assessment area have an unfavourable conservation status, probably due to excessive hunt. The West Greenland subpopulation is listed as 'Endangered' (EN) and the North Water population as 'Critically Endangered' (CR) in Greenland´s Redlist (Boertmann 2008). In Greenland Atlantic walrus is listed as a species of 'special concern' (COSEWIC 2006).

4.8.3 Seals

A. Rosing-Asvid

Four species of seals are common in the Disko West assessment area (Table 7); the ringed seal, harp seal, hooded seal and bearded seal. They are all included in the subsistence hunt and they rank from being very numerous to relatively common. Harbour seals are today very rare in the assessment area and hunt on this species is now prohibited (Rosing-Asvid 2010a, 2011). Harp and hooded seals are migrants occurring only during the open water season, and they whelp outside the assessment area. Ringed seal occur mainly in ice-covered waters and they whelp on the fast ice of the fjords and on consolidated pack ice in offshore areas. Most bearded seals are visitors occurring when the pack ice reach the area during winter and spring and some bearded seals mate and whelp in the assessment area in early spring. Bearded seals tend to stay near sea-ice. They can make breathing holes, but unlike the ringed seal, only in relatively thin ice, so many of them will follow the pulse of the pack ice in and out of the assessment area.

In the following a short description is given of the five seal species occurring in the Disko West assessment area.

Hooded seal (*Cystophora cristata*)

Hooded seals are migratory seals. The vast majority of the seals from the West Atlantic population concentrate in the whelping areas off Newfoundland and in Davis Strait during March-early-April (Stenson et al. 1996). In late April-May most of these seals swim toward Southeast Greenland where almost the entire population moult on the drift ice during late June-July (Figure 21). Most juveniles stay near the drift ice off the Greenland east coast until they mature. The adult seals start a migration toward Davis Strait and Baffin Bay during the end of July (Andersen et al. 2009c). A large fraction of the adult seals move up into the Baffin Bay in September and until November they forage on the steep part of the shelf in the Baffin Bay mainly feeding on large fish and squids (Andersen et al. 2009c). Observations of hooded seals from surveys since 1988 in the assessment area are shown in Figure 22.

Catch

The annual catch of hooded seals in the settlements on the Greenland west coast between 66° N-70° N (including most of the assessment area) is on average 1095 (Table 9). The catch statistics show that some seals arrive in the assessment area when sea-ice starts to break up in May, and a few will stay there throughout the open-water period May-November. Most hooded seals will, however, follow the migratory pattern described above. This is not reflected in the catch, because the seals migrate offshore and not near shore where most of the hunting take place.

Conservation status

The population occurring in the assessment area has a favourable conservation status and the hooded seal is listed as of ‘Least Concern’ (LC) on the Greenland Red List. However, internationally the hooded seal is considered as ‘Vulnerable’ (VU), due to a decrease in the Northeast Atlantic population (IUCN 2012). The seals are part of a very large population in the Davis Strait/Baffin bay region, which is managed internationally through a working group under ICES and NAFO and catches are considered sustainable (ICES 2006).

Important and critical areas

No particularly important areas are known for hooded seals within the assessment area.

Bearded seal (*Erignathus barbatus*)

Bearded seals are widespread in the Arctic. Some bearded seals are stationary, but seasonal changes in their densities in some areas indicate that a part of the population (probably mainly the adult females and young animals) is moving around. These distribution changes seem to be linked to the seasonal changes in the sea-ice conditions. Bearded seals do make breathing holes, but only in relatively thin ice so seals that summer in areas with thick winter ice either winter in reoccurring leads and polynyas or they follow the pulse of the expanding and shrinking sea-ice.

Bearded seals can be found in certain parts of the assessment area (Figure 22) throughout the year, but they are most often seen (and caught) along the ice edge during spring.

They are known to mainly feed on fish and benthic invertebrates found in waters down to 100 m water depth (Burns 1981, Gjertz et al. 2000). Ongoing studies show that bearded seals in South Greenland spend considerable time at much deeper

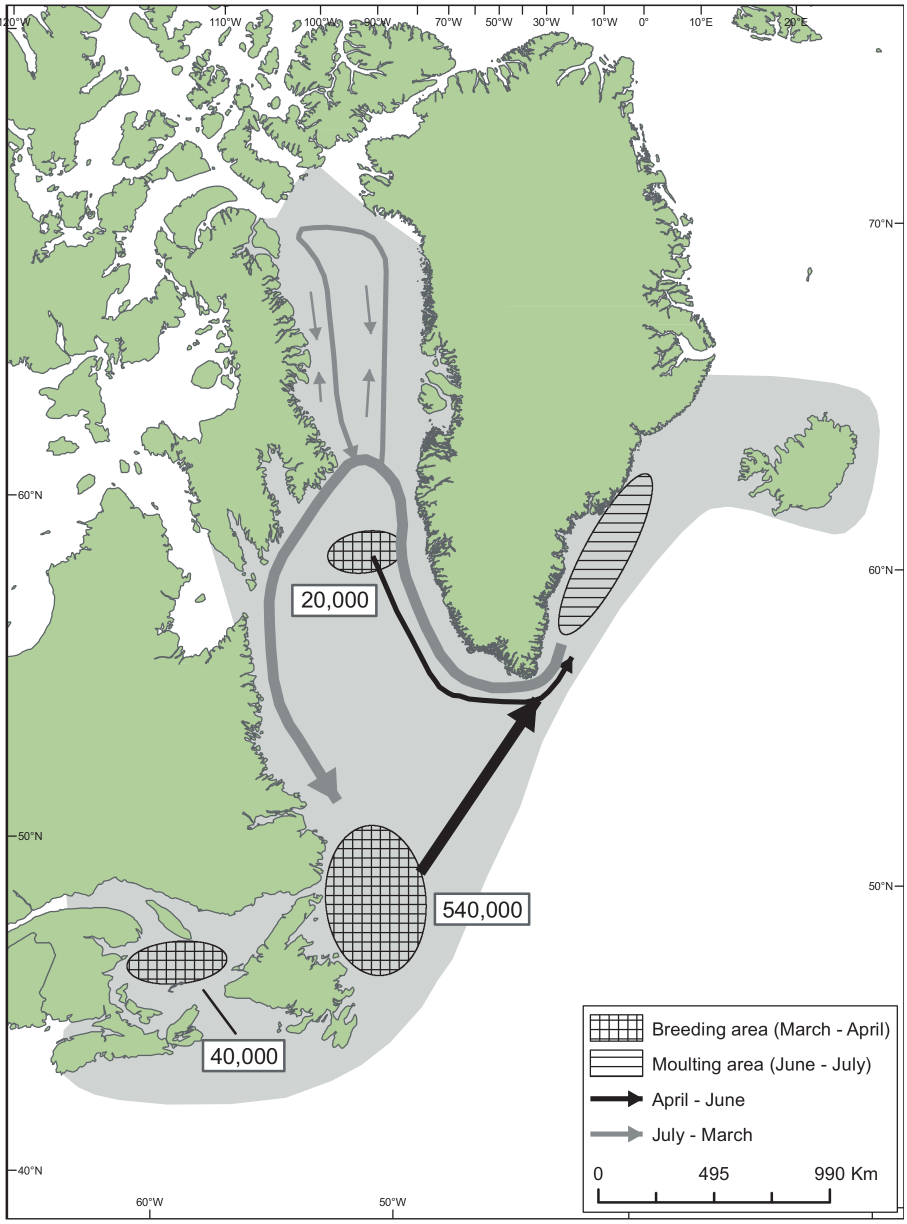


Figure 21. Distribution of the West Atlantic hooded seals. Numbers are the approximate number of seals associated with each of the three West Atlantic breeding areas in 2005.

water (>300 m) and shrimps are found to be the most important prey in that area (GINR unpublished).

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

<u>Catch</u>

The annual catch of bearded seals in the settlements on the Greenland west coast between 66° N-70° N (including most of the assessment area) is on average 467 (Table 9).

<u>Conservation status</u>

The bearded seal has a favourable conservation status, but it is listed as 'Data Deficient' on the Greenland Red List due to lack of knowledge about population boundaries and numbers. At global scale it is listed as 'Least Concern' (IUCN 2012).

<u>Critical and important habitat</u>

In the Disko West assessment area the Store Hellefiskebanke and especially the northern rim, seems to be an important habitat during winter and spring (Figure 22).

Harp seal (*Pagophilus groenlandica*)

Harp seals are migratory seals. The vast majority of the seals from the West Atlantic population concentrate around the whelping areas off Newfoundland in February-April. They give birth on the drift ice in March and they moult in April. After the moult they spread out in the waters between Greenland and Canada and some seals move up along the Greenland east coast (Figure 23). Observations of harp seals in the assessment area made during surveys since 1988 are shown in Figure 22.

Harp seals are widely distributed in the assessment area (Figure 23) and their numbers increase throughout the summer and early fall, but when the sea-ice starts to form they migrate towards the whelping areas off Newfoundland. During summer most adult harp seals will forage in pods typically consisting of 5-20 individuals. Juvenile seals forage alone. All age-classes will in the coastal part of the assessment area mainly feed on capelin, whereas sandeel was the main prey in a study from the Store Hellefiskebanke (Kapel 1995).

The West Atlantic population that whelp on the ice off Newfoundland in early March is estimated to have increased from around 1.8 million in the early 1970s to about 9 million individuals in 2011 (ICES 2011). The proportion of seals found in the assessment area is unknown and probably also variable, but might be in the region of 10 % of the population.

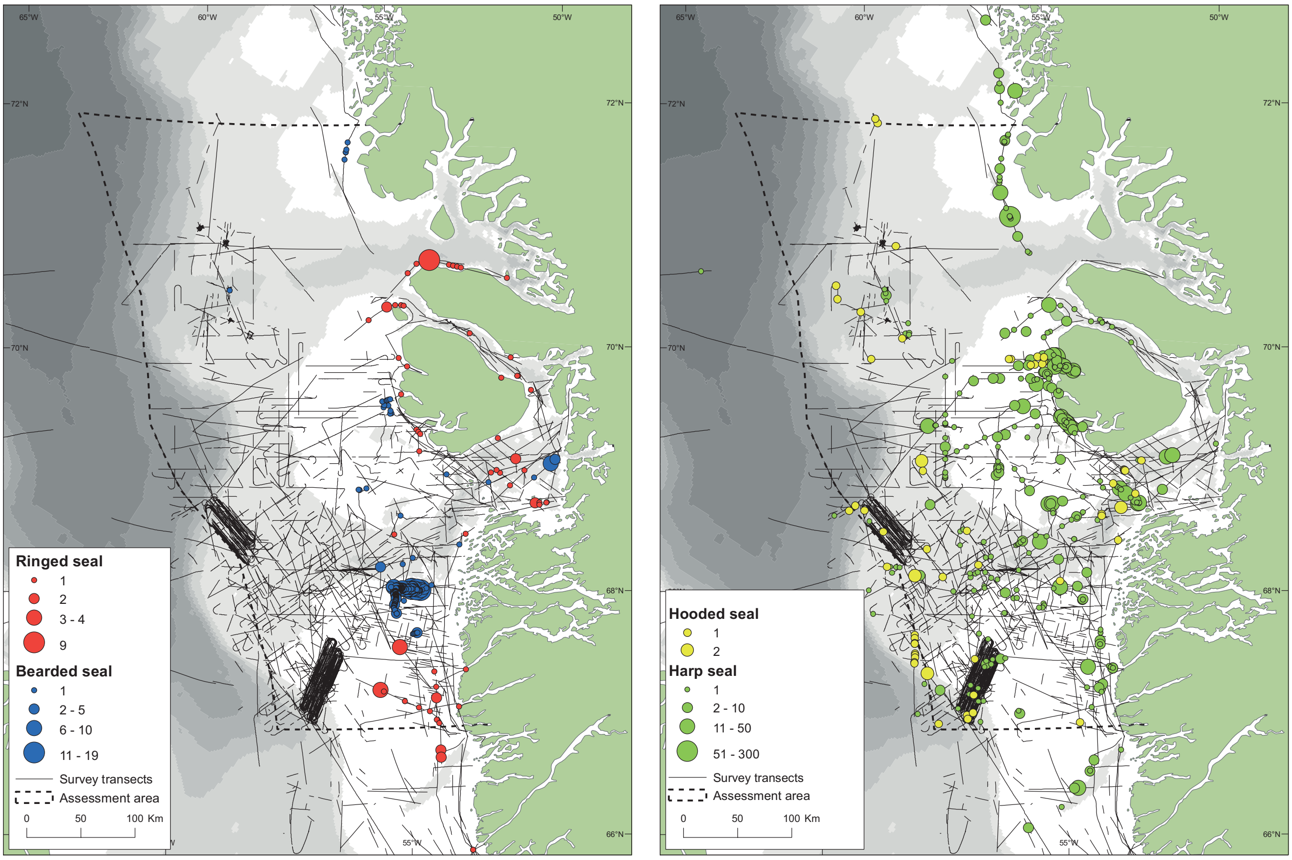


Figure 22. Sightings of seals made during 20 systematic seabird and marine mammal surveys from seismic vessels and biological research vessels between 1988 and 2010 (DCE Seabirds-at-Sea Database, unpublished). The spatial distribution of effort is indicated by the transect lines. The surveys were conducted between April and November, but with a peak in August and September.

Table 8. The quotas in 2010 for marine mammals in North and West Greenland (APNN). 1: A total quota of 68 polar bears was given for the Baffin Bay/Davis Strait subpopulations to be taken by hunters living in the areas between Savissivik and Nuuk (i.e. between ca. 76° and ca. 64° N) in West Greenland. Of these 9 could be taken between Uummannaq and Nuuk (minus 4 taken in excess in this area in 2009; Anon 2011c).

Area in 2010	Species			
	Walrus	Polar bear	White whale	Narwhale
Baffin Bay population	64	–	–	–
Kane Basin population	–	6	–	–
Qaanaaq	–	–	20	–
Inglefield Bredning & Smith Sound	–	–	–	85
Upernavik, Uummannaq & Disko Bay	27	–	–	–
Baffin Bay/Davis Strait population	–	68 1)	–	–
Upernavik	–	–	115	–
Melville Bay	–	–	–	81
Uummannaq	–	–	19	85
Rest of West Greenland	34	–	156	59

Table 9. Mean nnual catch of seals from the settlements in the area between 66° and 70° N including most the assessment area in the period 1999-2008.

Species	Mean annual catch	Range
Harp seal	25,380	19,306-30,654
Ringed seal	11,757	8,093-19,093
Hooded seal	1095	669-1,261
Bearded seal	467	287-586
Harbour seal	protected	–

Catch

The annual catch of harp seals in the settlements on the Greenland west coast between 66° N-70° N including most of the assessment area) is on average 25,380 (Table 9).

Conservation status

The population occurring in the assessment area has a favourable conservation status. Harp seals are the most numerous marine mammals on the northern hemisphere and the West Atlantic population is probably at the highest level in historic time. It is listed as of ‘Least Concern’ on the Greenland Red List.

Critical and important habitats

No particularly important areas are known for harp seals within the assessment area.

Ringed seal (*Pusa hispida*)

Ringed seals are present in all parts of the Arctic that have annual sea-ice. They give birth in March-April in lairs dug out in a snowdrift that is covering a breathing hole. The pups lactate in up to 7 weeks (Hammill et al. 1991). The moulting period is mainly in June and during the moult, the seals will spend most of the day basking on the ice. They need to be near the ice in this period. 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

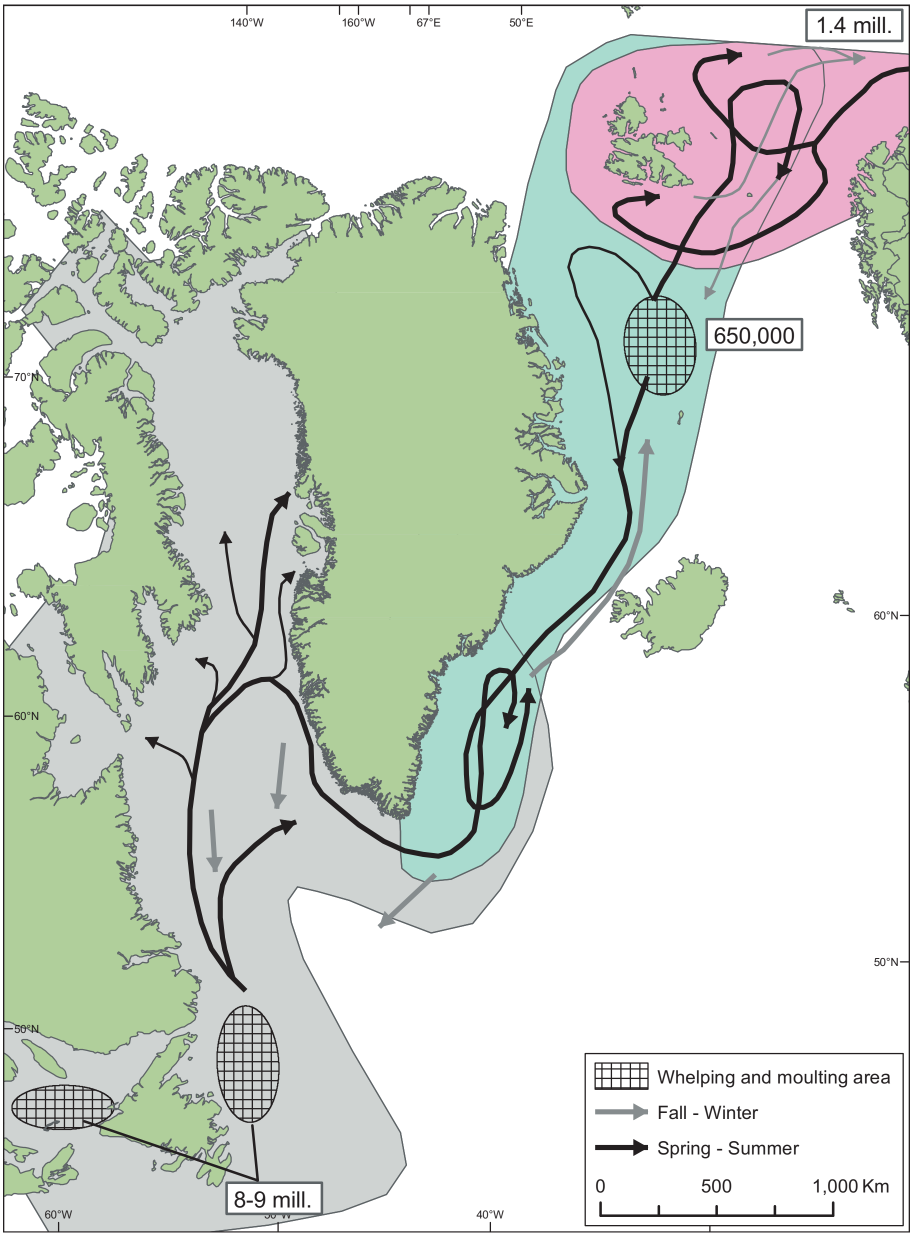


Figure 23. Harp seal distribution and numbers associated with known whelping areas. Red is White Sea population, turquise East Greenland population and grey Newfoundland population.

during early winter they spread out again. Ringed seals make breathing holes in the new ice and they maintain the breathing holes in fast ice areas and in consolidated pack ice throughout the winter. Adult seals establish territories in these areas, whereas the juvenile seals mainly spend the winter in areas with loose unconsolidated sea-ice. Observations of ringed seals in the Disko West assessment area made during surveys since 1988 is shown in Figure 22.

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

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

Catch

The annual catch of harp seals in the settlements on the Greenland west coast between 66° N-70° N (including most of the assessment area) is on average 11,757 (Table 9).

Conservation status

The ringed seal has a favourable conservation status, because of a relatively uniform and widespread circumpolar distribution, which prevents overexploitation on an overall population level. Ringed seals are listed as of 'Least Concern' (LC) on the Greenland Red List.

Critical and important habitats

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

4.8.4 Whales, dolphins and porpoises

F. Ugarte, T.K. Boye, M. Simon and M.P. Heide-Jørgensen

The order Cetacea, which includes whales, dolphins and porpoises, is divided into two sub-orders: Mysticeti (baleen whales) and Odontoceti (toothed whales). They differ in foraging behaviour and ecology. Baleen whales catch prey by filtering large volumes of prey laden water through a curtain of baleen plates hanging from the roof of their mouth, while toothed whales catch individual prey with their teeth. There are also general differences in their residency and migration patterns, with most baleen whales showing well defined seasonal migrations between breeding and feeding grounds.

Baleen whales and toothed whales differ in the frequency ranges of the sounds used for communication, navigation and feeding. Baleen whales emit low frequency calls (10-10,000 Hz), audible over distances of tens of kilometres (Mellinger et al. 2007). In contrast, toothed whales use higher frequencies (80 Hz-130 kHz) to produce tonal sounds for communication, and clicks for echolocation and communication (Mellinger et al. 2007). An overview of the frequencies used by cetaceans present in the assessment area is given in Figure 24.

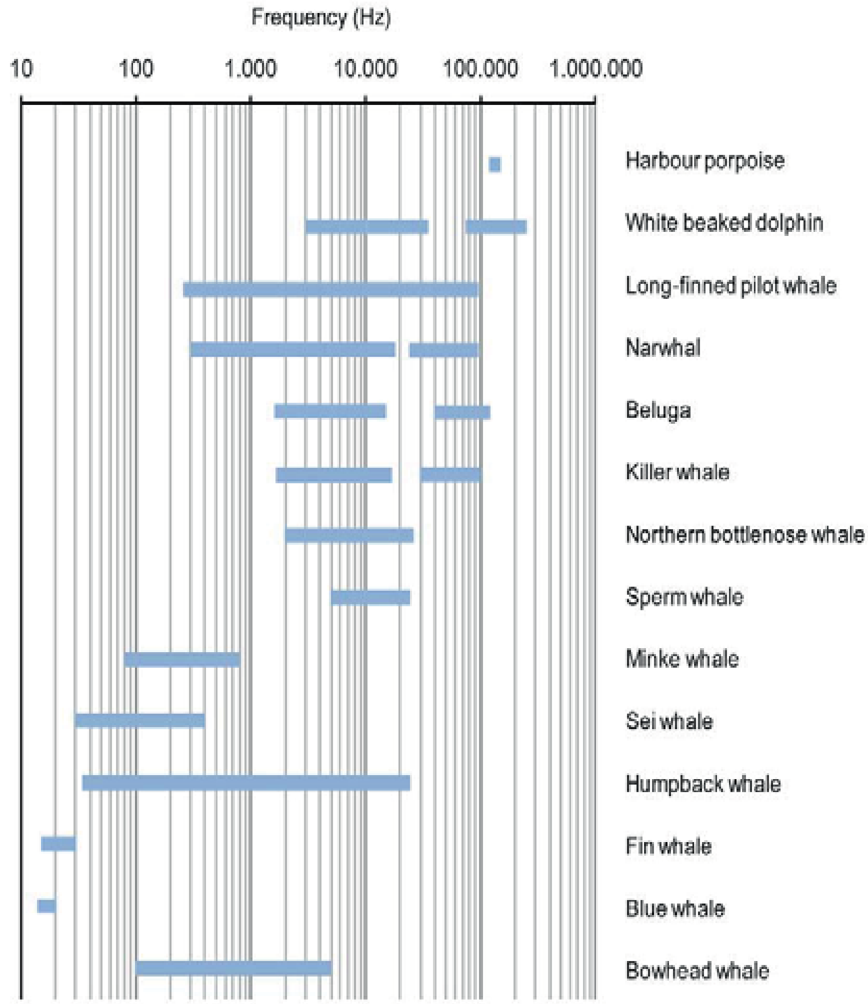
Oil activities that potentially can impact whales include seismic exploration, exploratory drilling, ship, helicopter and aircraft noise, discharges to water, dredging, and marine constructions.

Baleen whales

Baleen whales regularly occurring in the assessment area include the bowhead whale and four species of rorquals (family Balaenopteridae: minke, fin, blue and humpback whale). In addition, a fifth rorqual, the sei whale, is believed to have a fluctuating abundance during summer.

All five rorqual species migrate between southerly calving and mating grounds during winter and northern feeding grounds during summer. Their summer distribution includes parts of the northern North Atlantic, including the seas around Greenland. From different surveys performed during 1988 to 2010 information is available concerning the occurrence of the four baleen whale species that are regularly present in the assessment area (Figure 25). The rorquals undertake long migrations to take advantage of the summer peak of productivity in northern wa-

Figure 24. The main frequency range of sounds used by cetaceans in the assessment area. See also Table 6 for details.



ters. Climate change will likely impact these migratory species in terms of distribution changes due to geographic shifts in the locations of frontal and upwelling areas that concentrate their food.

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 24). Due to their potential ability to communicate acoustically over very long distances, the baleen whales are sensitive to activities that raise the ambient noise level (acoustic pollution) from sources such as seismic airguns, drilling, offshore construction, aircrafts and vessel supply activities.

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

The bowhead whales belonging to the Baffin Bay stock spend most of the year in the Canadian high Arctic around Baffin Island (Heide-Jørgensen et al. 2010b). In winter (January-February) part of the population migrates to West Greenland to feed on the high densities of Arctic copepods in Disko Bay (Heide-Jørgensen et al.

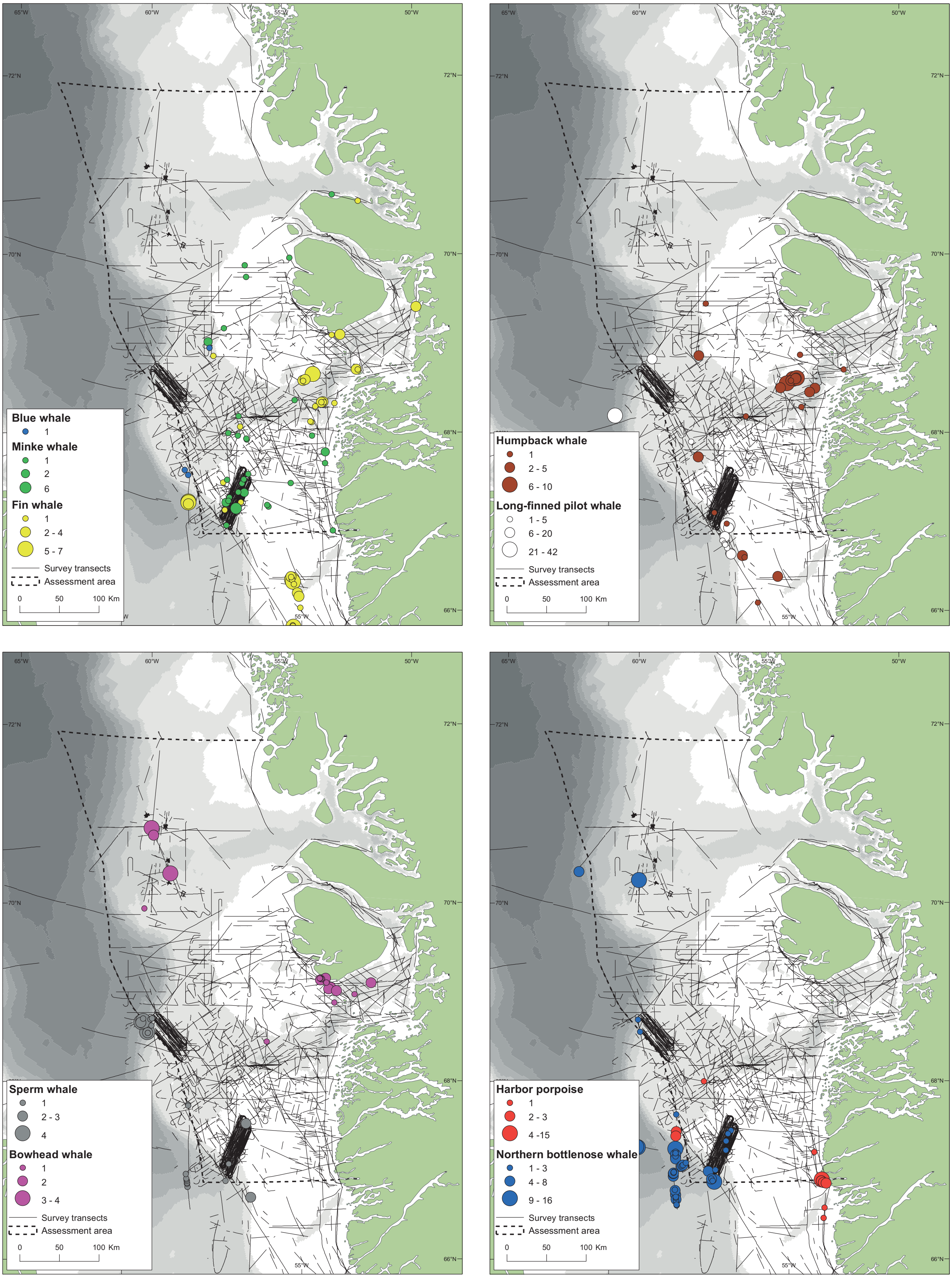


Figure 25. Sightings of different species of whales made during 20 systematic seabird and marine mammal survey from seismic vessels and biological research vessels between 1988 and 2010 (DCE Seabirds-at-Sea Database, unpublished). The spatial distribution of effort is indicated by the transect lines. The surveys were conducted between April and November, but with a peak in August and September.

2006a, 2010b Laidre et al. 2007). Besides feeding the whales may use the area as a mating ground (Heide-Jørgensen et al. 2010b).

Extensive commercial whaling of bowhead whales reduced the stock to a level where whaling was no longer profitable by the end of the nineteenth century (Ross 1993) and sightings were seldom in West Greenland. However, the stock is now recovering and the whales have returned to the Disko Bay feeding/mating area.

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

Current distribution of bowhead whales

Today bowheads are primarily spring and summer visitors and found along the west coast between Nordre Strømfjord and southern part of Qaanaaq (Box 9 and Figure 26). The core area for bowhead whales today is the Disko Bay and waters west and southwest of Disko Island.

Migrations

The first bowhead whales appear in Disko Bay in February (2005, 2006, 2009 and 2010) at Kitsissuarsuit and Qeqertarsuaq. The whales remain in the bay until June where they are mainly concentrated in the northern section near the coast of Disko Island, but some whales have been observed in the eastern part of the bay towards Ilulissat or around the islands in the opening of the bay. The timing of the departure from the bay varies slightly, but usually occurs around mid-May. The predominant migration route is taken in a northwest direction across the Baffin Bay assessment area, probably through leads and cracks in the pack ice (Heide-Jørgensen et al. 2006a). The traverse of Baffin Bay likely requires that whales move north along the West Greenland coast until they find a lead that intersect Baffin Bay running northwest to southeast, facilitating open water availability during the relatively short time span the whales use to cross the bay (Box 9).

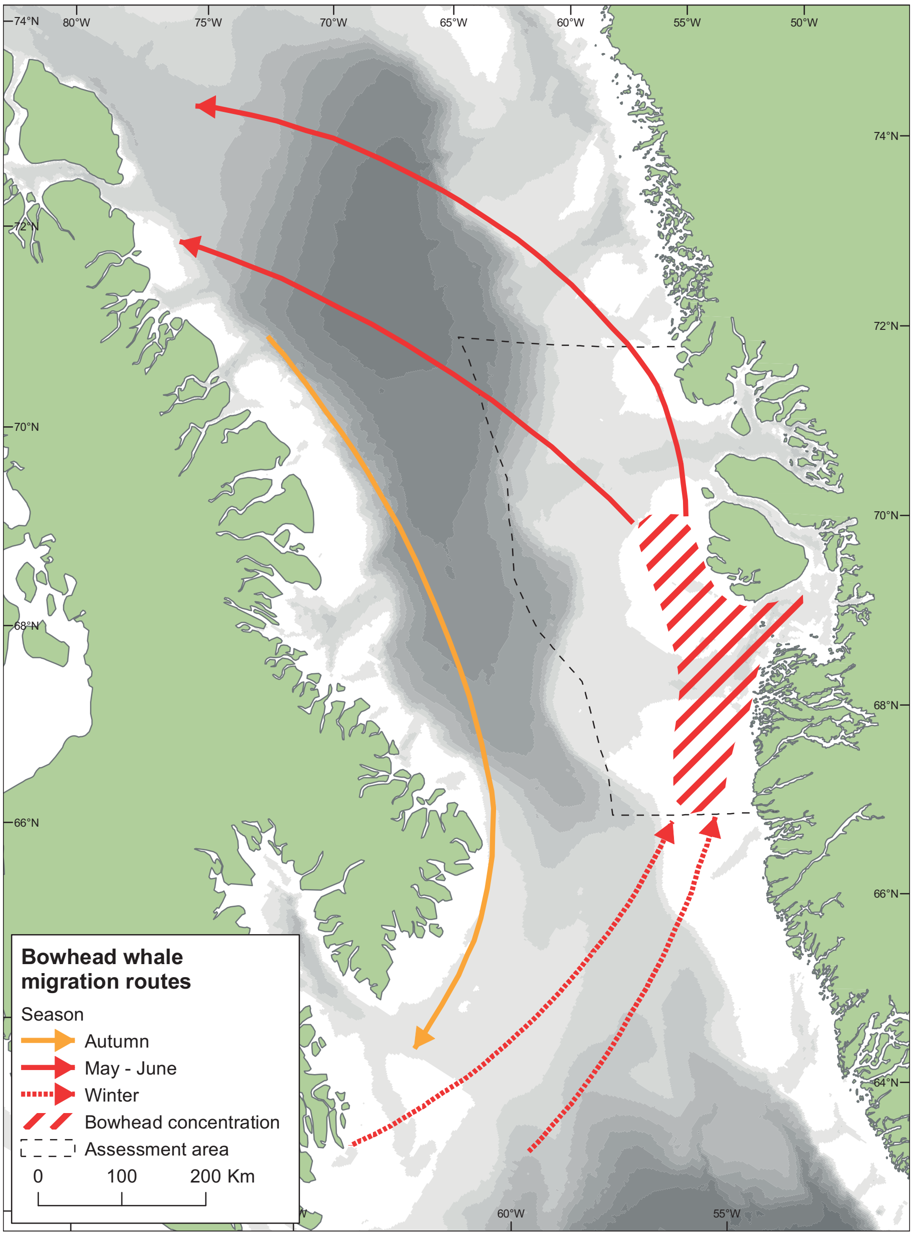
Stock identity

Recent satellite tracking studies in Canada and Greenland (Box 9) shows that bowhead whales that occur in West Greenland are part of a population that extends from Foxe Basin through the Canadian high-Arctic archipelago, Hudson Bay and Hudson Strait, and along the east coast of Baffin Island (Heide-Jørgensen et al. 2006a), i.e. the range of the two now debated stocks BBDS and FBHB.

Population segregation

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

Figure 26. Migration routes for bowhead whales in the Davis Strait and Baffin Bay. In January-February the whales migrate to their feeding/mating grounds in the Disko West assessment area (hatched area).



portion 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 with up to three unique songs per individual were recorded in April 2007 (Stafford et al. 2008, Tervo et al. 2009). Singing is an activity that usually is attributed to male display in baleen whales and, given most singing activity was recorded during spring; mating between the relatively few males and the large fraction of females is assumed to occur in Disko Bay in March.

Current abundance in West Greenland

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

Diving and foraging ecology

Dive data collected from bowhead whales in Disko Bay indicate deep dives with great variability following the highly complex bottom contours of Disko Bay as well as mid-water and near-surface feeding dives (Laidre et al. 2007, Simon et al. 2009). In these depths, densities of copepods are very high (Laidre et al. 2007). Given the requirement to strain enormous quantities of water (Simon et al. 2009), bowhead whales likely have evolved to exploit their zooplankton prey in regions with high density aggregations.

Feeding habits of bowhead whales in Disko Bay have been studied through examination of stomach contents of whales captured in the subsistence harvest for whales. Four stomach samples were collected in 2009 and 2010 and in all stomachs the prey items were > 99 % calanoid copepods > 3 mm long (Heide-Jørgensen et al. 2012b). In one stomach, where species determination was possible, it was primarily *Calanus hyperboreus* that was found. The stomach content of the bowhead whales from Disko Bay indicate that they feed almost exclusively on calanoid copepods and that no other prey items contribute substantially to their diet. This is in agreement with observations of diving behaviour and area utilization by whales instrumented with time-depth-recorders and satellite transmitters (Laidre et al. 2007, Simon et al. 2009). 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).

Conservation status and catch

Bowhead whales in West Greenland are listed as ‘Near Threatened’ (NT) on the Greenland Red List (Boertmann 2008) because, despite the recent signs of recovery (Heide-Jørgensen & Laidre 2010), numbers of bowhead whales in Baffin Bay are probably still much lower than the original population size (Allen & Keay 2006). At a global level, bowhead whales are listed as ‘Least Concern’ (LC) on the international Red List (IUCN 2012).

Critical and important areas

The assessment area is extensively used by bowhead whales, e.g. as feeding and mating ground (Figure 26). The Disko Bay and the waters to the southwest of Disko must be classified as one of the most important bowhead whale habitats worldwide; it is used extensively for foraging by mature whales of both sexes and it is especially important for mature females that – aside from feeding – are also mating in the bay (Heide-Jørgensen et al. 2012b). The migration corridors between Disko Bay and northern Baffin Island during May and June and between southern Baffin Island and Disko Bay during February are also critical habitats.

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

Minke Whale (*Balaenoptera acutorostrata*)

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

Minke whales feed on a large variety of prey, including small schooling fish and krill. Preferred prey in West Greenland include capelin and sandeels (Larsen & Kapel 1981).

Box 9. Movements and space-use patterns of bowhead whales in the Baffin Bay, 2009 and 2010

M.P. Heide-Jørgensen and K. Laidre

A total of 78 bowhead whales have been instrumented with satellite-linked radio transmitters in Disko Bay in 2009 (n = 28) and 2010 (n = 50). Three types of transmitter configurations were used: cylindrical implantable SPOT 5 tags that provide only positions of the whales (n = 33), cylindrical implantable Mk10 tags that collect and transmit compressed and binned dive data (n = 16) and external SWING SPLASH tags secured with a spear with barbs that also collect dive data (n = 29). All tags were deployed in Disko Bay between 15 February and 5 June with most deployments in April. Data from the tags have been collected for as long as 14 months (Fig. 1, 2, 3, 4 and 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) (Fig. 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) (Fig. 7). Third, home ranges were calculated for the combined data sets for the spring and summer season using whales tagged in 2009 and 2010 (Fig. 8). Currently, autumn home ranges are only available based on whales from 2009 because the tags from 2010 are still transmitting.

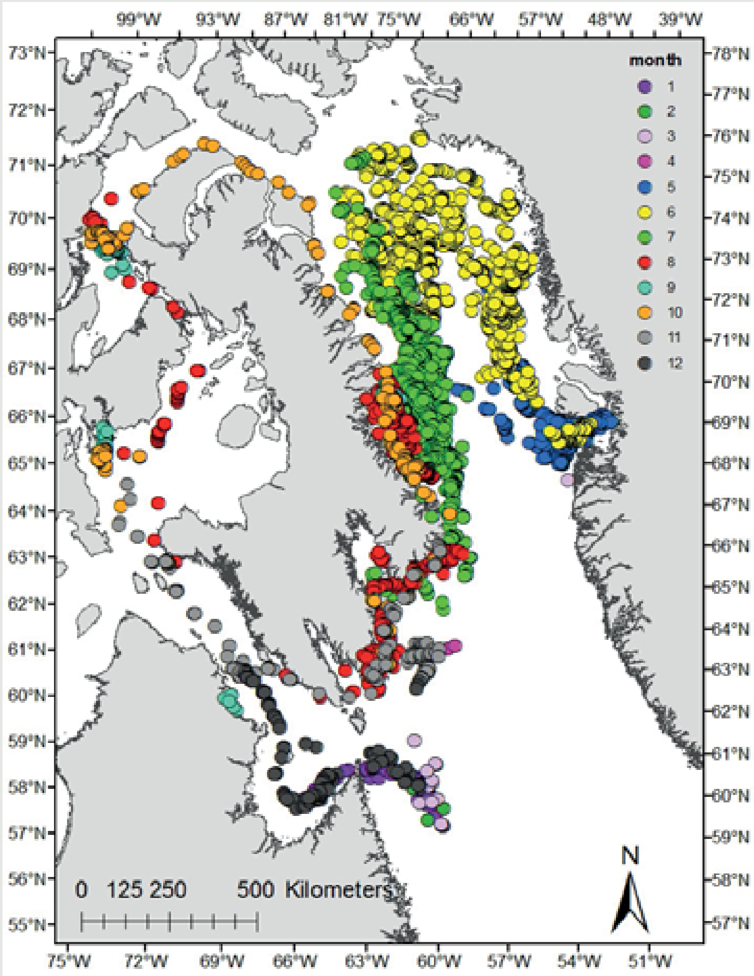


Figure 1. Locations of all bowhead whales tagged in 2009 in Disko Bay and tracked through December 2009 (n = 28).

Winter: January – March

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

Spring: April – May

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

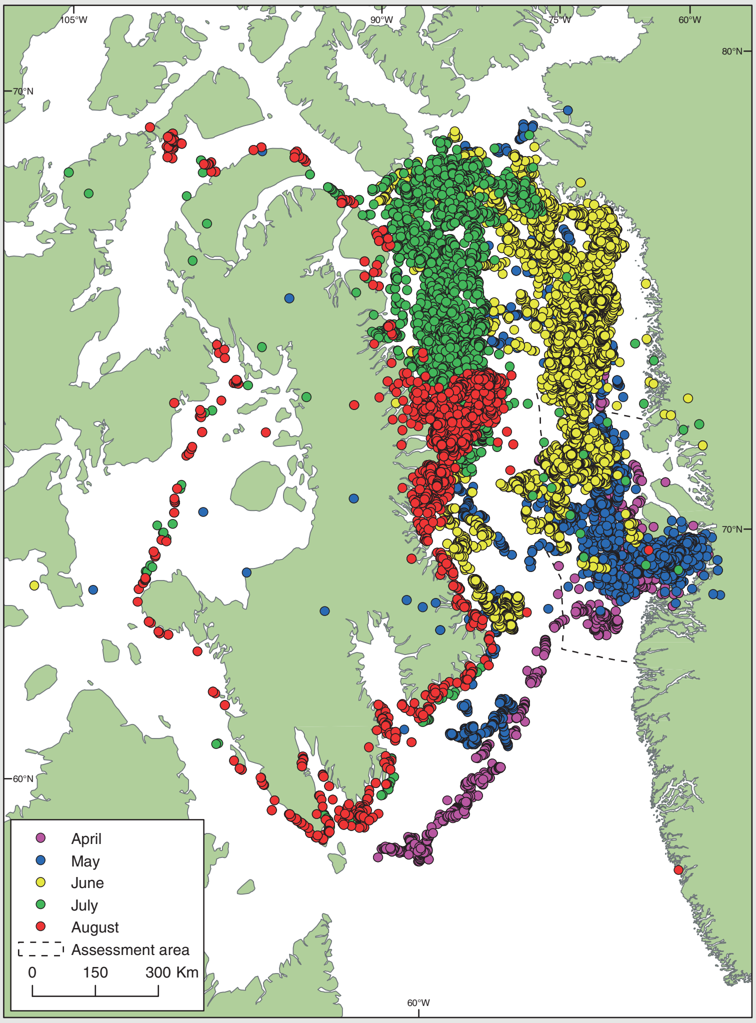


Figure 2. Locations of all bowhead whales tagged in Disko Bay in 2010 and tracked through August 2010 (n = 50).

The spring home ranges (Fig. 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 (Fig. 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.

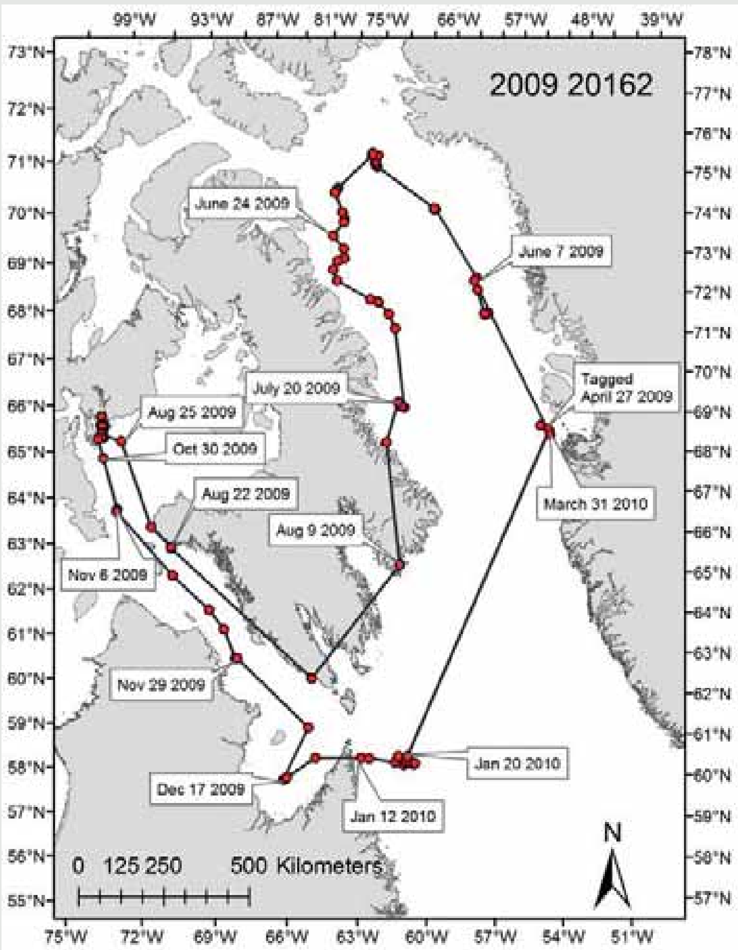


Figure 3. Track of a female bowhead whale (Id. no. 20162) tagged on 27 April 2009 in Disko Bay and tracked through March 2010.

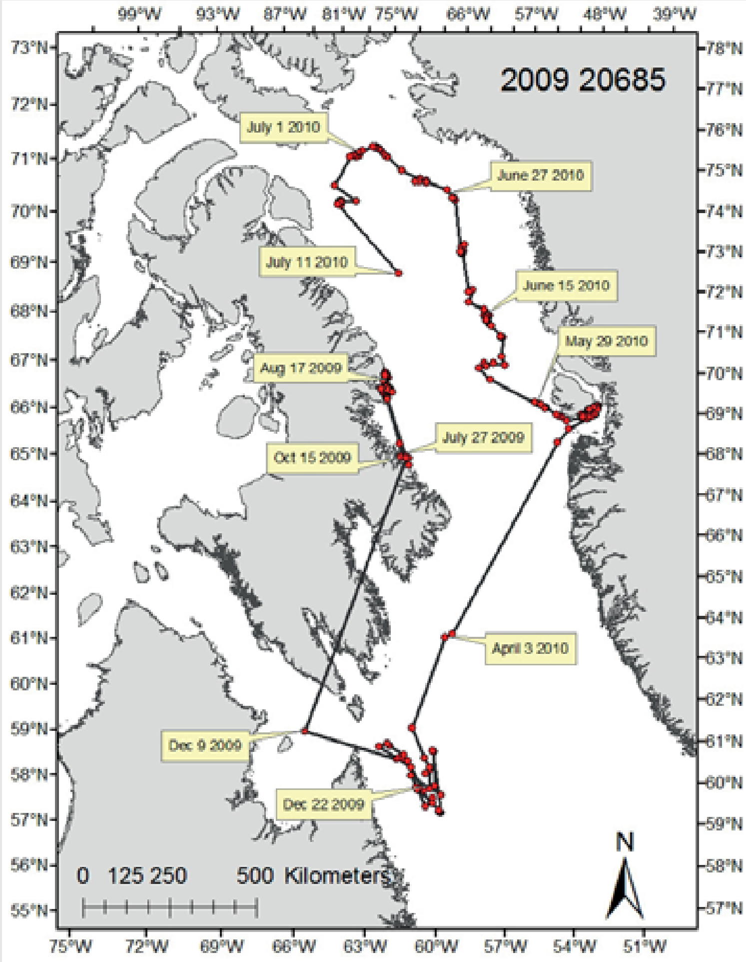


Figure 4. Track of a female bowhead whale (Id. no. 20167) tagged 17 May 2009 in Disko Bay and tracked through 11 July 2010.

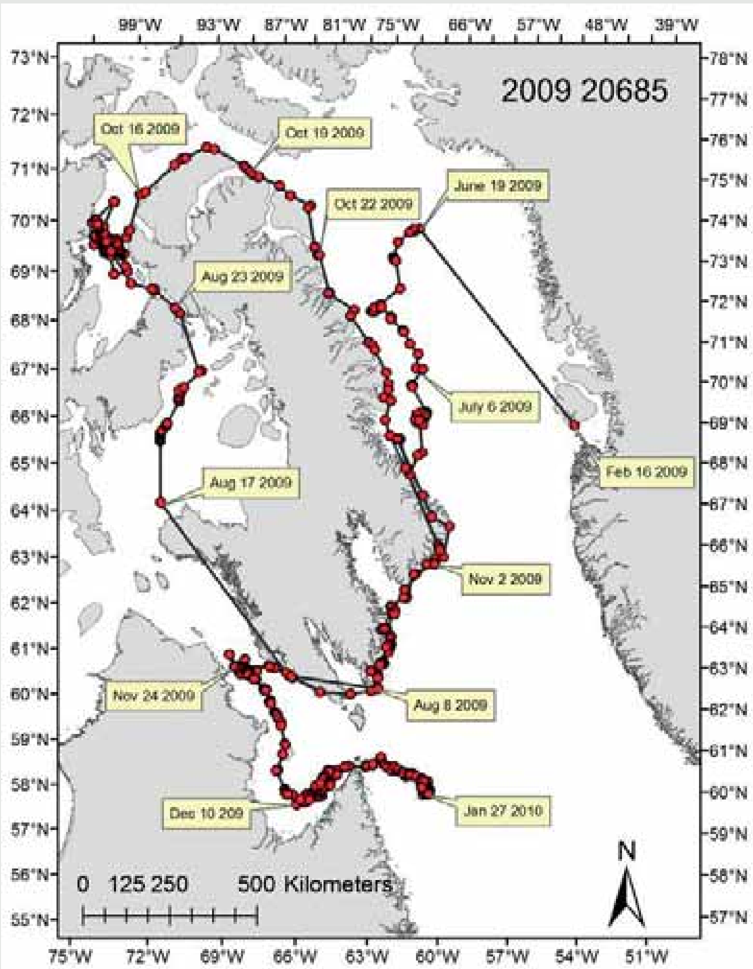


Figure 5. Track of a bowhead whale (sex unknown, Id. no 20685) tagged 27 April 2009 in Disko Bay and tracked through 27 January 2010.

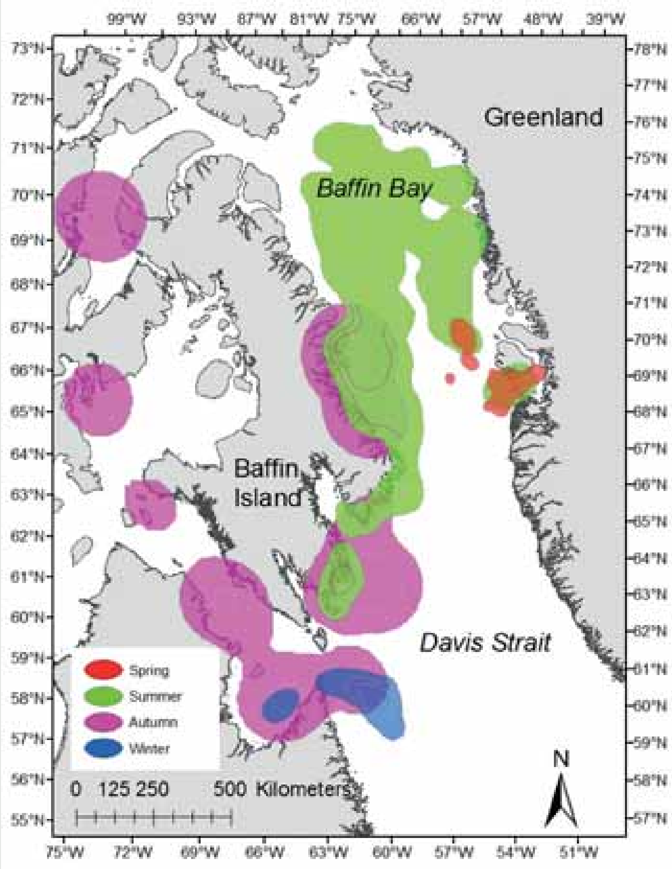


Figure 6. Seasonal home range distributions (calculated by the kernel method) of bowhead whales from 2009 (n = 28).

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

The summer home range demonstrated the vast area over which the bowhead whales range during these months (Fig. 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 fall and early winter. In the fall whales from Disko Bay can be located in the Canadian Arctic Archipelago as far west as 90° W, but are primarily concentrated in Prince Regent Inlet, Foxe Basin and in fjords along the east coast of Baffin Island (e.g. Isabella Bay and Cumberland Sound) and Hudson Strait. At this time of the year the whales are also concentrated in coastal areas or move between coastal locations.

The 95, 75, and 50% autumn kernel home range was concentrated in multiple smaller focal areas which included the east coast of Baffin Island (Isabella Bay and offshore from Cumberland Sound), Prince Recent Inlet, Repulse Bay, and multiple areas within Hudson Strait (Fig. 6).

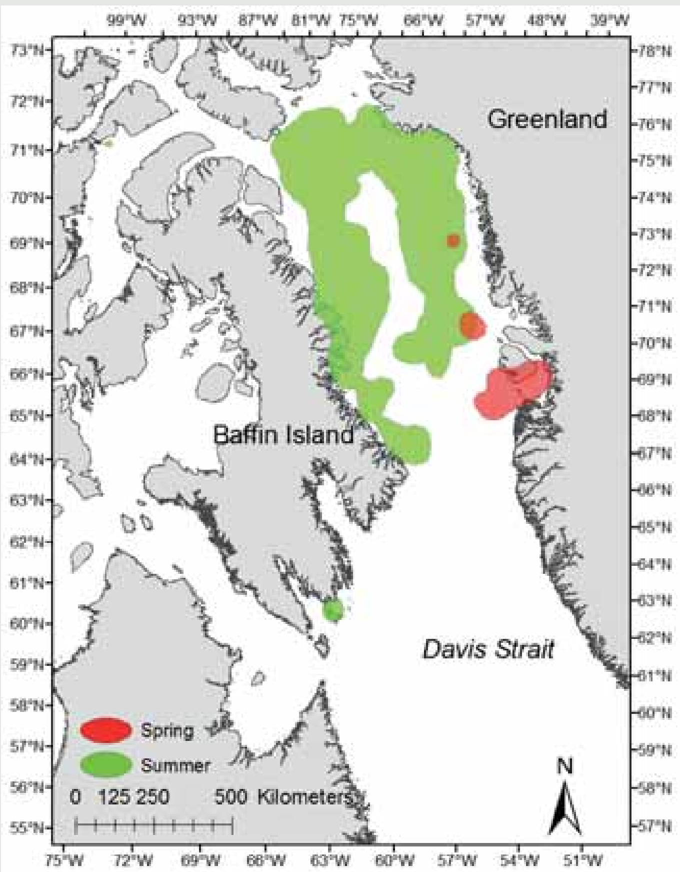


Figure 7. Seasonal home range distributions (calculated by the kernel method) of bowhead whales from 2010 (n = 50).

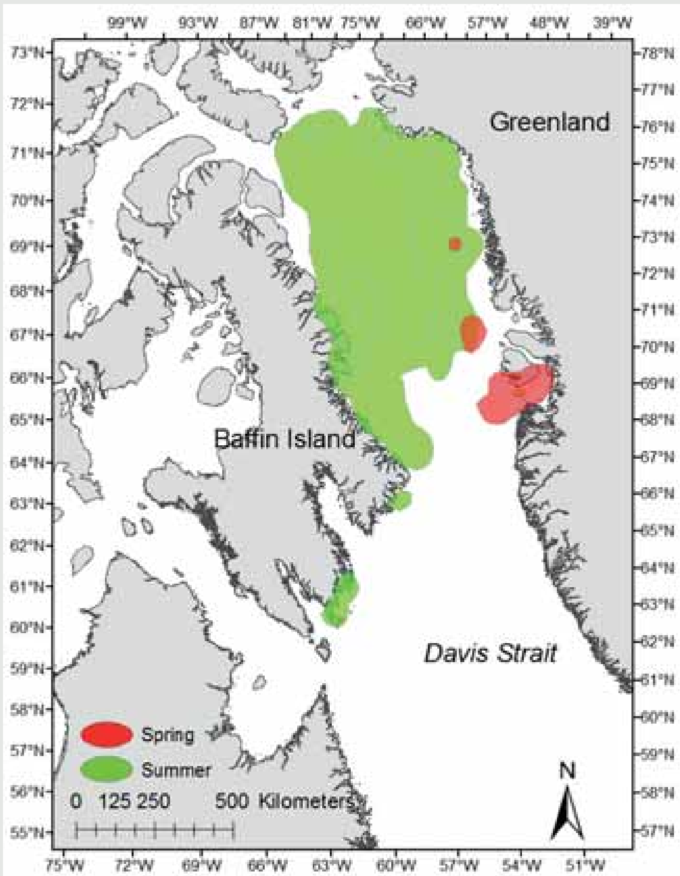


Figure 8. Combined spring and summer home ranges (calculated by the kernel method) for bowhead whales tracked in 2009 and 2010 (n = 78).

Distribution

As other rorquals, minke whales 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 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 during winters. Minke whales occur as summer visitors in the Disko West assessment area (Figure 43). In recent years minke whales have been reported as far north as Siorapaluk in the former Qaanaaq Municipality, which most likely is an effect of climate change.

Stocks

For management purposes, the International Whaling Commission (IWC) recognizes four different minke whale management stocks in the North Atlantic (Figure 27). 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).

Abundance

The available data indicate 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, including the assessment area have been carried out since 1984 (Heide-Jørgensen et al. 2008), the most recent in 2007. Based on the fluctuation of abundance estimates from eight different years, Heide-Jørgensen & Laidre (2008) concluded that a varying proportion of North Atlantic minke whales use the West Greenland banks as summer feeding grounds.

From a survey in 2007, the minke whale abundance for West Greenland was estimated to be 16,609 whales (95% CI 7,172-38,461; Heide-Jørgensen et al. 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 where minke whales also occur.

Conservation

The population occurring in the assessment area has a favourable conservation status. Both the global Red List (IUCN 2012) and the Greenland Red List categorise the minke whale as of 'Least Concern' (LC).

Critical and important areas

The whole assessment area is used by minke whales during summer. A variety of data, including catch statistics (Laidre et al. 2009) sighting surveys (Laidre et al. 2010) and diverse observations indicate that the fishing banks in the south of the assessment area (Store Hellefiskebanke), as well as the entire Disko Bay are important areas for minke whales during summer.

Blue whale (*Balaenoptera musculus*)

The blue whale is the largest animal in the world, with an average length of 25-26 m and average weight of 100-120 t, females being larger than males. Their main prey is krill.

Figure 27. Minke whale management stocks in the North Atlantic. In the assessment area only one stock occurs (West Greenland stock).

Blue whales produce distinctive calls with low frequency and high intensity and they can be detected over hundreds of kilometres (Širovic et al. 2007). They synchronise their call sequences and display very fine pitch discrimination and control over their calling frequency (McDonald et al. 2009). The physical characteristic of their synchronous calls might allow blue whales to use the Doppler shift to navigate and to acquire information about the direction to other calling whales (Hoffman et al. 2010).

Distribution
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. Blue whales have been observed in the assessment area (Figure 25), but exact numbers are not known yet. 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 acoustic data indicates that blue whales frequently use the Davis Strait area, including the area immediately south of the assessment area (Simon 2010).

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

Conservation status

The population occurring in the Disko West assessment area has an unfavourable conservation status, because it was heavily exploited by commercial whaling in several areas of the North Atlantic during the first half of the 20th century. The population shows signs of recovery since global protection was applied in 1966, but population size remains at a very low level (IUCN 2012). There are roughly approximately 1,500 blue whales in the North Atlantic waters. Blue whales are categorised as 'Data Deficient' in the Greenland Red List. In the global Red List, blue whales are classified as 'Endangered' (EN) (IUCN 2012).

Critical and important areas

Due to their mainly offshore habits and low numbers, important areas for blue whales in West Greenland have not been identified yet.

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 t.

Fin whales favour prey items such as krill and small schooling fish, e.g. 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 sound recordings (Simon et al. 2007a) indicate that at least some individuals remain at high latitudes year round. Recently, passive acoustic monitoring in the Davis Strait indicated that fin whales may mate during winter in West Greenland, and that fin whales remain in the Davis Strait until they are apparently excluded from the area by the advance of the sea-ice (Simon et al. 2010).

Fin whales produce distinctive low frequency calls that can be detected over tens of kilometres (Širović et al. 2007).

Distribution

Fin whales are found worldwide from temperate to polar waters, but are less common in the tropics. Fin whales occur during summer in the Disko West assessment area (Figure 25).

Due to their economic importance, there have been considerable efforts to estimate the number and the abundance trends of large whales, including fin whales in West Greenland. 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). 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.

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

Conservation

Fin whales have an unfavourable conservation status on a global scale, and are categorised as 'Endangered' (EN) in the global Red List (IUCN 2012). 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, the population therefore has a favourable conservation status and the species is listed as of 'Least Concern' (LC) on the Greenland Red List.

Critical and important areas

Fin whale use Disko Bay extensively and are often seen close to shore in Qeqertarsuaq. The fishing banks to the south of Disko Bay e.g. Store Hellefiskebanke, are also an important area for fin whales during summer.

Humpback Whale (*Megaptera novaeangliae*)

Humpback whales are on average 12-14 m long and weigh 25-30 t. They feed on a variety of small schooling fish and krill. Besides their ecological importance, humpback whales in West Greenland are an economic resource because they are a target for both whale watching and whaling.

Humpback whales produce distinctive broadband calls and songs with fundamental frequencies ranging from 30 to 4000 Hz (Payne & Payne 1985b, Cerchio et al. 2001).

Distribution and abundance

Humpback whales are widely distributed and occur seasonally in all oceans from the Arctic to the Antarctic. They 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).

Several photographically identified humpback whales migrate between summer feeding grounds off West Greenland and winter breeding grounds off the Dominican Republic.

Part of the West Greenlandic humpback whale population uses the Disko West assessment area (Figure 25). A series of eight line-transect surveys carried out between 1984 and 2007 was used to estimate a rate of population increase of 9.4% per year (Heide-Jørgensen et al. 2012a). This high rate of increase is consistent with reports from other humpback whale feeding grounds in the North Atlantic. The abundance estimate of the West Greenlandic humpback whale was 3,272 (95% CI 1,300-8,233) in 2007. However, the actual abundance may be larger, since the survey did not cover important humpback whale habitats in the far north or offshore areas with depths exceeding 200 m.

It is likely that the range of humpback whales in West Greenland will expand as the population continues to increase. In recent years humpback whales are found more widely distributed in West Greenland and records of observations north of the assessment area are now frequent.

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 28): Gulf of Maine, eastern Canada, West Greenland and the eastern North Atlantic (Stevick et al. 2006).

Figure 28. Feeding aggregations of humpback whales in the North Atlantic: Gulf of Maine, Eastern Canada, West Greenland and Eastern North Atlantic. There are also humpback whales in East Greenland (i.e. off Tasiilaq), but their relation to the other feeding aggregations is not known.

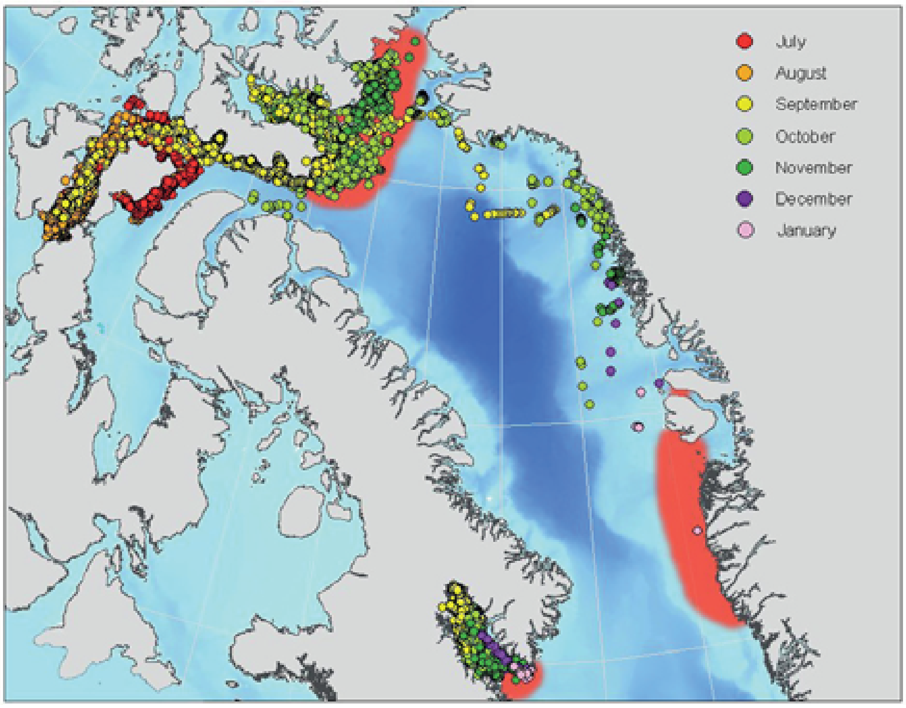
Satellite telemetry suggests that humpback whales use much of the West Greenland waters as feeding grounds by remaining relatively stationary for a period of days and then moving up to hundreds of kilometres to a different location, where they remain stationary again (Heide-Jørgensen & Laidre 2007).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

The main prey items of humpback whales in West Greenland are probably capelin, which is abundant in coastal and fjord waters; sandeels, abundant in offshore banks such as Store Hellefiskebanke 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.

Vocalization

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

Figure 29. Positions of satellite-tracked white whales distributed according to month. Red areas indicated the winter grounds. Only two whales have been tracked in Greenland waters (GINR unpublished).



Conservation

The population occurring in the assessment area has a favourable conservation status as it is abundant and increasing. During the 1900´s, whaling 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) in the global Red List (IUCN 2012). Their classification in the Greenland Red List is also 'Least Concern' (LC).

Critical and important areas

Humpback whales use the entire assessment area and are abundant both offshore and inshore. Sightings from all towns and settlements are common, with reports often coming from Qeqertarsuaq, Ilulissat and Aasiaat. As for fin and minke whales, the fishing banks (especially Store Hellefiskebanke) are important areas for humpback whales during summer.

Sei whale (*Balaenoptera borealis*)

Sei whales are on average 14 m long and weigh 20–25 t. In the North Atlantic, sei whales seem to subsist on a limited variety of food, feeding almost exclusively on calanoid copepods and euphasiids (krill), although small schooling fish and squid form an important part of their diet in other areas (Prieto et al. 2011 and references therein). A study from the 1970s showed that sei whales in Greenland feed almost exclusively on krill (Kapel 1979).

Sei whales produce a variety of vocalisations, using frequencies that vary from about 40–600 Hz (Rankin & Barlow 2007).

Distribution and abundance

The species is believed to make seasonal migrations between low-latitude wintering grounds and high-latitude feeding grounds. However, the distribution of sei whales is poorly understood. On feeding grounds, they are associated with oceanic frontal systems (Prieto et al. 2011 and references therein). The occurrence of sei whales in West Greenland may be linked to years with increased influx of relatively warm Atlantic water (Kapel 1985). Sei whale sound signals were recorded in the Davis Strait in August-September, 2006-07 (Simon 2010). The abundance of sei whales in West Greenland was estimated from a ship survey in 2005 to 1,599 individuals (95 % CI = 690-3,705). The overall distribution of these rorquals is correlated with high densities of krill occurring deeper than 150 m (Laidre et al. 2010).

Conservation

Sei whale numbers were severely reduced during whaling in the early twentieth century. Although protected, the sei whales have an unfavourable conservation status and are considered as 'Endangered' (EN) on the IUCN global red list (2012). Poor knowledge on this species' distribution and abundance in West Greenland places the sei whale as 'Data deficient' (DD) on the Greenland Red List (Boertmann 2008).

Critical and important areas

No critical areas for sei whales in the assessment area have been identified so far.

4.8.5 Toothed whales

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

Eight species of toothed whales occur in the Disko West assessment area, and of these two are specialised inhabitants of the Arctic, the narwhal and the white whale, that occur in the assessment area during winter.

Six other species of toothed whales that are common in the northern North Atlantic are also regularly present in the assessment area; killer whale, sperm whale, pilot whale, white-beaked dolphin and bottlenose whale. In addition harbour porpoise (*Phocaena phocaena*) occur, but mainly in the southern part of the assessment area. These species are also found in boreal waters and sperm whale and killer whales occur in all oceans. All of them avoid densely ice-covered waters, so their occurrence in the assessment area is restricted to the ice-free months. With the expected reduction of sea-ice cover due to climate change, the period of their occurrence in the assessment area may however be extended.

Toothed whales produce clicks for echolocation[1] 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 also 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 24 shows the frequency ranges of echolocation clicks, calls and whistles produced by toothed whales in the assessment area.

Long-finned pilot whale (*Globicephala melas*)

The long-finned pilot whale occurs in temperate and sub-polar zones and, according to most literature ranges from Disko Bay and Ungava Bay in the North West, from 68° N in eastern Greenland across Iceland and the Faroe Islands to mid-Norway, and south to North Carolina, the Azores, Madeira and Mauritania (e.g. Jefferson et al. 2008). Greenlandic catch statistics (APNN, unpublished data) show, however, that pilot whales occasionally occur as far north as Uummannaq and Upernavik in the in late summer or early autumn.

---

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

Long-finned pilot whales are social and generally found in groups of 20-100 individuals, and 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).

Their diet consists primarily of squid, but also small to medium-sized fishes are taken, such as Atlantic cod and herring (although not in Greenland waters).

<u>Population</u>
Pilot whales occurring in Greenland and in the assessment area probably represent vagrants from a large North Atlantic population. The 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 2010). The surveys covered only part of the range of pilot whales in West Greenland and it must be considered a minimum estimate. During seismic surveys and other research cruises performed between 1988 and 2010, pilot whales were sighted in the Disko West assessment area (Figure 25).

<u>Conservation</u>
Long-finned pilot whale is listed as of 'Least Concern' according to both the global Red List (IUCN 2012) and the Greenland Red List.

<u>Critical and important areas</u>
The preferred habitat of pilot whales is in deep water offshore areas (Hansen 2010). Numerous observations have been documented from the south-western part of the assessment area (Hansen 2010), but no important areas have been identified.

White-beaked dolphin (*Lagenorhynchus albirostris*)
White-beaked dolphins inhabit the North Atlantic Ocean in the cold temperate zone and the southern part of the Arctic. According to several published sources, Disko Bay is the northern limit of their distribution in West Greenland (e.g. Reeves et al. 1999, Kinze 2002). However, unpublished and unverified catch statistics indicate that white-beaked dolphins occur as far north as Upernavik, north of the assessment area.

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

The species has been very little studied and thus not much is known about its biology and ecology. The diet of white-beaked dolphins in West Greenland is unknown. In other areas, they feed mainly on a variety of small schooling fishes such as herring, capelin, sandeel and Atlantic cod, but they may also eat squid and crustaceans (Jefferson et al. 2008).

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

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 2010). The surveys only covered part of the range of white-beaked dolphins in West Greenland and it must be considered a minimum estimate.

<u>Conservation</u>
The global status of the white-beaked dolphin is 'Least concern' (IUCN 2012). On the Greenland Red List, the white-beaked dolphin is listed as 'not applicable (NA)'.

Critical and important areas

The preferred habitat of white beaked dolphins in western Greenland consists of deep water over steep slope areas in South Greenland areas (Hansen 2010). However, most of the recorded observations are from relatively shallow waters off the continental shelf in the southern part of Disko Bay and southwards (Hansen 2010).

Killer whale (*Orcinus orca*)

Killer whales are top predators that occur in all oceans, but tend to concentrate in colder regions with high productivity. They feed on prey that varies in size from herring to adult blue whales. Different killer whale populations tend to specialise and feed on locally abundant prey species. Across populations the movements and behaviour of the prey influences killer whale behaviour, movements and social organisation. As a result of these specialisations, there are different ecotypes of killer whales. Examples of such ecotypes include killer whales that feed seasonally on sea lion and elephant seal pups in Patagonia (Lopez & Lopez 1985), herring in Norway and Iceland (Simon et al. 2007b), sharks in New Zealand (Visser 2005) and tuna fish in the Gibraltar Strait (Guinet et al. 2007). In some cases, up to three different ecotypes are known to overlap in one area, such as in the northeastern Pacific where the ecotypes called 'residents', 'transients' and 'offshores' feed on salmon, marine mammals and sharks, respectively (Baird & Dill 1995, Herman et al. 2005, Ford & Ellis 2006). 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 (Bigg et al. 1990, Similä & Ugarte 1997, Visser 2005, Ford & Ellis 2003). Based on genetic analyses performed on 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. 2007b). 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.

Conservation

Killer whales are listed as 'Data Deficient' (DD) on the global IUCN Red List (IUCN 2012) and as (NA) 'not applicable' on the Greenland Red List (Boertmann 2008).

Critical and important areas

Due to the unpredictable presence of killer whales in Greenland, important areas for this species have not been identified.

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 main prey is polar cod and other fish but also squid and shrimps (Heide-Jørgensen & Teilmann 1994). White whales usually travel in groups of two to ten whales, although larger pods often occur.

Distribution

White whales can be found along the whole northwest coast of Greenland during migration between winter and summer grounds (Figure 30). One of their wintering grounds is located in the Disko West assessment area (Figure 30). In recent years they seem to winter and migrate further out from the coast than previously, probably due to the reduced amounts of sea-ice (Heide-Jørgensen et al. 2009).

The summer grounds of white whales are in the Canadian Arctic archipelago, where they often occur in estuaries.

Movements

Their migration has been documented by two white whales equipped with satellite transmitters in Canada and tracked to the winter quarters south of Disko Bay (Heide-Jørgensen et al. 2003b) (Figure 29). Generally knowledge on the migrations of white whales in West Greenland is limited compared to that on narwhal migrations.

White whales are expected to acquire the major part of their annual food intake in their winter quarters in West Greenland and in the North Water.

Abundance

Aerial surveys flown in West Greenland between 1981 and 1994 document that the numbers of white whale decreased by 62% during that period, because of overharvesting (Heide-Jørgensen & Reeves 1996).

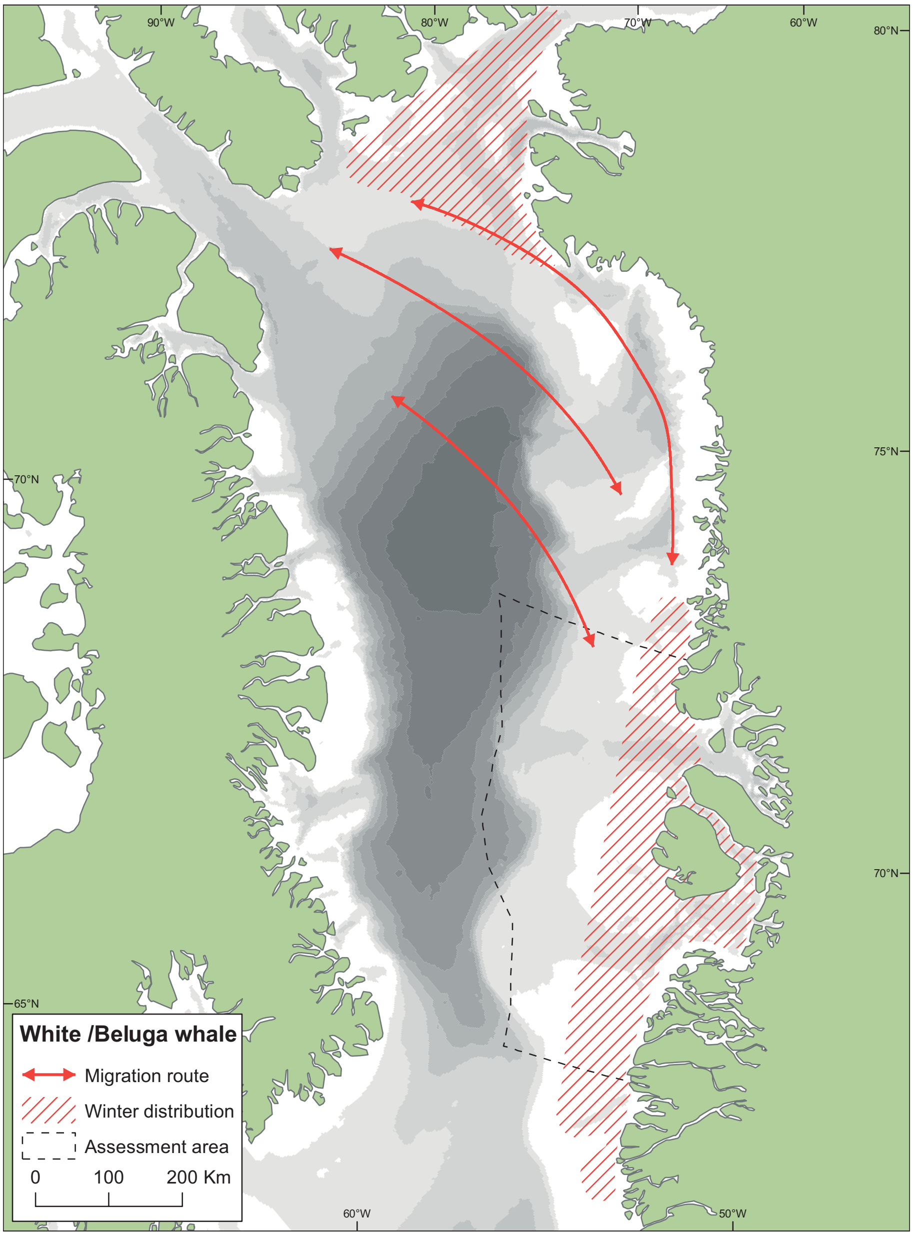
Further surveys in 1998 and 1999 confirmed the decline and in average 7,941 (95% CI: 3650-17,278) white whales were found in West Greenland, including whales missed by the observers and whales that were submerged during the survey (Heide-Jørgensen & Acquarone 2002).

In 2006, the total abundance of white whales in West Greenland was estimated to be 10,595 (95% CI 4,904-24,650) individuals, again corrected for missed and submerged animals. The greatest abundance of white whales in 2006 was found in the areas south of Disko Bay at the northern portion of Store Hellefiskebanke, a pattern similar to that found in previous surveys conducted since 1981. The whales were mainly observed at the eastern edge of the pack ice that covers Baffin Bay and Davis Strait. The survey from 2006 suggested that the population is increasing after a period with significantly reduced catches (Heide-Jørgensen et al. 2010c).

Conservation status

The population occurring in the assessment area is listed as 'Critical Endangered' (CR) on the Greenland Red List. The population is recovering from hunting and subject to restricted hunting that will allow further recovery (Ugarte & Heide-Jørgensen 2008, Heide-Jørgensen et al. 2010c). In Canada it is listed as 'Threatened/Special Concern' depending on the stocks. In the Global Red List, the white whale was moved from 'Vulnerable' (VU) to 'Near Threatened' (NT) in 2008 (IUCN 2012), although with the notification that the white whale is 'unquestionably a conservation dependent species'.

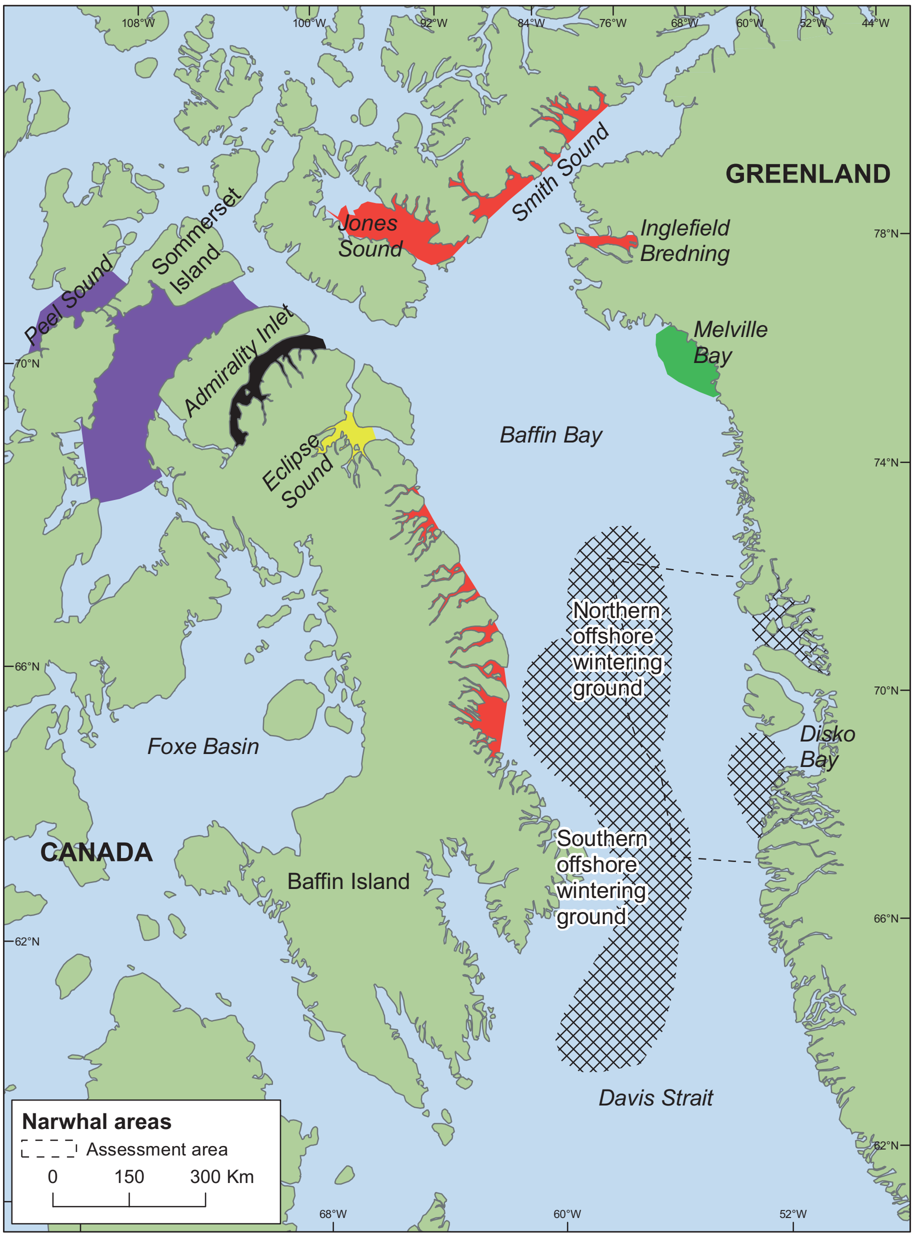
Figure 30. Map showing the known wintering grounds and migration routes of white whales in West Greenland and the Disko West assessment area.



Narwhal (*Monodon monoceros*)

Narwhals have high site fidelity to migration routes and summering and wintering grounds, and generally use the same areas year after year (Heide-Jørgensen et al. 2003a). In the summer months, narwhals stay in inshore bays and fjords in the Canadian Arctic archipelago and Greenland (Figure 31). In 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. 2008a). During winter months, narwhals are widely dispersed in Baffin Bay and Davis Strait with high concentrations between 55°-64°W and 68°-71° N and off Disko Bay (Heide-Jørgensen et al. 1993, Koski & Davis 1994, Dietz et al. 2001, Heide-Jørgensen & Acquarone 2002, Dietz et al. 2008a, Laidre & Heide-Jørgensen 2011). During spring, concentrations of narwhals are seen along ice edges on the east coast of Baffin Island, at the entrances of Lancaster and Jones Sound, and in Smith Sound (e.g. Bradstreet 1982, Koski & Davis 1994). Narwhals are also known to move along the ice edges off West Greenland and to concentrate in the North Water Polynya in spring before entering Inglefield Bredning (Born et al. 1994b, Heide-Jørgensen 2004, GINR unpubl. data).

Figure 31. Summer population units of narwhals in West Greenland and the Eastern Canadian Arctic (red, green, purple, black and yellow) and main wintering grounds (hatched). Red areas inshore Canada and northwest Greenland indicate where important summer concentrations occur, but their relationship to other concentrations areas is not known. The hatched area in Disko Bay indicates an important winter concentration area, where the stock identities of the whales have not been established. Repulse Bay and Northern Hudson Bay are further narwhal grounds not marked on the map.



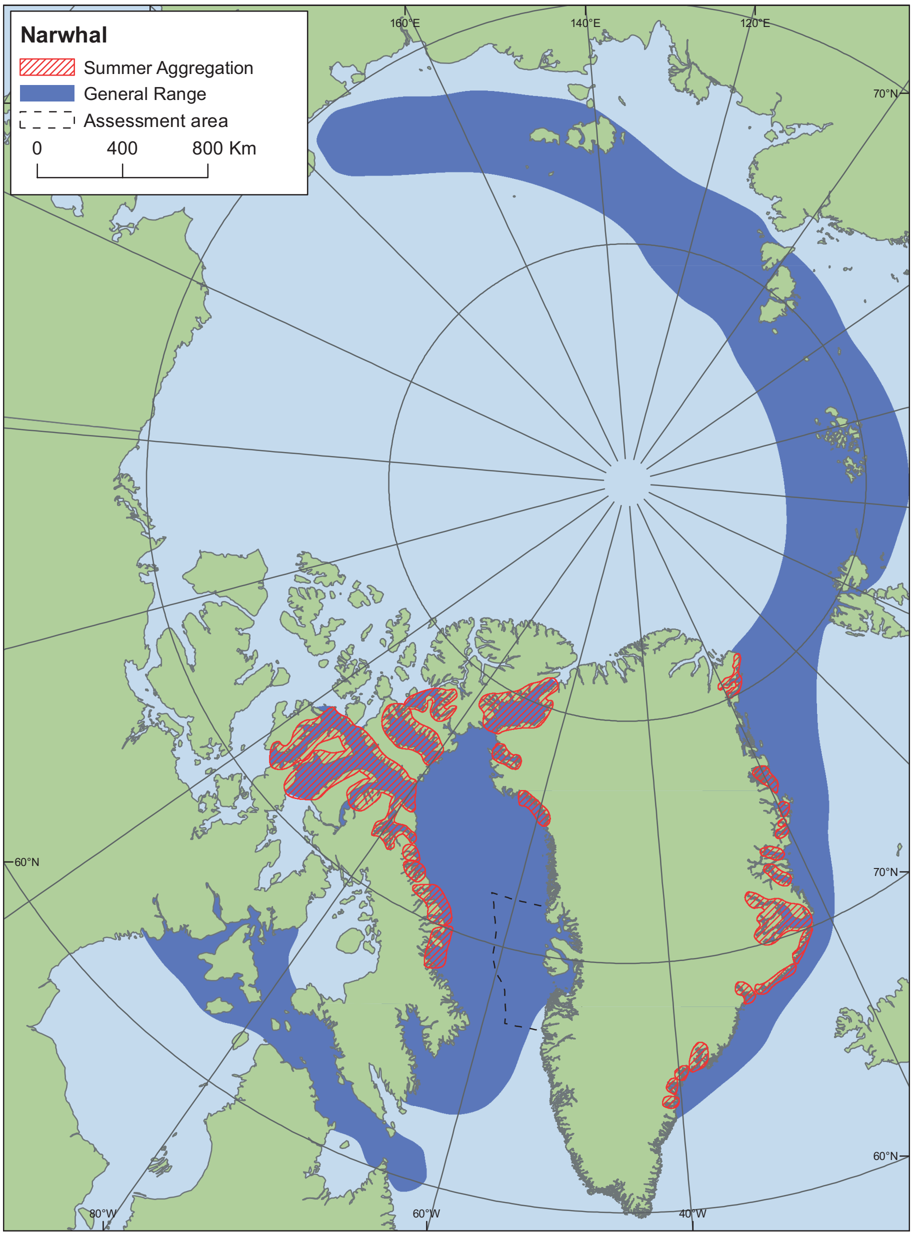
Distribution of narwhals

Figure 32 shows the global distribution range of narwhals. They are regularly seen along the coast of West Greenland south of Melville Bay and caught from October through May. They are primarily found north of about 66° N and the main areas of concentrations are Uummannaq in November-December, Disko Bay in December-March and in offshore areas from February through April (Figure 31). Aerial surveys conducted in 1981 and 1982 demonstrated the widespread offshore winter distribution of narwhals in the pack-ice in central Baffin Bay (Figure 33).

Stock identity

Narwhals stocks or management units of narwhals are traditionally identified based on the summer aggregations (Dietz & Heide-Jørgensen 1995, Dietz et al. 2001, Heide-Jørgensen et al. 2002, Heide-Jørgensen et al. 2003a, Dietz et al. 2008a). 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 31).

Figure 32. Overall distribution of narwhals with indication of important summer grounds. The assessment area is indicated with hatched lines.



Other Canadian summer aggregations exist along the east coast of Baffin Island and their stock identity is unknown (Figure 31). Jones Sound and Smith Sound also have smaller aggregations that likely constitute separate stocks.

In November an aggregation occur in Uummannaq, West Greenland. This is not a wintering ground because the whales are forced to leave the fjord in late December to winter offshore once the fast ice forms. These narwhals essentially winter in the eastern part of Baffin Bay in the same general area where whales from other stocks are found. Two whales tagged in Uummannaq in November 2007 departed at the same time and took a similar route north into the Baffin Bay area (Figure 34); a more detailed account is presented below.

The winter aggregation in Disko Bay has been visited by whales from both Melville Bay, Tremblay Sound and Admiralty Inlet (Figures 35 and 36, Richard et al. 2010), many of which pass through the Baffin Bay in autumn and again in spring. Apparently Disko Bay is a mixing ground for narwhals from several summering stocks.

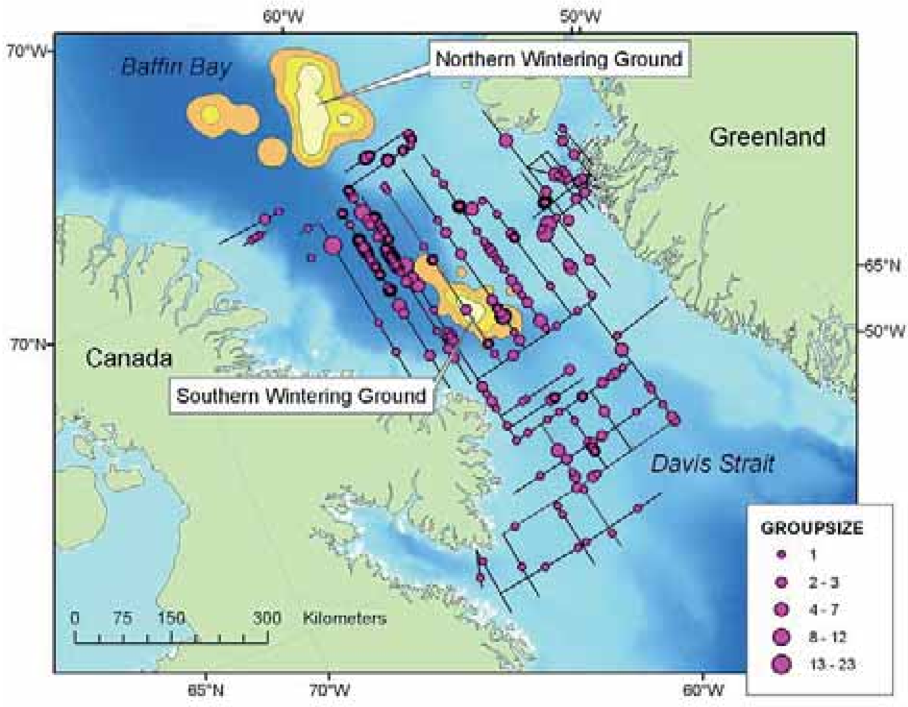


Figure 33. Offshore winter distribution of narwhals in March 1981 and 1982 in central Baffin Bay, based on aerial surveys.

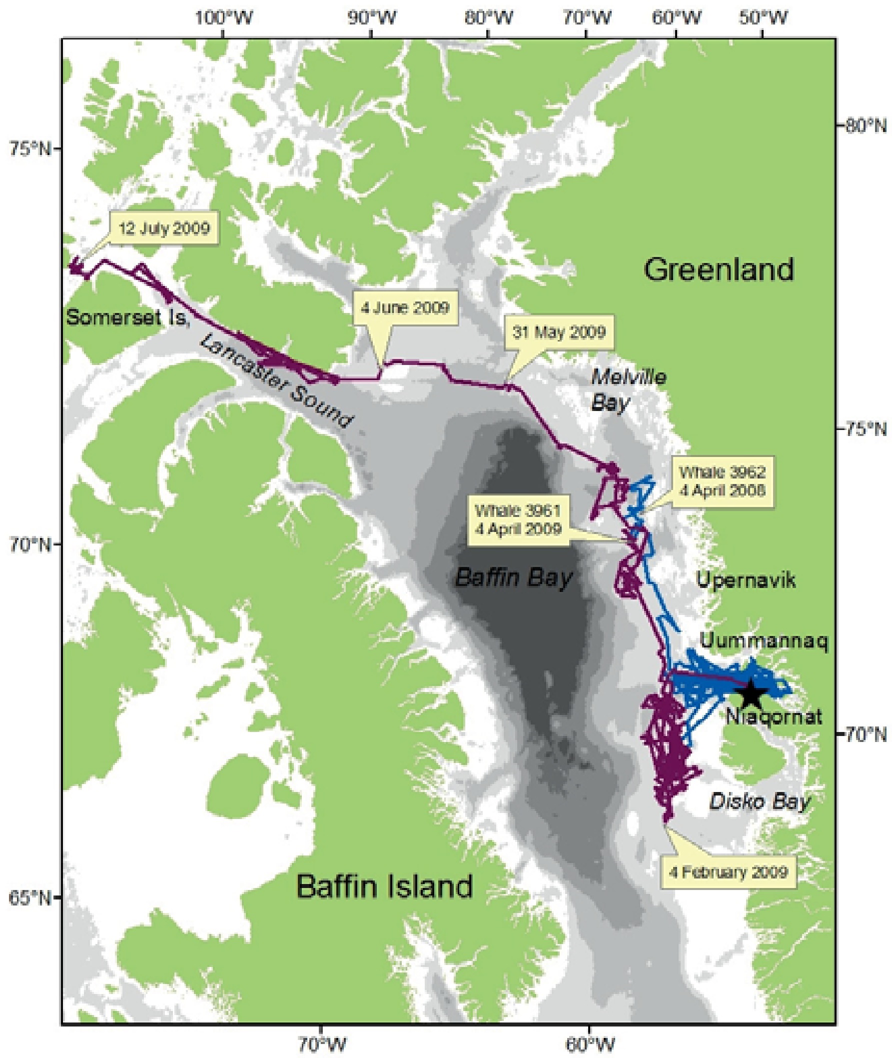


Figure 34. Tracks of two narwhals tagged in Uummannaq in 2007.

Current abundance in West Greenland

Abundance of narwhals off West Greenland was assessed from an aerial survey conducted in March and April 2006. The surveyed area included the region between Sisimiut and Upernavik and up to approximately 100 km offshore and the resulting abundance estimate was 7,819 (95% CI: 4,358-14,029) narwhals for the surveyed area (Heide-Jørgensen et al. 2010c). A new survey is scheduled for 2012.

Abundance of narwhals at the summering grounds in Inglefield Bredning and Melville Bay was estimated in 2007 and were 8,368 (95% CI 5,209-13,442) and 6,024 (95% CI 1,403-25,860) respectively.

Migrations

Narwhals leave their summering grounds at about the same time each year and they follow traditional 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 initiation of the spring migration.

Data on migrations are available from satellite tracking of 85 individual narwhals from five different coastal localities in Arctic Canada (n = 3) and West Greenland (n = 2). Published results from tagging before 2005 are summarized in Figure 37 whereas recent tracking results from 2005-2008 are presented in the Figures 34, 35 and 36).

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 central Davis Strait which were in the same general vicinity as the wintering grounds of narwhals from Melville Bay. This 'Southern Wintering Ground' is centered on 69° N and 60° W. In 2010 one male narwhal from Eclipse Sound entered the southern part of Disko Bay in December.
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' centered on 71°N and 62°W, a wintering area distinct from the wintering area used by whales from the Eclipse Sound and Melville Bay stocks and within the Baffin Bay assessment area. The Somerset Island whales remained stationary on the 'Northern Wintering Ground' through March when they started the return migration through Lancaster Sound along the southern shoreline of Devon to the Somerset Island summering ground (Heide-Jørgensen et al. 2003a, Dietz et al. 2008a).
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 north of Home Bay. The range of the wintering ground varied between 2004 and 2005. 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 37.) Some of the whales extended their southbound migration to the northern part of Davis Strait where they have also been located to winter in 2004 and 2005. One male from Admiralty Inlet moved to the coastal areas of West Greenland in January 2006 close to Disko Island and Uummannaq (Figure 35).

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 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 beginning of October with movements inside Melville Bay, they made a southbound migration route towards the wintering grounds. In 2006 the whales took a more coastal route after departing from Melville Bay (south of 74° N) on 18-25 October (Figure 35). Wintering took place in the same area used by the whales from Melville Bay tracked in 1993-1994 (cf. Dietz & Heide-Jørgensen 1995). After arriving at the offshore wintering ground in December, one of the whales (a male of 437 cm) left the offshore wintering ground and went to the southern part of Disko Bay. The whale left Disko Bay on 13 January and returned to the offshore wintering ground. In 2007, a more diverse movement pattern was observed, both in the summer period when the whales were more widespread in Melville Bay and in the fall where some whales remained close to Upernavik (Figures 34). In 2007, the whales departed from Melville Bay between 26 October and 16 December and spent considerable time in the Upernavik and Uummannaq area before wintering a bit further north than the traditional 'southern wintering ground' used in previous years (Dietz & Heide-Jørgensen 1995, Heide-Jørgensen & Dietz 1995). One whale was tracked for 13 months and it returned to Melville Bay the year after it was tagged.
5. **Uummannaq**. Two narwhals were tagged in Uummannaq 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 35). On 13 March 2008 it headed north (< 72° N) along the West Greenland coast however contact was lost on 4 April 2008. The female narwhal tagged in 2008 immediately left Uummannaq Fjord and spent December through mid-February 2009 off the banks of Disko Island. On 24 March it initiated a northward migration along West Greenland and into the assessment area. It halted the migration in the northern part of Baffin Bay in April and May and continued the migration in late May where it reached the eastern entrance of Lancaster Sound on 6 June where after it followed the northern coast of the sound close to the southern shore of Devon Island and reached Barrow Strait on 3rd July. The whale moved south into Peel Sound where contact was lost on 24 July.

<u>Diving and foraging ecology</u>

Feeding habits of narwhals have been studied in Disko Bay where fresh stomach samples from narwhals can be obtained from the Greenland subsistence harvest. Greenland halibut, the squid *Gonatus fabricii*, and *Pandalus* shrimp spp. are the dominant prey items. Greenland halibut is an important winter resource, observed in 64 % of stomachs collected in winter and the only prey species detected in almost half of all stomachs in the 49 samples (Laidre & Heide-Jørgensen 2005). Greenland halibut taken by narwhals were on average 36 cm (sd 9) and 430 g (sd 275) and *Gonatus* prey were on average 35.6 g (sd 31.1) with mean mantle lengths 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. The availability of this important prey is the most likely explanation for the occurrence of narwhals in these ice covered offshore areas (Laidre et al. 2003). Other species like polar cod and squids may also contribute to the offshore diet as they seasonally do

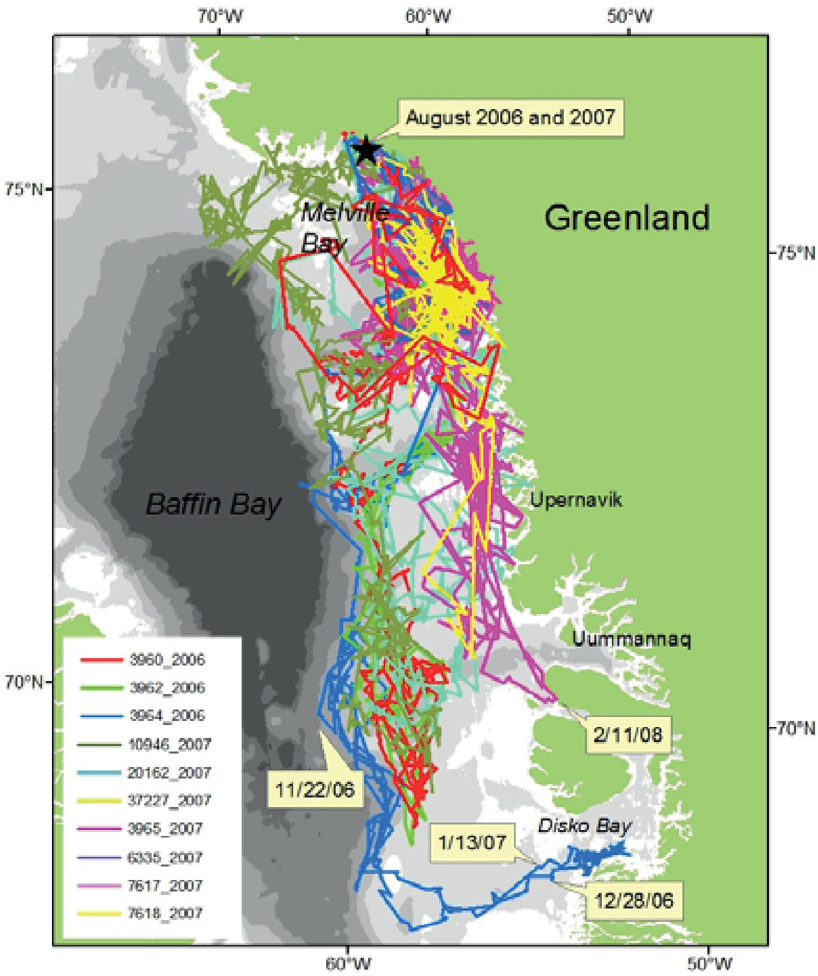


Figure 35. Tracks of 10 narwhals tagged in Melville Bay in 2006 and 2007.

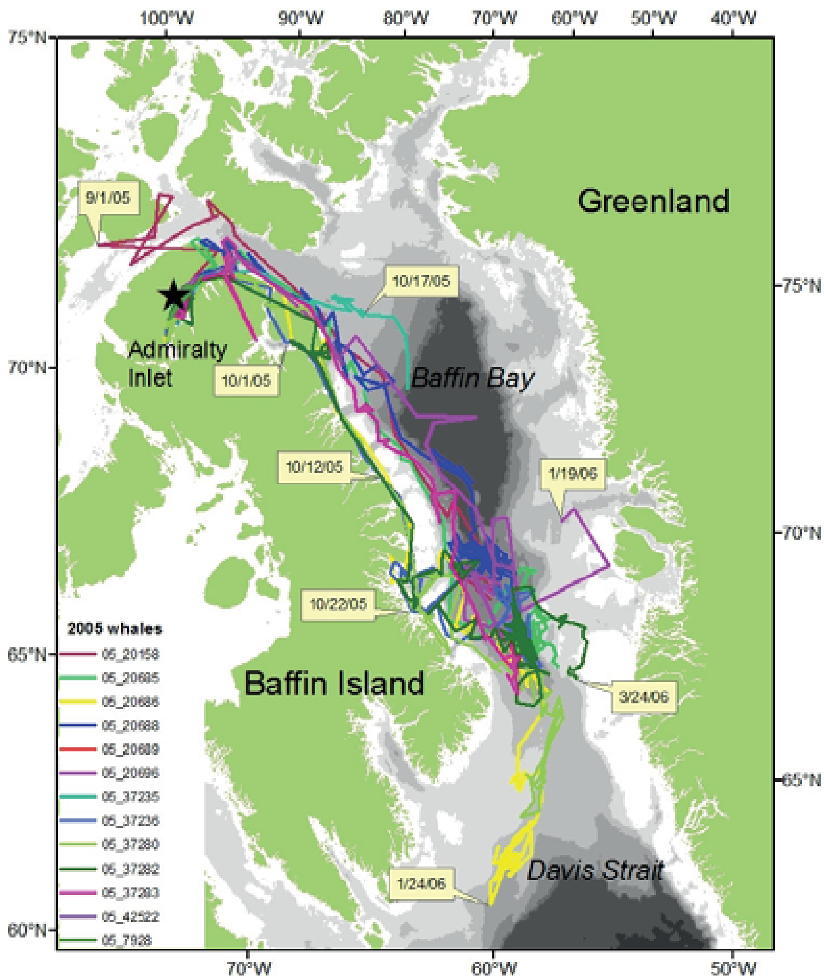
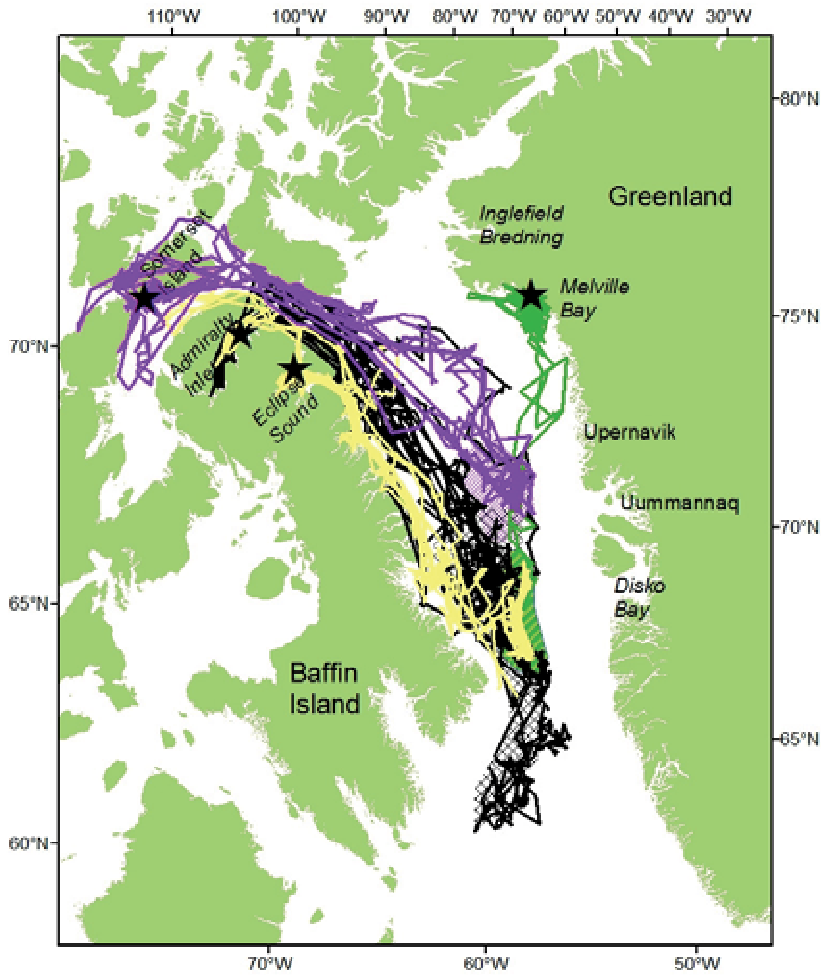


Figure 36. Tracks of 13 narwhals tagged in Admiralty Inlet in 2005.

Figure 37. Tracks of narwhals from Canada and Greenland tagged before 2005 (n = 60). Asterisks indicate tagging sites. Each whale is indicated by a colour.



in inshore waters in both Canada and West Greenland (Laidre & Heide-Jørgensen 2005). Compared to the summer feeding habits it is obvious that the major food intake takes place during the > 6 months stay on the fall and winter feeding grounds.

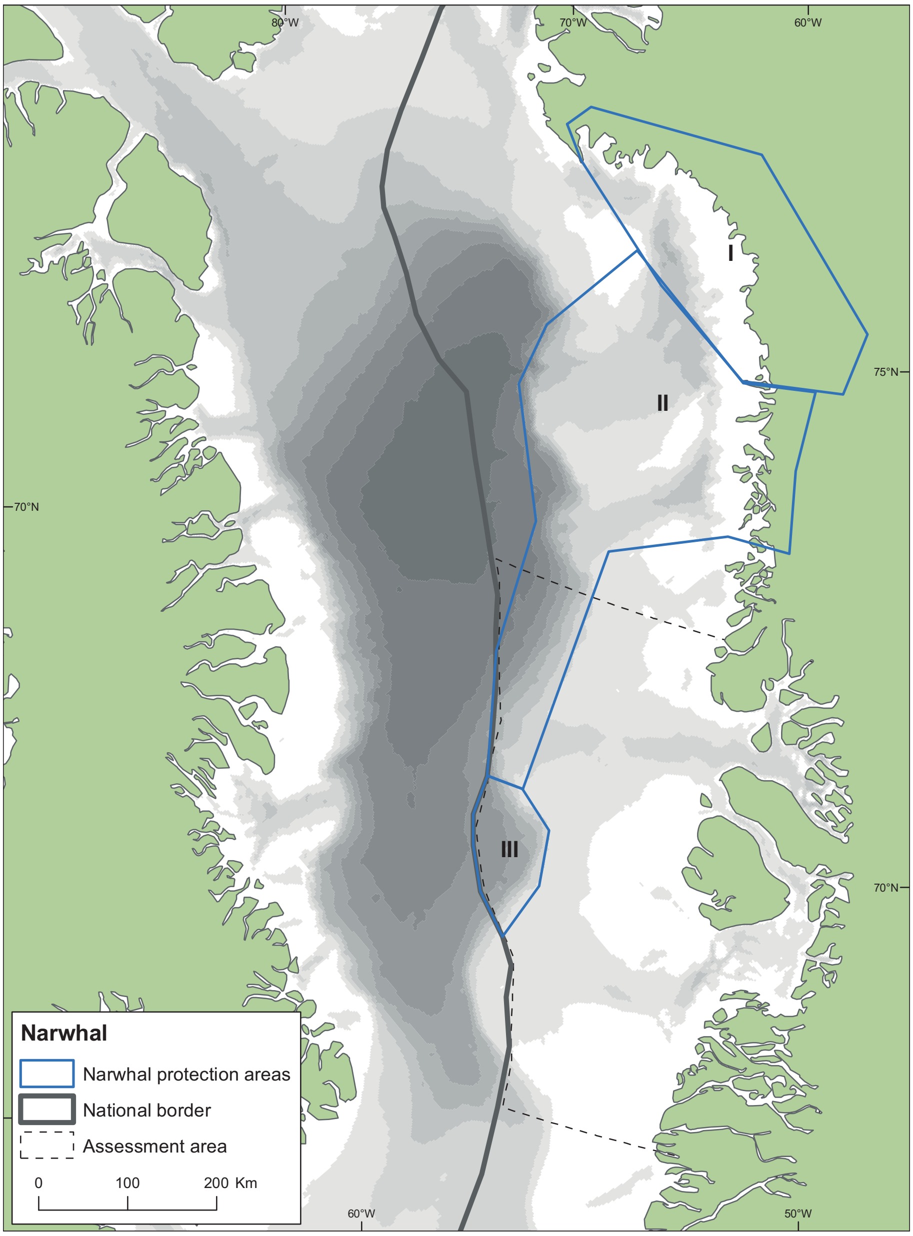
<u>Importance of the assessment area to the narwhals</u>

The assessment area is of critical importance to the different narwhal stocks wintering there. As described above, narwhals occur within the assessment area November through May. From late fall and through the winter especially whales from the Melville Bay summer aggregation and the Uummannaq November aggregation (Somerset Island) are present. Narwhals from the Admiralty Inlet and Tremblay Sound stocks are also present in winter and especially Disko Bay seems to attract whales from several stocks.

The whales depend on the assessment area for winter feeding and this is the most important period and area for the annual food consumption. The assessment area is therefore critically important to narwhals in Baffin Bay. This is also where the world's largest abundance of narwhals is found and any exploitation and exploration for resources in this area could potentially impact a major proportion of the global population of narwhals.

The so far known most important wintering areas within the assessment area are the southern and the northern offshore wintering grounds, outer Uummannaq Fjord (November) and the outer Disko Bay (Figure 31).

Figure 38. Narwhal protection areas in relation to seismic operations in West Greenland, including the Disko West assessment area. Area I is the summer habitat where seismic activities should be avoided or limited in the period 15 July to 25 October. Area II is the migration corridor, where seismic operations should be minimized (15 October to 1 December). Area III is the winter habitat where seismic operations should be avoided and usually are impossible to conduct due to ice. These area are subject to revision in winter 2013/14.



Conservation concern

The population in West Greenland is red-listed as 'Critically Endangered' (CR), while the global population is listed as 'Near Threatened' (NT). In light of the most recent survey results from Melville Bay and Baffin Bay the status in the Greenland Red List should be revised.

I relation to seismic activities some protection areas for narwhals have been designated (Kyhn et al. 2012). These are shown in Figure 38.

Sperm whale (*Physeter macrocephalus*)

With males reaching lengths of 18 m and weights of 50 t, the sperm whale is the largest toothed whale. On average, male sperm whales are 15 m long and weigh 45 t, while females are 11 m long and weigh 20 t. As in the case of bottlenose whales, sperm whales are found in deep waters, often seaward of the continental shelf and near submarine canyons. Sperm whales are found in all oceans, from the ice edges to the equator. Females and calves remain in tropical and sub-tropical waters year round, while males segregate to high latitudes at the onset of puberty, aged between 4 and 15 years (Best 1979, Mendes et al.

2007). The larger males, in their late twenties or older migrate occasionally to lower latitudes in search of mating opportunities. When in lower latitudes, males move between different groups of females and their offspring (Whitehead & Weilgart 2000).

The echolocation clicks of sperm whales have a source energy flux density of up to 193 dB re 1 μPa^{2s}. 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.

Sperm whales forage on a wide variety of deep-sea cephalopods and fish. Prey size ranges from a few centimetres long fish to 3-metre long sharks and even giant squids of the family Architeutidae that weigh up to 400 kg (reviews in Rice 1989, Whitehead 2003). In the north-eastern Atlantic sperm whales feed heavily on the deep-water squid *Gonatus fabricii* (Santos et al. 1999), favouring mature squid with mantle length of approx. 19-26 cm (Simon et al. 2003). Male sperm whales off northern Norway tagged with multi-sensor instruments feed both at shallow depths of approx. 117 m and at the sea bottom at depths down to 1860 m, showing that male sperm whales have flexible feeding habits (Teloni et al. 2008). In some areas, sperm whales take fish from long-line fisheries (e.g. Roche & Guinet 2007) or approach trawlers in search of discarded fish (e.g. Karpouzli & Leaper 2003).

Stomach samples from sperm whales caught between Iceland and Greenland were dominated by fish, squid being a secondary food item (Roe 1969, Martin & Clarke 1986). The most important fish species in the diet was lumpfish, 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 note 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).

Sperm whales were sighted in the Disko West assessment area between 1988 and 2000 by MMSO on seismic ships (Figure 25) and in the winter of 2010 six sperm whales were found dead amongst the ice near Sisimiut, just south of the Disko west assessment area (GINR unpubl. data). 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 over two centuries. By the second half of the 20th century, sperm whales were still numerous, but several populations were depleted. Commercial whaling of sperm whales stopped with the moratorium on whaling at the end of the 1980s. Presently, sperm whales are not caught anywhere in the North Atlantic. In the Greenland Red List, sperm whale is listed as 'Not Applicable' (NA) and globally as 'Vulnerable' (VU) (IUCN 2012).

Northern bottlenose whale (*Hyperoodon ampullatus*)
Next to the sperm whale, the northern bottlenose whale is the largest toothed whale in the North Atlantic, with adult females measuring up to 9 m in length and males up to 11 m. They are found in deep waters, often seaward of the continental shelf and near submarine canyons, from the ice edges south to approximately

30° N. They have a fission-fusion social system (i.e. live in groups that join and split), with group sizes from about 4 to 20 animals. Groups may be segregated by age and sex and males may form long-term companionships with other males (Wimmer & Whitehead 2004).

The main prey of the bottlenose whale is squid (*Gonatus* spp.), but prey items also include fish, such as herring or redfish, and invertebrates, such as sea cucumbers, starfish and prawns (Hooker et al. 2002). The 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 such small, isolated and stationary populations.

Distribution

In the North East Atlantic, bottlenose whales were caught by Norwegian whalers as far north as the ice edge west of Svalbard (Benjaminsen & Christensen 1979). In the Davis Strait and southern Baffin Bay bottlenose whales are frequently observed from fishing boats and oil exploration ships operating in deep waters. In the assessment area they have been sighted mainly in the deeper offshore areas (Figure 25).

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 2012, Boertmann 2008).

Critical and important habitats

As bottlenose whales are poorly studied in Greenland it is not possible to point out critical and important habitats for this species within the Disko West assessment area. However, the shelf breaks at the western and south-western parts of the assessment area are probably important habitats for this species.

4.9 Summary of Valued Ecosystem Components (VECs)

In environmental impact assessments, the concept of Valued Ecosystem Components (VEC) is often used to identify important ecosystem components. This is useful because it is often impossible to evaluate all ecological components individually. VECs can be species, populations, biological events or other environmental features. VECs can have a national or international profile, can act as indicators for environmental change, or a focus of management or other administrative efforts. VECs can also be important flora and fauna groups, habitats and processes such as the spring bloom resulting from primary production.

Based on the knowledge available, summarised in the preceding chapters, and the evaluation of the ecological, economic and cultural importance of organisms and habitats, the following VECs have been identified for the Disko West assessment area. See Chapter 9 for a more detailed description of the VEC concept and how it has been applied here.

Pelagic hotspots
Pelagic hotspots are recurrent/predictable areas in the marine environment characterised by intensive biological production or by dense aggregations of organisms – e.g. seabirds and/or marine mammals.

The shelf bank areas (e.g. Store Hellefiskebanke) and the shelf breaks (continental slopes) are assumed to have increased primary productivity in spring due to nutrient-rich upwelling events from wind and tidal motions in the Baffin Bay/Davis Strait.

The enhanced primary production supports zooplankton species such as copepods, which again are utilized by fish larvae. In general, the slopes of the shelf and shelf banks are believed to be important for fish larvae development due to high biomass of their copepod prey.

The key copepod species *Calanus hyperboreus*, *C. glacialis*, *C. finmarchicus* and or other zooplankton species such as *Themisto libellula* or *Metridia longa* are widely distributed but may be concentrated at the shelf areas. Their spring distribution is concentrated in the upper water column; while the study performed in autumn 2009 suggest a distribution in deeper water column (Box 1). Thus, zooplankton is presumed to be more vulnerable to an oil spill in spring where the main concentrations of zooplankton are near the water surface.

For Greenland halibut, some of the main nursery areas are assumed to be located in the assessment area and the eggs and larvae are known to drift in the water column.

For organisms on higher trophic levels, a particular shelf area has been documented to be an extremely important pelagic hotspot. This is the shallow part of the Store Hellefiskebanke, where both walruses and king eider assemble during winter (Box 5) and where the benthos surveys found a very high diversity of invertebrates (Box 3) and high densities of sandeels (Box 4).

The tidal/subtidal zone
The tidal and subtidal zone is an important habitat for macroalgae, many invertebrates, fish, marine mammals and seabirds. Among others, it provides critical spawning and nursery habitat for capelin and lumpsucker. Capelin is an ecological key species, important for larger fish species, whales, seals, seabirds and human use, while lumpsucker support a small-scale commercial fishery aimed at the roe. The benthic macrofauna, such as bivalves, play a key role for benthic feeders, such as common eider, king eider and long-tailed duck. In addition, the tidal/subtidal zone is very important for seabird hunting and tourism.

Ice flora and fauna
Due to lack of data and wide variability it is not possible to point out particularly important, recurrent areas for sympagic flora and fauna.

Demersal fish and benthos
The sea floor and the adjacent parts of the water column support the commercially important fisheries of Greenland halibut, northern shrimp and snow crab. The sandeel, distributed in high densities in sandy sediments at the shelf banks (e.g. Store Hellefiskebanke), is another key species, since it represents an important food item for many seabirds and whales.

Another ecological important fish species at least for the northern part of the assessment area is polar cod as also shown during the study in September 2009 (Box 1).

Benthic macrofauna, such as bivalves, play a central role for benthic feeders at the shelf banks, such as king eiders, bearded seal and walrus.

Breeding seabirds

Northern fulmar, great cormorant, common eider, black-legged kittiwake, Iceland gull, black guillemot, razorbill, thick-billed murre and Atlantic puffin are important breeding species in the assessment area. Most nests in colonies are on steep cliffs and/or on low islands. The most important colonies are found in the Disko Bay area, e.g. the Ritenbenk-site with thick-billed murres and kittiwakes, the archipelago Grønne Ejland with a high diversty of breeding species.

Non-breeding seabirds

This VEC comprise concentrations of moulting, postbreeding, migrating and wintering seabirds. Concentrations of moulting birds in the assessment area include especially the king eiders, which assemble in certain fjords (Figure 14). The post breeding seabirds include the thick-billed murres performing swiming migration (Box 6), but the tracking studies did not indicate particular concentration areas in the offshore waters. The most important seabirds in winter are the wintering king eiders on Store Hellefiskebanke (Box 5). Most species are associated with the coastal areas and partly the fjords and the shelf, but some species also utilize the more oceanic western part of the assessment area, such as little auk, kittiwake and ivory gull.

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

Marine mammals (summer)

During the open water period, the assessment area is an important foraging area for several marine mammal species such as harp seals, baleen whales, pilot whales, sperm whales and bottlenose whales. They are feeding on a variety of species including krill and fish, e.g. capelin and sandeels.

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

Marine mammals (winter)

Marine mammals associated with sea-ice in the assessment area include polar bears, narwhals, white whales, bowhead whales, walrus, bearded seal and ringed seals.

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

5 Natural resource use

5.1 Commercial fisheries

A. Burmeister, N. Hammeken, R. Hedeholm, R. Nygaard, H. Siegstad and A. Retzel

Commercial fisheries represent the most important export industry in Greenland, underlined by the fact that fishery products accounted for 88 % of the total Greenlandic export revenue (1.7 billion DKK) in 2009 (Statistics of Greenland 2010).

Very few species are exploited by the commercial fisheries in the assessment area and in Greenland as a whole. The four most important species on a national scale are northern shrimp (export revenue in 2009: 1,044 million DKK), Greenland halibut (398 million DKK), Atlantic cod (130 million) and snow crab (45 million DKK) (Statistics of Greenland 2010).

In the assessment area the following species are of importance in relation to commercial fisheries:

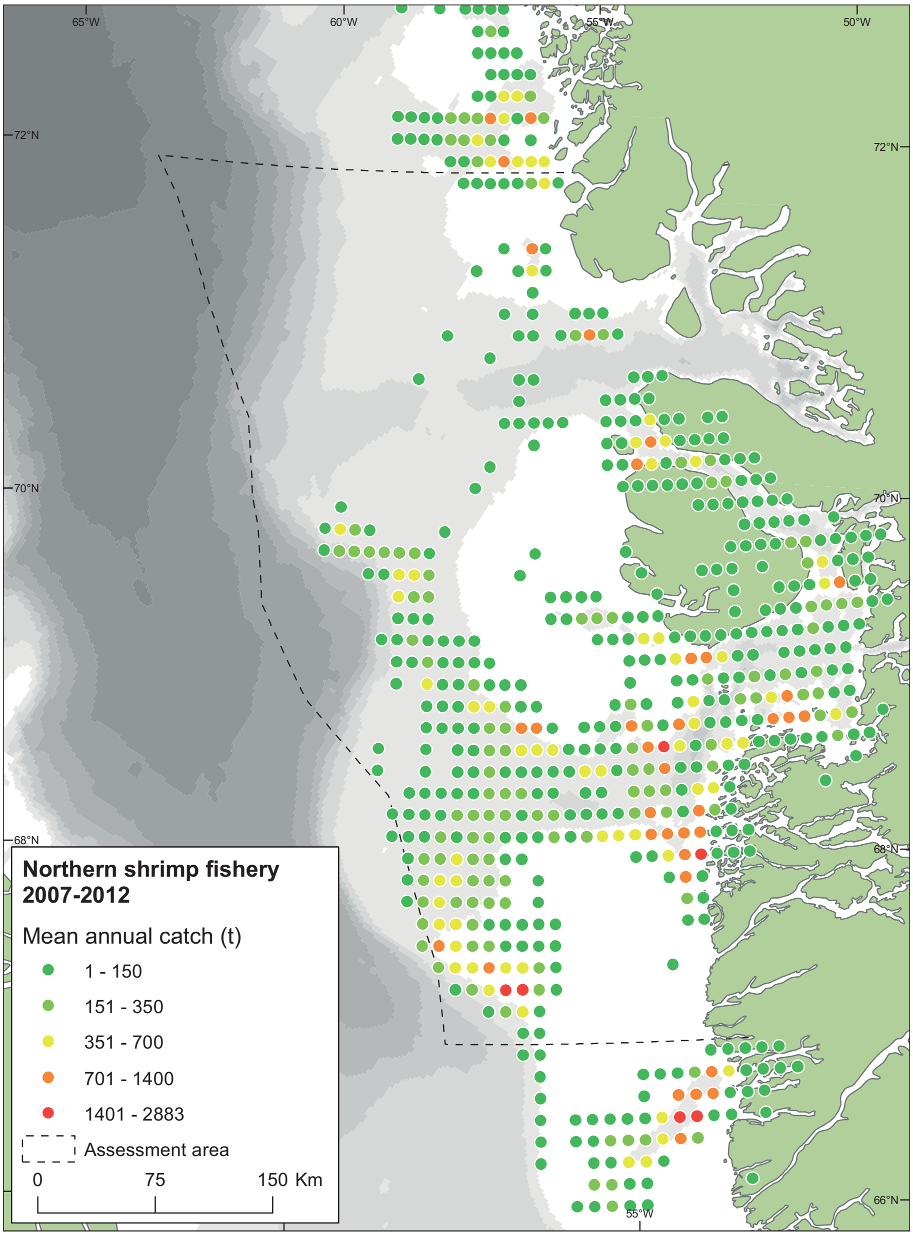
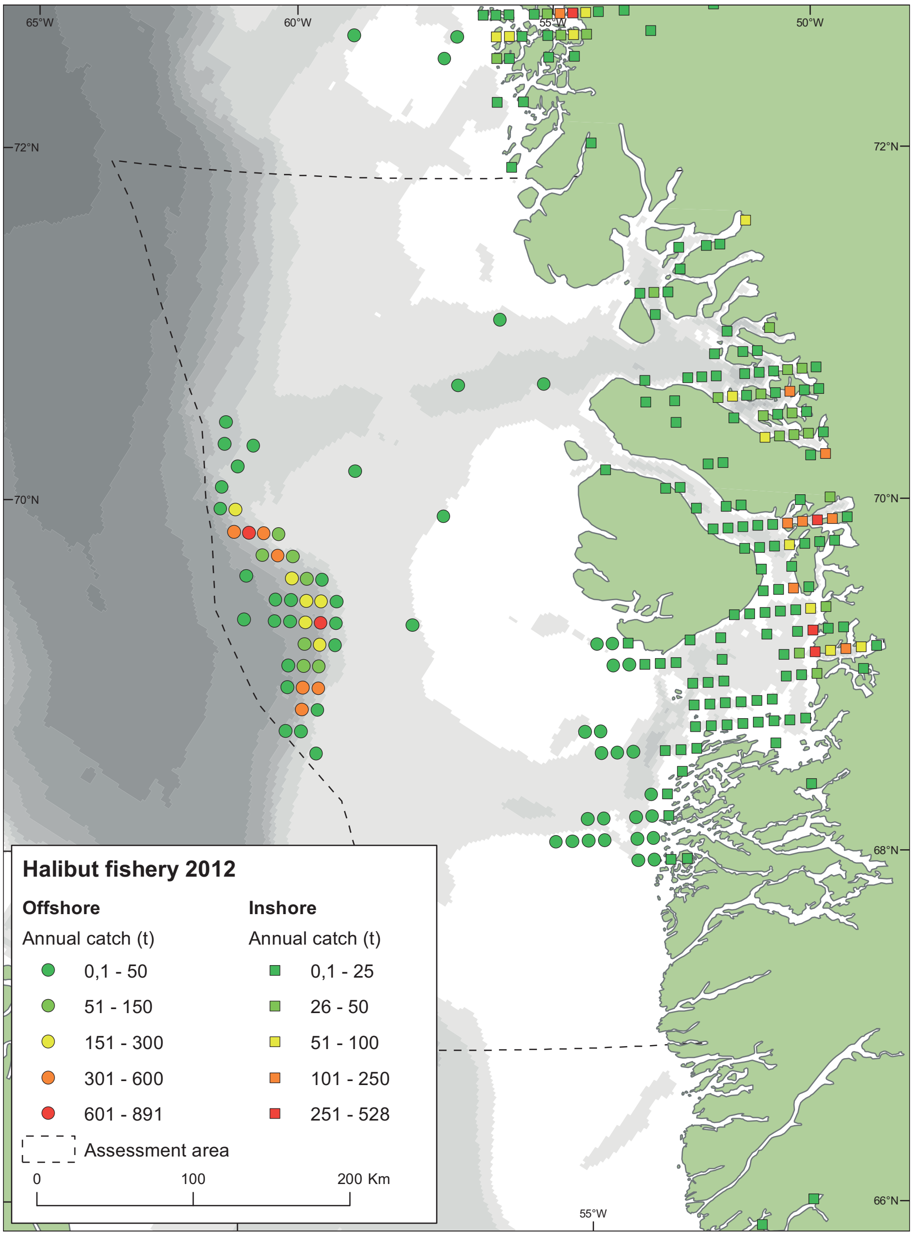


Figure 39. Distribution and amounts of the northern shrimp catches within and nearby the assessment area. Catch size shown as the mean annual catch over the period for 2007-2012 and distribution based on the NAFO-grid.

Figure 40. Distribution of the Greenland halibut landings in the assessment area for inshore (2012) and offshore (2012) fisheries. Distribution based on the NAFO-grid.



Northern shrimp (*Pandalus borealis*)

In West Greenland waters the northern shrimp fishery extends from 59° 30' N to 74° N, mainly on the bank slopes and in Disko Bay. Shrimp fishery was started in 1935 as small-scale fishery mainly in inshore areas. Since then it has developed slowly to a total catch of up to 150,000 t/year (2004-2008). The major part of the catch is taken by large modern trawlers, which process the catches onboard. In the Disko Bay and other inshore waters smaller vessels are used and the catches are usually delivered to factories in the towns. The fishery takes place whenever the sea-ice does not close the waters. Since the late 1990s the fishery has contracted northward and the fishery is now concentrated in Disko Bay and offshore north of 67° N.

In the period 2005–2009 catches taken in the assessment area (inshore as well as offshore) amounted to up to 80% of total catch (Arboe & Kingsley 2010) and thus clearly documenting the importance of the assessment area for the shrimp fisheries (Figure 39).

Greenland halibut (*Reinhardtius hippoglossoides*)

The fishery on Greenland halibut has two components in the assessment area (Figure 40). The first is an inshore fishery, going on throughout the year in Disko Bay, Uummanaaq and Upernavik districts. In 2011, landings from Disko Bay where approx. 8,000 t, from Uummannaq 6,400 t and from Upernavik 6,500 t (Nygaard 2012). The fish is caught on long-lines either from small vessels or from the winter ice. Jakobshavn Isfjord (interior Disko Bay) is by far the most important site for this type of fishery within the assessment area followed by Torsukattaq (inner Disko Bay) and parts of Uummannaq Fjord.

The other component is an offshore fishery with large trawlers using single and twin trawl. The fishery peaks during summer and autumn, where 65.5 % of the total catches are fished in 3. quater and 32.5 % in 4. quater (Jørgensen & Hanmmeken-Arboe 2013). The fishery is distributed from 70° N to 75° N on the edge of shelf at 600-1800 depth m and the main fishery is situated west of Disko between 68° and 70° 30' N (Jørgensen & Hanmmeken-Arboe 2013). Before 2000 the commercial catches in Greenlandic part of Baffin Bay were limited, but increased gradually from 96 t in 2000 to approx. 6,200 t in 2006 and have since remained on that catch level. The annual catch level in the Canadian part of Baffin Bay is approx. 6,200 t. The commercial catches from the Davis Strait south of the assessment area amounted 14,000 t of which 50 % is based on fishery in Canadian waters (Jørgensen 2012).

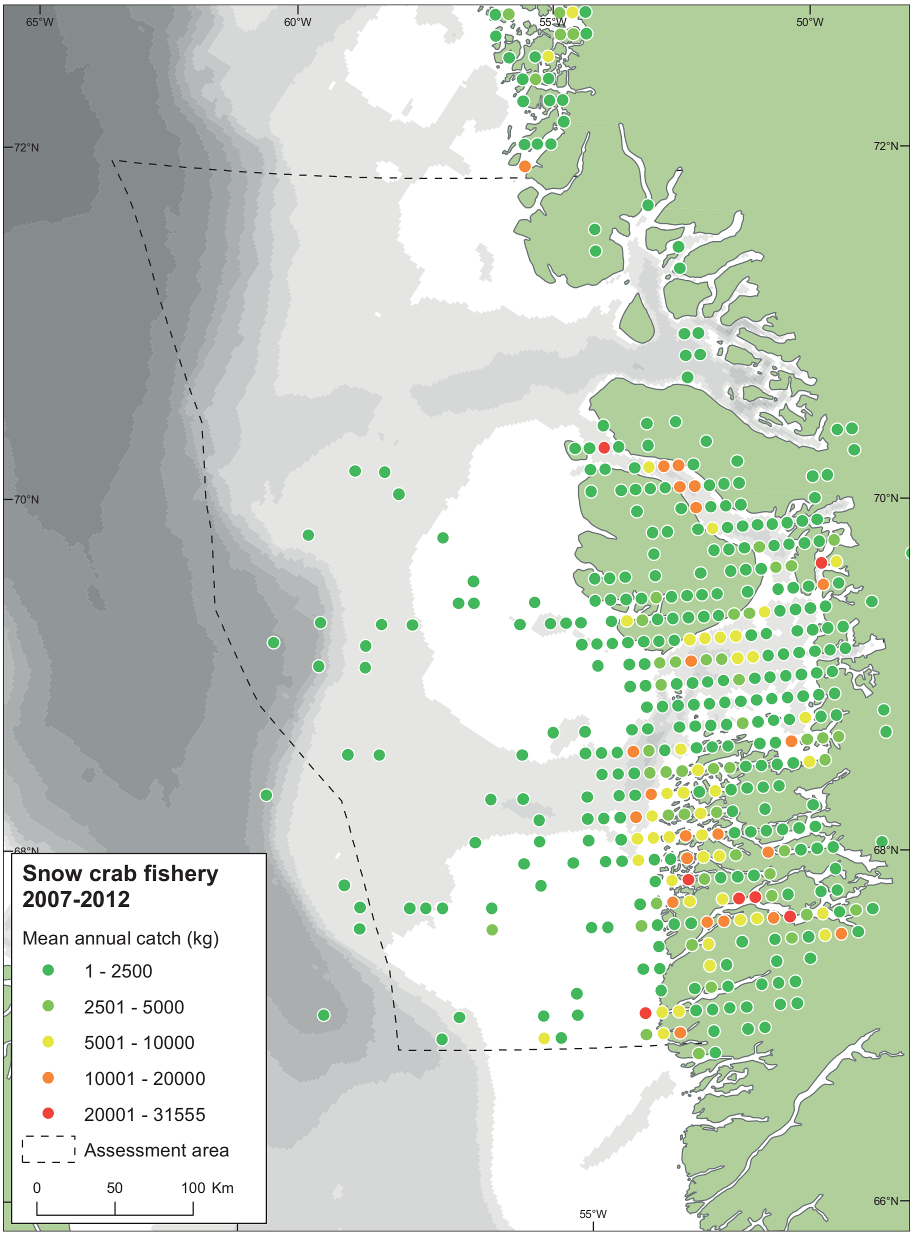


Figure 41. Distribution and size of the snow crab catches within assessment area (mean annual catch over the years 2007-2012). Distribution based on the NAFO-grid.

Snow crab (*Chionoecetes opilio*)

Snow crabs are caught in both in- and offshore waters in the assessment area and are conducted in the period from April to December. The season is however dependendt on the sea ice covarage. The fishery was initiated in 1992 in the Disko Bay area and around Sisimiut and increased rapidly. In the period 2003-2009, catches within the assessment area comprised 3 to 6% of the total Greenland catch and with annual catches of up to 162 t (Burmeister 2012). In recent years 2010-2012, catches have decreased to less than 20 t/year. In the inshore area from 67 to 71°N catches comprised 27% to 38% of the total catches along the west coast of Greenland. Since 2010 annual inshore catches in entire West Greenland has been stable at approx. 625 t (Burmeister 2012) (Figure 41).

Iceland scallop (*Chlamys islandica*)

Iceland scallops are caught in rather shallow water where currents are strong. This fishery has been relatively important in the assessment area. In the years 2003 and 2004 the fraction of the total catch in Greenland (about 2500 t) has ranged between 58 and 68% (Mosbech et al. 2007a). Presently there are no ongoing fishing activities for scallops in the assessment area.

Lumpsucker (*Cyclopterus lumpus*)

Lumpsucker is caught commercially along the entire Greenland west coast with total catches up to 10,000 t in 2006 (GINR, unpubl. data). The fishery is mainly conducted using gillnets and takes place in spring and early summer when the fish move into shallow coastal waters to spawn. The roe is the commercial product and the amount bought by the local factories in the assessment area varies considerably between years. Presently about 2000 t are landed in the assessment area.

5.2 Subsistence and recreational fisheries and hunting

L.M. Rasmussen and A. Rosing-Asvid

Hunting and fishing is an integrated part of Greenlandic way of living. Subsistence hunting is still of economic importance and recreational hunting and fishing activities are contributing significantly to private households especially in the small communities. However, in the larger towns this way of living has gradually developed into recreational activities.

But the income generated from selling hunting products, i.e., the local sale of meat and skin, is still an important source of livelihood and also as a supplementary food supply for hunters and their relatives (Rasmussen 2005). Many hunting products are also used for clothing, handicrafts and art.

A proportion of the catch figures presented under the commercial fisheries section include subsistence and recreational fisheries, but these contributions cannot be separated. It is however assumed that the majority of the Greenlanders participate and benefit from subsistence and recreational fisheries.

Many species of fish are utilised on subsistence basis, such as: spotted wolffish, Greenland halibut, redfish, Atlantic cod, polar cod, Greenland cod and Greenland shark.

The species most important to hunters and fishermen that will be most vulnerable to an oil spill are those caught close to the shoreline: capelin, lumpsucker and Arctic char. Important areas for fisheries of these species were mapped by the oil spill sensitivity mapping project covering West Greenland as far north as 72°N (Olsvig & Mosbech 2003, Mosbech et al. 2007a).

5.2.1 Bird hunting

F. Merkel

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.

Since 1993 all catches have been reported annually to Piniarneq, the official Greenlandic hunting statistics, which represents the major source of information on bird hunting. The data are generally not quality assured, but the reported numbers of birds are assumed to be comparable indices for hunting activities over time. Since the late 1990s the reported catch of all species listed above has been greatly reduced, especially from 2002 when the hunting season was shortened by approximately two months (Figure 42). Within the assessment area the average number of murres reported annually declined from ~51,000 before the harvest regulation change (1993-2001) to ~21,000 after the regulation change (2002-2008). The corresponding numbers reported for common eider were ~21,000 versus ~5,500 birds.

In the 1990s the thick-billed murre was by far the most important hunted seabird, followed by common eider and kittiwake. Today the murre is still the most important species, but black guillemot is now equally important to common eider and both are more common than the kittiwake. Specific hunting seasons are established by the Department of Fisheries, Hunting and Agriculture (APNN) and vary between species and region. For most species, the main hunting season in the assessment area is from 1 September to 1 March (15 October – 1 April for common eider). Daily quotas for the most hunted species are 30 birds for commercial licences and 5 for recreational licences (Anon 2009).

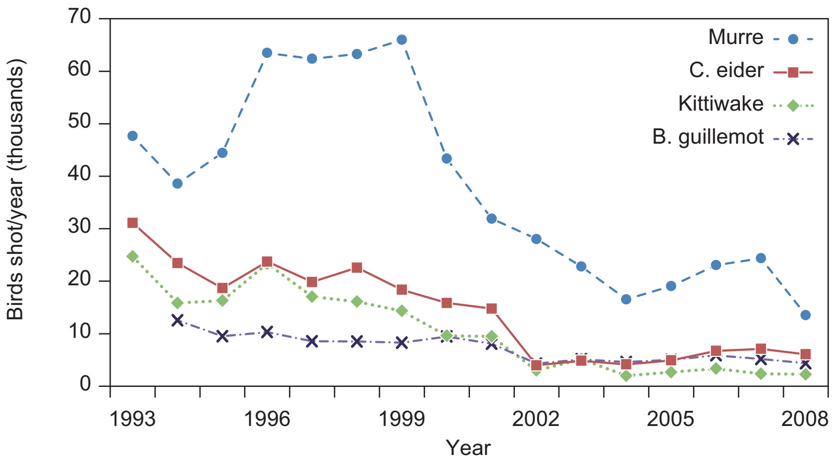


Figure 42. Annual number of harvested thick-billed murre, common eider, black-legged kittiwake and black guillemot reported to the bag-record system in West Greenland (Piniarneq) from Sisimiut to Uummannaq (~the assessment area) in the period 1993-2008 (data from Piniarneq, APNN).

5.2.2 Subsistence hunting of marine mammals

T.K. Boye, F. Ugarte, M. Simon, E.W. Born and M.P. Heide-Jørgensen

Subsistence harvest in Greenland does not solely refer to the value of the meat or other household products derived from skins, bones or teeth, but also to the income that such products can generate on a local or non-local market. The species mentioned in this section are those that only subsistence hunters ('full-time' hunters) are allowed to hunt, as opposed to e.g. seals or seabirds, which to some extent are accessible to recreational hunters also (see above).

Table 10. 2011 quotas for the four species of baleen whales and two species of toothed whales caught in West Greenland waters (APNN 2011a & b).

Species	West Greenland quota	Quota in the assessment area*	Catch in the assessment area in 2010
Minke whale	185 (178+7 transferred from 2010)	Open (12 for collective hunt)	56
Fin whale	10	Open	2
Humpback whale	9	5	3
Bowhead whale	3 (2+1 transferred from 2010)	3	2
Narwhal	310	225	NA
White whale	310	290	NA

*Included in West Greenland quota

Minke whales, fin whales, bowhead whales and humpback whales are hunted in West Greenland and annual quotas were until 2012 set every 5 years by the IWC (The International Whaling Commission) (Table 10). The Greenland government then divides the quota among the different municipalities.

Polar bear hunting

Polar bears are hunted in Greenland, also in the Disko West assessment area. During 1993-2005 (i.e. since the introduction of a new catch reporting system – '*Piniarneq*' – but before introduction of quotas in 2006), the catch of polar bears in the Disko West assessment area (i.e. from Sisimiut to Uummannaq) averaged 24/year (sd = 12.5, range: 7-51; source: APNN) with a significantly increasing trend during this period ($r^2 = 0.353$, $p = 0.03$). The 2010-quota for the catch of polar bears in this region is 9 polar bears (minus 4 that were taken in excess of the 2009-quota of 9; source: Anon 2011c, Table 8, p. 127).

Walrus hunting

Walruses are hunted in the West Greenland winter quaters mainly during spring until retreat of the pack ice (Born et al. 1994, Born et al. 1995). Walruses from this stock are also hunted along southeast Baffin Island (Nunavut) mainly during the period May-November (COSEWIC 2006, Stewart 2008) – i.e. when they generally are absent from West Greenland.

The Greenland quota for the period 2010-2012 is 61 landed in each year (Anon 2010a, b).

Seal hunting

Seals are important for both part time and full time hunters in the assessment area (Table 9). The skins are purchased and prepared for the international marked by the tannery in South Greenland, and the meat is eaten locally. In the period 2000-2008, more than half a million seal skins were traded in Greenland. However, in 2008-2009 the market for seal skins collapsed and now it is difficult to sell the skins (Rosing-Asvid 2010b).

Harp seals are caught in high numbers (Table 9) especially during summer. In winter and early spring most of the West Atlantic harp- and hooded seals congregate near the whelping areas off Newfoundland. However, a small fraction of these seals will stay in West Greenland throughout the year.

Hooded seal can also be caught throughout the year, but most catches are done during spring just prior to and after the whelping, when many hooded seals are close to the assessment area, or in the fall when post moulted seals migrate through the assessment area towards their foraging grounds in Davis Strait and Baffin Bay (Table 9).

The ringed seals are normally associated with sea-ice and some ringed seals live in or near glacier fjords in the assessment area throughout the year. The catches increase during winter and spring. Most catches are juvenile seals of which some are likely to be seals that have been ‘pushed’ out of the fjords where adult seals establish territories when fast ice starts to form. The assessment area is, however, also likely to have an influx of seals coming from the West Ice when it approach the coast during winter.

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

Whale hunting
Bowhead whales were hunted since the time the Thule Inuit settled in Greenland about 1,000 years ago (Jensen et al. 2008a). European and North American whalers decimated the population in the 17^{th}-19^{th} centuries and by the start of the 20^{th} century the species had become rare in Greenland. In 1927 the species was protected. The Baffin Bay stock has been protected since 1910, but in recent years a few have been taken in Canada. The population has now recovered to the extent that a Greenland quota of 2 animals per year for the period 2008-2012 was approved by the IWC. Three bowhead whales were taken in Disko Bay in both 2009 and 2010 and the remaining part of the quota will be taken in 2011 and 2012.

Minke whales have been hunted in West Greenland since the middle of the 20^{th} century. From 1968 to 1986, small-type whaling boats from Norway caught minke whales in the waters off West Greenland. During the early and mid-1970s, Norwegian catches off West Greenland averaged 175 minke whales annually. After 1977, following recommendations by the IWC, the Norwegian catches were reduced to 75 minke whales annually (Kapel & Petersen 1982). The Norwegian boats stopped catching minke whales in Greenland in 1986.

Quotas for West Greenland are set by the IWC. The Greenland government divides the quota among the towns. The annual quota for West Greenland in the period 2010-2012 is 178 minke whales. Most whales are taken south of Disko Island, where there are boats equipped with harpoon guns. Further north, 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’ (Anon 2010c). In 2010, the total catch of minke whales reported in zones within the assessment area was 56 individuals: 11 minke whales for the Uummannaq area, 9 for Qeqertarsuaq, 15 for Ilulissat, 2 for Qasigiannguit, 13 for Aasiaat and 6 for Kangaatsiaq (APNN, unpubl. data) (Figure 43).

Fin whales, bowhead whales and humpback whales can only be hunted using harpoon guns and explosive penthrite grenades (Anon 2010c). Due to a lack of boats equipped with this equipment in the northernmost parts of West Greenland, fin whales and humpback whales are normally taken in Disko Bay or further south (as mentioned above, bowhead whales are hunted only in Disko Bay).

In 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 guns in 1948, but as early as 1924 was a steam ship especially designated (by the Danish authorities) to catch large whales in West Greenland. Until the 1970s, this catch took 0-13 fin whales per year. The IWC aboriginal subsistence quotas have regulated fin whale takes in West Greenland since 1977. The quotas have ranged from 6 to 23 whales annually and remained stable at 19 whales from 1995 to 2009. The quota is seldom used and the average catch has been 10 fin whales per year (Kapel & Petersen 1982, Caulfield 1997, Witting 2008). Although the quota for 2010 was reduced to 10 fin whales per year, it still provides 100 t of meat, or approximately 30 % of the total amount of meat from large whales consumed in Greenland (Figure 43).

In 2010, two fin whales were caught within the assessment area, south of Disko Island in Qeqertarsuaq and Ilulissat.

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 t of whale meat (IWC 1991). In 2008, the Scientific Committee of the IWC advised that a catch of ten humpback whales per year would be sustainable (IWC 2008). On the basis of this advice, a quota of 9 humpback whales per year was installed by the IWC to Greenland for 2010-2012. Five out of the 9 humpback whales from the quota for 2010 and 2011 can be taken within, or close to the assessment area (APNN 2011b). From the quota of 9 humpback whales for each of the years 2010 and 2011, 3 whales were given to the municipality of Qeqqata and two were given to the municipality of Qaasuisup (The assessment area lies within these two municipalities). In 2010 humpback whales were caught at three locations within the assessment area (Figure 43).

In addition to the hunt, up to approximately 5 humpback whales are unintentionally caught in fishing gear every year in Greenland.

Catches of narwhals and white whales are amongst the most important for the communities of Northwest Greenland (Heide-Jørgensen 1994). They are the only species of toothed whales whose hunt is regulated by quotas in Greenland (Anon 2011b). Sisimiut and Maniitsoq are the southernmost places where narwhals and white whales are regularly caught.

Commercial harvesting of white whale in West Greenland and Baffin Bay began in the late-1800s (NAMMCO 2008). After a period with large catches in Nuuk (from 1906-22) and in Maniitsoq (1915-29), white 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) (Figure 43).

As the number of white whale wintering off West Greenland has declined since 1981, the Canada/Greenland 'Joint Commission on Conservation and Management of Narwhal and Beluga' (JCNB) concluded that the West Greenland stock was substantially depleted and advised that delay in reducing the catch would result in further population decline and further delay the recovery of this stock (NAMMCO 2001). In 2004, a quota of 320 white whales per year was established for West Greenland. This quota has been gradually reduced and in the 2007/2008 season it was 160. In accordance with the new biological advice from JCNB, the quota increased to 310 in 2009 (Table 10).

Equal to the white whales the quota of narwhals is also 310 animals per year and with these current quotas for white whales and narwhals there is a 70 % chance that the population sizes of both species will increase (NAMMCO 2010). Figure 43 shows a small part of the positions of white whale catches from 2007-2010.

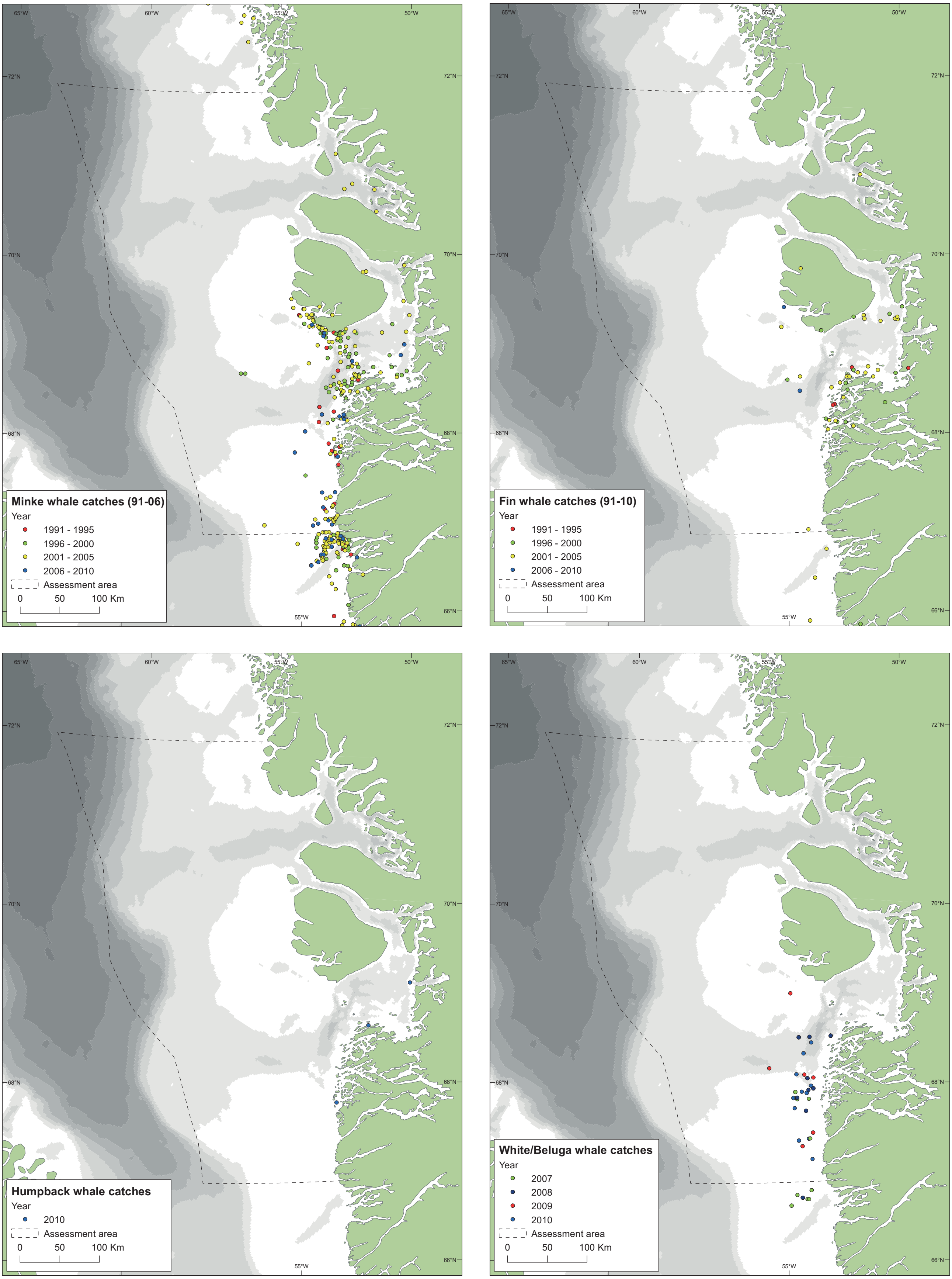


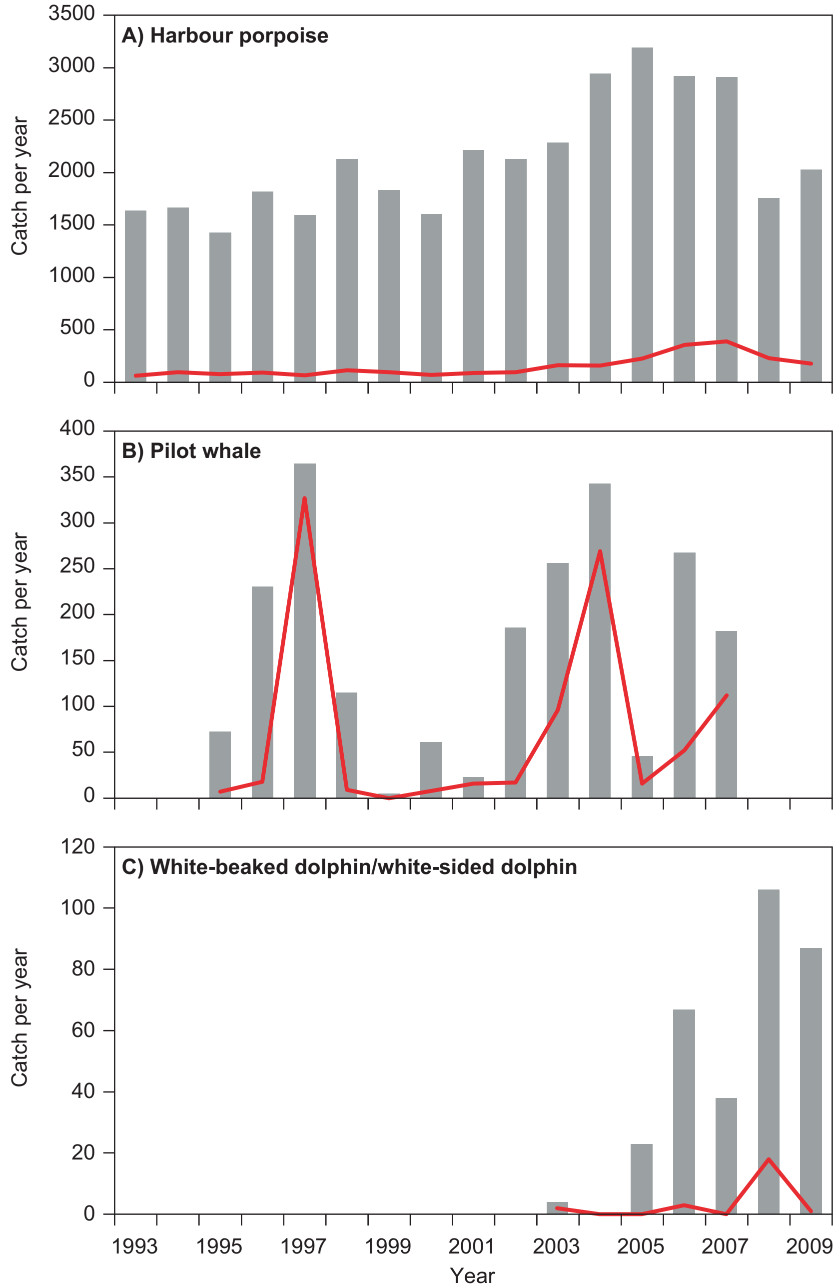
Figure 43. Overview of the locations where fin whales and minke whales were caught in 1991-2010 and humpback whales in 2010.

Harbour porpoise, pilot whales and, to some extent white beaked dolphins, killer whales, and perhaps bottlenose whales are also hunted. Catch of these species is unregulated, but there is a voluntary reporting system that has included harbour porpoises since 1993. Pilot whales and killer whales were included into the reporting system in 1996 and white beaked dolphins and bottlenose whales were added in 2003. The data is entered into a large database administrated by the Ministry of Fisheries, Hunting and Agriculture (APNN). The data presented below comes from this database. A partial validation of killer whale data showed that there are many errors in the reports.

In the period from 1993-2009 an average of 2123 harbour porpoises were taken annually. For West Greenland in total 36,093 catches were reported for 1993-2009 of which 2550 (7 %) were caught within the assesment area (Figure 44a).

Due to their unpredictable occurrence, pilot whales, white beaked dolphins and killer whales are caught opportunistically. The occurrence of pilot whales

Figure 44. The West Greenland catch (grey bars) and the catch in the assessment area (red line) of **A)** harbour porpoise, **B)** pilot whale, **C)** white beaked dolphin.



is probably correlated with the influx of relatively warm Atlantic water (Heide-Jørgensen & Bunch 1991). Annual catches of pilot whales in West Greenland vary between 0 and 300 and from 1996-2009 a total of 2,154 pilot whales have been caught, most of them south of Disko Bay and 947 (44 %) within the assessment area (Figure 44b).

In Greenland, white-beaked dolphins are caught for subsistence. White-beaked dolphins and white-sided dolphins are not separated in the reporting system. In Greenlandic both species have the same name. However, it can be assumed that the greater majority of dolphin catches are white beaked dolphins, as white-sided dolphins have a more southern distribution. On average, 46 dolphins have been caught annually in the period from 2003-2009 (Figure 44c). However most are caught south of the assessment area and less than 7.5 % have been caught within the assessment area.

Killer whales are hunted partly for human subsistence and partly to feed sledge dogs. They are also considered competitors for seal and whale hunters, and this is an additional reason for the hunt of killer whales. From 1996-2009 a total of 93 killer whales have been caught in West Greenland and the annual average catch for the entire period was 7, ranging between 0 and 26 killer whales per year. The killer whales have been caught irregularly along the entire West coast from Upernavik in the north to Nanortalik in the south, with almost 39 % of the catches (i.e. 36 animals) taken within the assessment area.

Northern bottlenose whales were heavily hunted during the 19th and 20th century throughout the North Atlantic, also in the assessment area. Today, bottlenose whales are not used for consumption in Greenland because their blubber causes diarrhea to humans as well as dogs. Nevertheless, a few catches have been reported. It is possible that these reports are mostly mistakes, but until they have been validated it should be mentioned that catches reported from 2006, 2007, 2008 and 2009 were 2, 9, 21 and 1 bottlenose whales, respectively, with only 3 reports from the assessment area, all from 2008.

5.3 Tourism

M. Dünweber and D. Boertmann

The tourist industry is one of three major sectors within the Greenland economy, and the industry is increasing greatly 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. There are no statistics on the number of tourists and their regional distribution in Greenland available, but hotels report the number of guests they have accommodated and how many ‘bed nights’ they have sold. Overall figures for Greenland as a whole in 2008 were approximately 82,000 guests and approximately 240,000 ‘bed nights’ (Statistics of Greenland 2010). In the Disko Bay region, which includes the main town Ilulissat, approximately 69,000 bed nights were recorded. 30 % of bed nights were in the assessment area and only 5-10 % in Northwest and East Greenland (= former municipalities of Qaanaaq, Upernavik, Uummannaq, Scoresbysund and Tasiilaq). However, the region of mid Greenland which includes the capital of Nuuk has by far the highest number of bed nights (approx. 120,000) (Statistics of Greenland 2010).

In addition, cruise ships bring an increasing number of tourists to Greenland. The cruise ships increased from 37 in 2007 to 42 in 2008, where the ship deployment also increased from 148 to 165 in the same period (Statistics of Greenland 2010). According to the Danish Naval Authorities in Greenland, the number of visitors from

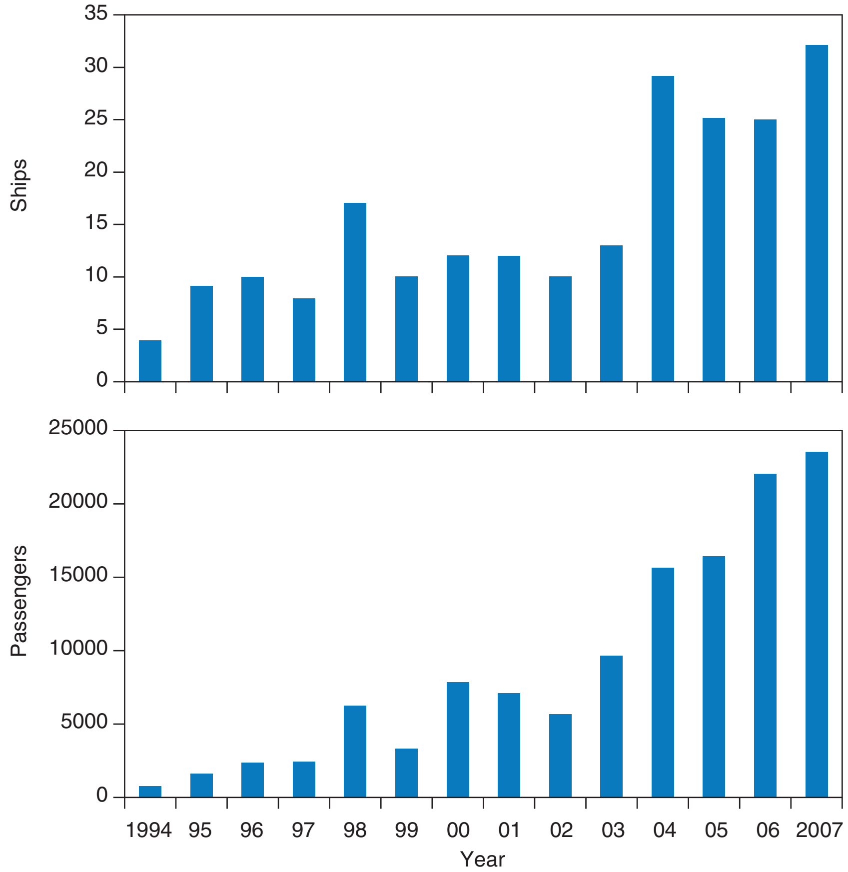


Figure 45. The number of cruise ships (upper graph) and the number of passengers (lower graph) in Greenland, 1994–2007. There is no data on the cruise ship activity available for the assessment area, but the trends are similar (Greenland Tourism, pers. comm.).

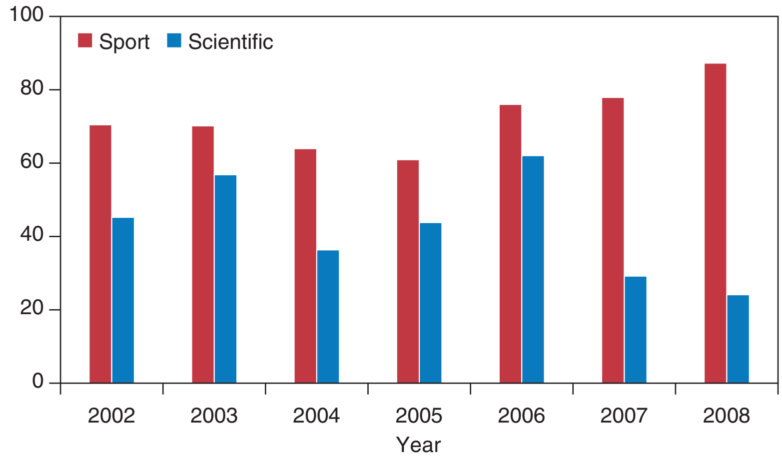


Figure 46. The number of expeditions in Greenland by year. Data provided by the Danish Polar Centre (DPC). It is not possible to filter out the expeditions visiting the assessment area.

cruise ships increased from 23,000 in 2006 to 55,000 in 2007 (Figure 45). The National Strategy of Tourism 2008–2010 plans a 10 % increase per year in the number of cruise tourists (Erhvervsdirektoratet 2007). The cruise ships focus on the coastal zone and they often visit very remote areas that are otherwise almost inaccessible, and seabirds and marine mammals are among the highlights on these trips.

A number of tourists also go to Greenland for outdoor leisure activities (mountaineering, kayaking, etc.) or scientific expeditions (natural history) (Figure 46).

5.3.1 Tourist activities

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

- Whale watching cruises and wildlife exploring- summer and autumn
- Jakobshavn Isfjord and glacier sightseeing by helicopter or hiking
- Kayaking in June to August; kayakers explore the coastal zone and bring equipment and provisions on their own
- Cruise ships, mainly in August and September. Visitors in Ilulissat mainly explore the town; sightseeing, museums, art exhibitions and restaurants and explore the Isfjord.
- Skiing (cross country), mainly February to April
- Hiking and mountaineering. Mainly spring and summer season

Many of the tourist activities within the assessment area take place in the coastal zone and extensive oil activities in this area will have the potential to impact on local tourist activity and the related industries.

6 Protected areas and threatened species

D. Boertmann and D.S. Clausen

6.1 International designations

According to the Convention on Wetlands (the Ramsar Convention, (http://www.ramsar.org), Greenland has designated eleven areas to be included in the Ramsar list of Wetlands of International Importance (Ramsar sites). These areas are to be conserved as wetlands and should be incorporated in the national conservation legislation; however, only one of the Greenland Ramsar sites has so far been protected legally. Six of the Ramsar sites are found within the assessment area (Figure 47). One of them is so far away from the outer coasts that it is not likely it could be affected by offshore petroleum activities, whereas this could be the case for the other five ones (Egevang & Boertmann 2001b).

In 2004, the Jakobshavn Isfjord was included into the UNESCO list of World heritage Sites as 'Ilulissat Icefjord'. Before this designation, it was protected according to the national nature protection law. This remarkable area is situated in the inner part of Disko Bay (Figure 47).

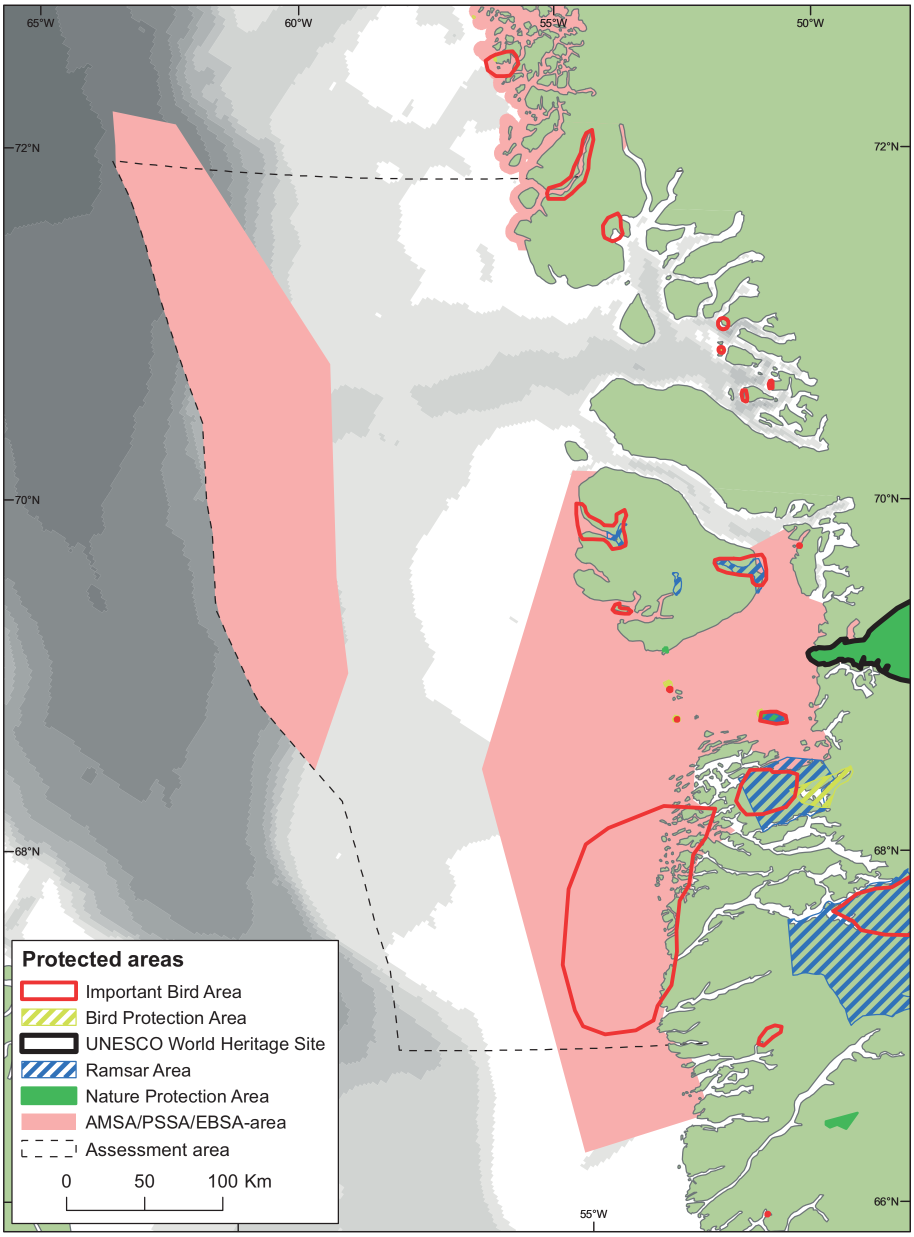
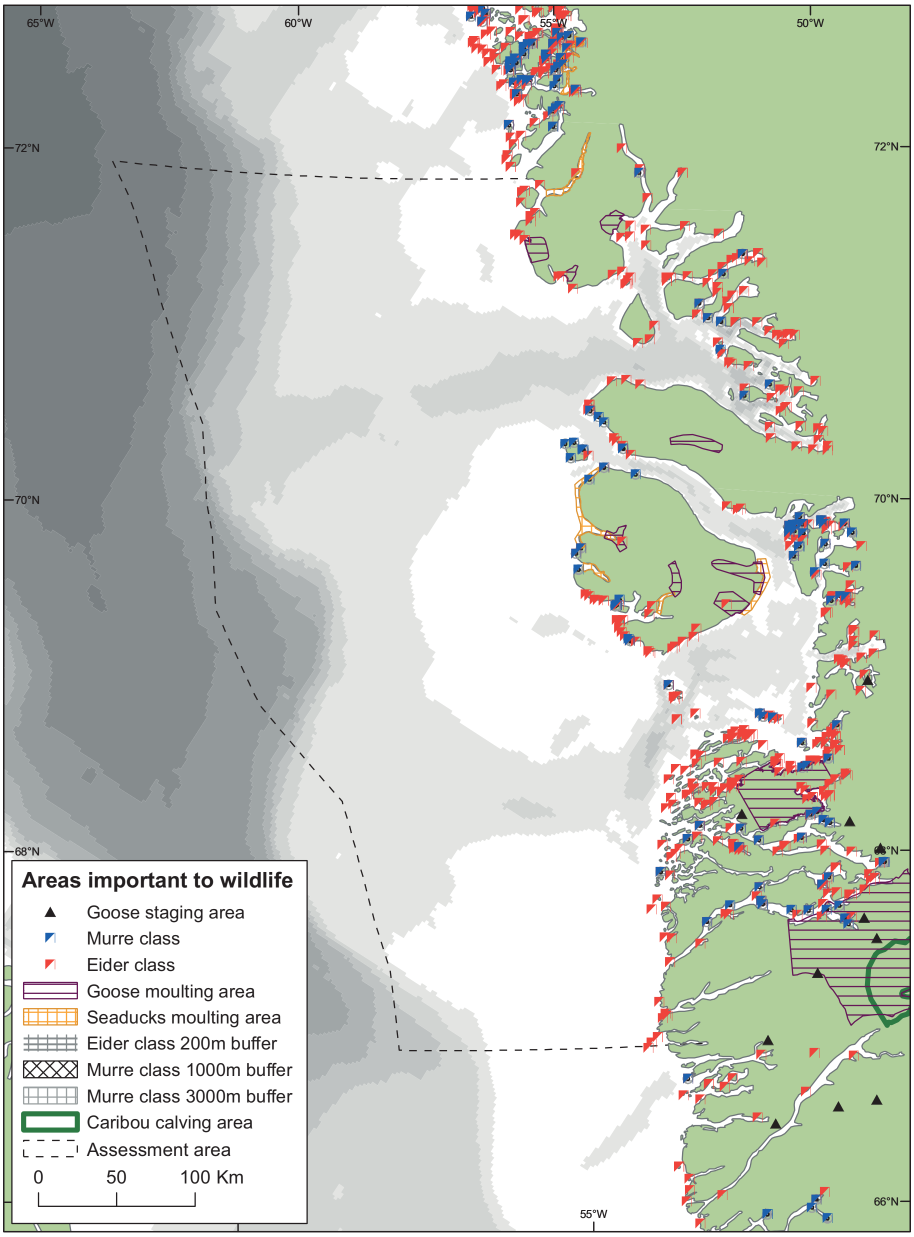


Figure 47. Areas protected according to international agreements (Ramsar areas or Word Heritage Sites) or the Greenland Nature Protection Law (Nature protection area and Bird Protection areas); areas designated as Important Bird Areas (IBAs) by BirdLife International and the areas under designation by PAME using the PSSA and EBSA criteria (see text).

As a follow up to the Arctic Marine Shipping Assessment (AMSA) (PAME 2009), areas of heightened ecological and cultural significance are under designation (PAME in prep.). The designation shall be followed up by measures to protect the areas from impacts of increased shipping due to the climate changes. Two areas within the assessment have been proposed for designation: A large area combining Store Hellefiskebanke and Disko Bay due to the high biodiversity year round and an area in central Baffin Bay due to its importance as narwhal winter habitat (Christensen et al. 2013).

The Disko Bay/Store Hellefiskebanke area is also listed as especially vulnerable marine area in relation to increased shipping by the "Danish Monarchy' strategy for the Arctic 2011-2020".

Figure 48. Areas designated as 'important to wildlife' by Bureau of Minerals and Petroleum (BMP), Greenland Government as a part of the field rules for prospecting and exploration activities. Protection areas for narwhals (related to seismic surveys) are shown in Figure 38.



6.2 National nature protection legislation

According to the Greenland nature protection law several areas within the assessment area are nature reserves (Figure 47). The bird protection law also designates bird protection areas, where access is prohibited in the breeding season (Figure 47). Moreover, seabird breeding colonies are generally protected. In all these areas activities are restricted and regulated in order to protect the conservation interest.

According to the Mineral Extraction Law, a number of ‘areas important to wildlife’ are designated and in these, mineral (and hydrocarbon) exploration activities are regulated in order to protect wildlife. There are several of these areas important to wildlife within the assessment area and they also include the most important seabird breeding colonies (Figure 48). Moreover some important narwhal-areas in the assessment area have been designated as narwhal-protection areas in relation to seismic surveys (Kyhn et al. 2012) (Figure 38).

6.3 Threatened species

Several species are included in the national Red List of Greenland (designated according to risk of extinction). In the assessment area these are five species of mammals, ten species of birds and one species of fish (Table 11) although some are rare (Boertmann 2008).

A few species have been categorised as ‘Data Deficient’ (DD) and they may become red-listed when additional information is available (Table 12). These are bearded seal, harbour porpoise, blue whale and sei whale.

Table 11. Nationally red-listed species occurring in the Disko West assessment area.

Species	Red List category
Polar bear	Vulnerable (VU)
Harbour seal	Critically endangered (CR)
Walrus	Critically endangered (CR)
Bowhead whale	Near threatened (NT)
White whale	Critically endangered (CR)
Narwhal	Critically endangered (CR)
Great northern diver	Near threatened (NT)
Greenland white-fronted goose	Endangered (EN)
Common eider	Vulnerable (VU)
Harlequin duck	Near threatened (NT)
White-tailed eagle	Vulnerable (VU)
Gyr falcon	Near threatened (NT)
Sabine’s gull	Near threatened (NT)
Black-legged kittiwake	Vulnerable (VU)
Ross’ gull	Vulnerable (VU)
Ivory gull	Vulnerable (VU)
Arctic tern	Near threatened (NT)
Thick-billed murre	Vulnerable (VU)
Atlantic puffin	Near threatened (NT)

Table 12. National responsibility species (defined as more than 2% of the global population in Greenland), species with isolated population in Greenland and species listed as 'Data Deficient' (DD) occurring in the assessment area. Only species which occur in marine habitats.

National responsibility species	Species listed as Data Deficient (DD)
Narwhal	Bearded seal
Walrus	Harbour porpoise
Polar bear	Blue whale
Light-bellied brent groose	Sei whale
Greenland white-fronted goose (endemic)	
Common eider	
Iceland Gull	
Black guillemot	
Little auk	
Species with isolated population in Greenland	
Great cormorant	
Red-breasted merganser	
Harlequin duck	
Mallard	

Table 13. Globally threatened species occurring in the assessment area include some marine mammals and a single bird (IUCN 2012).

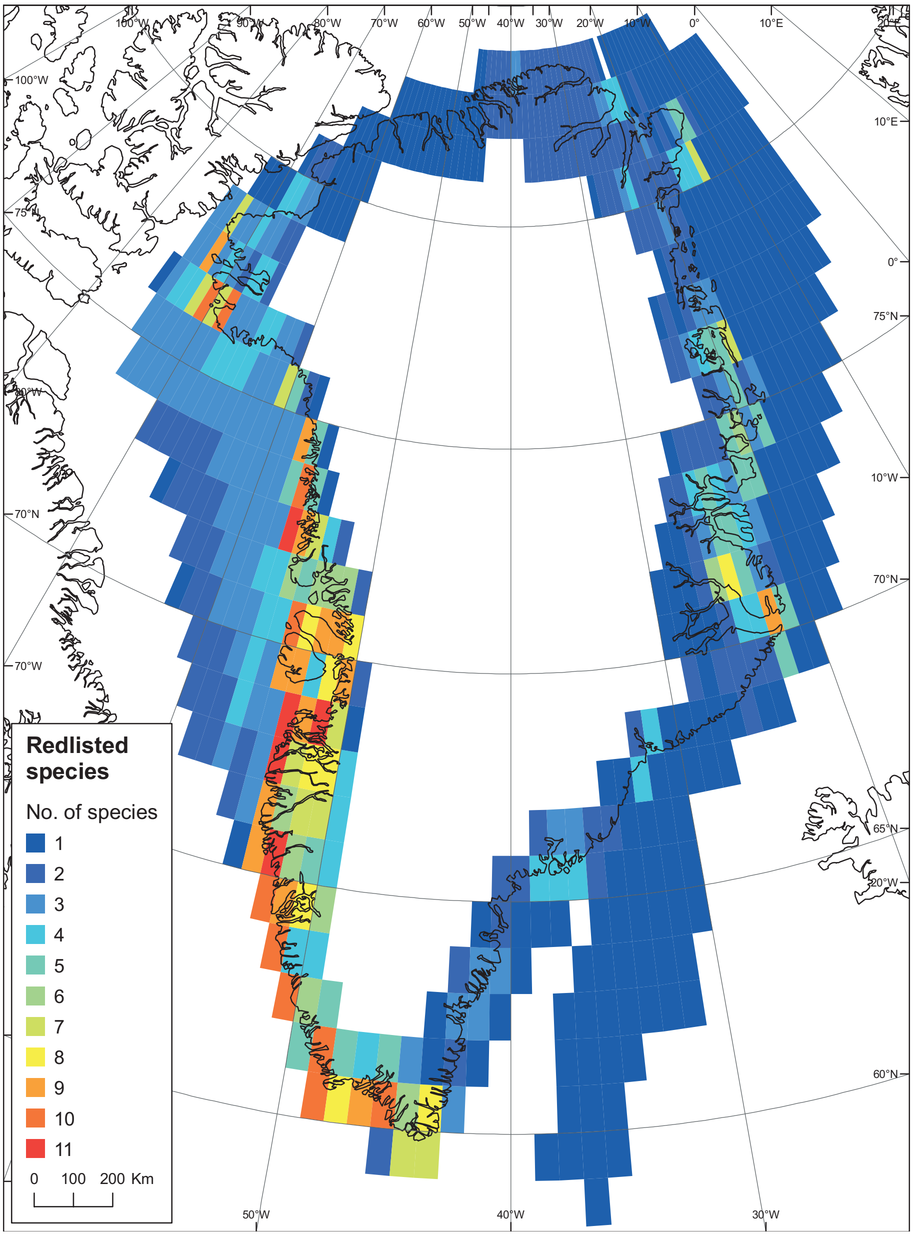
Species	Red List catetory
Ivory gull	Near Treatened (NT)
Polar bear	Vulnerable (VU)
Blue whale	Endangered (EN)
Fin whale	Endangered (EN)
Sperm whale	Vulnerable (VU)
Narwhal	Near Treatened (NT)
White whale	Near Treatened (NT)

Globally threatened species occurring in the assessment area include some marine mammals and a single bird (Table 13) (IUCN 2012). Within the assessment area there are some hot-spots for threatened species (Figure 49).

6.4 NGO designated areas

The international bird protection organisation BirdLife International has designated a number of Important Bird Areas (IBAs) in Greenland (Heath & Evans 2000), of which eight are located within the assessment area (Figure 47). These areas are designated using a set of criteria, for example, that at least 1% of a bird population should occur in the area. One of the most important of these is the Store Hellefiskebanke, where very high numbers of king eiders assemble during autumn and winter (see Box 5). For further information see the IBA website (Link). Some of the IBAs are included in or protected by the national regulations for example as seabird breeding sanctuaries, but many are without protection or activity regulations.

Figure 49. Distribution of red-listed species in Greenland shown as number of species in 1°×1° squares.



7 Contaminants, background levels and effects

D. Schiedek

Knowledge on background levels of contaminants in areas with foreseen hydrocarbon exploration and exploitation is important since it serves as baseline for the monitoring and assessment of potential contamination of the environment caused by these activities.

The occurrence of contaminants in the marine environment and their potential impact on biota has been studied in Greenland over the years in various regions and with different purposes. An overview is given in Boertmann et al. (2009).

In the following the present knowledge is summarised with focus on studies with relevance for the Disko West assessment area.

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

7.1 AMAP Monitoring Activities

In 1991 the Arctic Monitoring and Assessment Programme (AMAP) was established to monitor identified pollution risks and their impacts on Arctic ecosystems. The Arctic is a region with almost no industry or agriculture. Most of the persistent organic pollutants (POPs) and a substantial part of the metals (e.g. mercury) found in the Arctic environment are of anthropogenic origin. The POPs, mercury and other substances have reached the Arctic as a result of long-range transport by air and via oceans and rivers (AMAP 2004). The Arctic is a 'sink' for POPs and there is also some evidence for being a sink for global atmospheric mercury (Outridge et al. 2008). Once in the Arctic, contaminants can be taken up in the lipid rich Arctic marine food web. In general, the level of mercury has increased in the Arctic in terms of long-term trends, whereas the most recent trends show a more complicated picture. Some Arctic species, in particular marine top predators, exhibit levels of mercury in their tissues and organs that are believed to exceed thresholds for biological effects (Outridge et al. 2008).

As part of AMAP activities a biological time trend programme was set up in Greenland with focus on a suite of POPs, including PCBs (Polychlorinated Biphenyls) and different trace metals, i.e. cadmium (Cd), mercury (Hg) and selenium (Se).

A detailed overview of contaminant levels and temporal trends in the monitored species is given by Schiedek in Boertmann & Mosbech (2011) including results from the latest AMAP POP assessment in 2009 (Muir & de Witt 2010) and AMAP Hg assessment in 2011 (AMAP 2011b).

In general, AMAP activities have revealed that levels of organochlorines in Arctic biota are highest in the marine organisms belonging to the top trophic level (e.g.

great skuas, glaucous gulls, great black-backed gulls, killer whales, pilot whales, Arctic fox, and polar bears). This is particularly true for biomagnification of PCBs and DDT. AMAP activities have also shown a decrease in the levels of most of the 'legacy' POPs (e.g. PCBs and DDT), as result of the international regulations such as the Stockholm Convention (AMAP 2004, Muir & de Wit 2010). At the same time, however, new persistent pollutants, currently produced in large quantities, are increasing (AMAP 2004, Muir & de Witt, 2010). These substances have also been detected in animals from Greenland. Perfluorinated organic compounds (PFCs) have shown increasing trends in ringed seal and polar bears from Greenland (Dietz et al. 2008b, Bossi et al. 2005) although a decline has been observed in rent years (Rigét pers. comm.) The brominated flame retardants hexabromocyclododecane (HBCD) and tetrabromobisphenol A (TBBPA) are chemicals produced in high volumes. In recent years, their presence has been reported in sediment and biota from the marine environment (Frederiksen et al. 2007). Concentrations of HBCDs in animals from West Greenland are generally lower than in the same species and tissues from East Greenland. The same effect has previously been described for other halogenated compounds such as PBDEs (Vorkamp et al. 2007). The latest assessment concerning mercury in the Arctic, documents that this substance continues to present a risk to the health of Arctic wildlife and human populations (AMAP 2011b). In large areas of the Arctic, mercury levels are continuing to rise in some Arctic wildlife, despite reductions in emissions from human activities in some parts of the world. The AMAP assessment confirms the need for concerted international action if mercury levels in the Arctic and in the rest of the world are to be reduced.

7.2 Heavy metals

Another, more localized source of environmental pollution is due to mining activities. e.g. around Maarmorilik (Uummannaq) were lead and zinc ore was mined from 1973 to 1990 (Søndergaard et al. 2011a). The impact from the previous mining operation was still visible in 2009. The pollution with dust on land also seems to continue with no signs of a decrease, while the pollution in the sea is decreasing (Søndergaard et al. 2011a, 2011b).

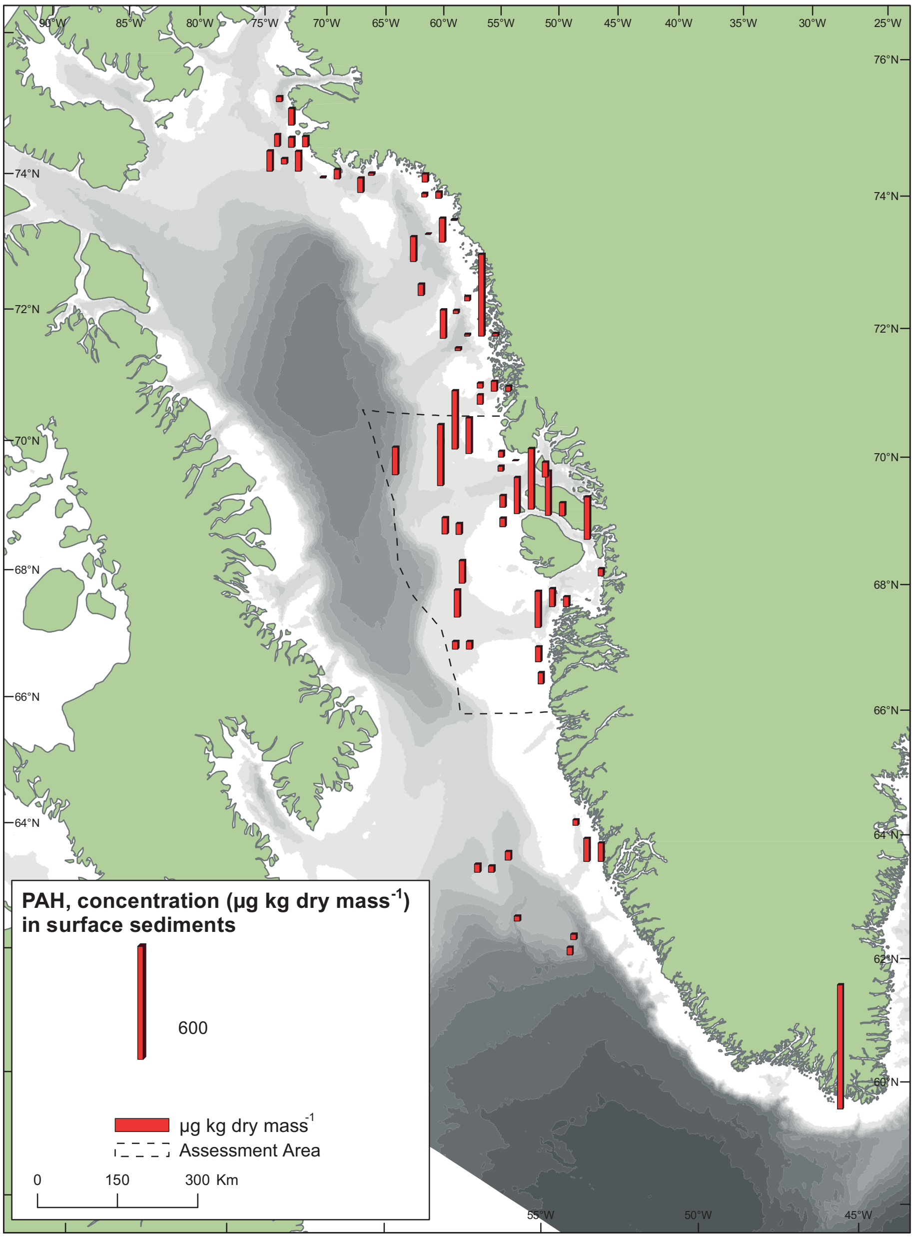
7.3 Tributyltin (TBT)

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 environment, TBT levels are usually low, except close to harbours, e. g. Sisimiut (Villumsen & Ottosen 2006) and shipping lanes (Strand & Asmund 2003, AMAP 2004, Berge et al. 2004). The presence of TBT residues in harbour porpoises from Greenland documents that organotin compounds also occur in the Arctic region even though the concentrations are rather low (Jacobsen & Asmund 2000, Strand et al. 2005).

7.4 Petroleum Hydrocarbons and Polycyclic Aromatic Hydrocarbons (PAH)

Petroleum hydrocarbons represent several hundred chemical compounds originating from crude oil e.g. gasoline, kerosene, and diesel fuel. Of primary interest for the assessment of environmental impacts are the aromatic hydrocarbons (i.e., benzene, ethylbenzene, toluene, and xylenes). Another important group are polycyclic aromatic hydrocarbons (PAHs), which originate from two main sources: combustion (pyrogenic) and crude oil (petrogenic). PAHs represent the most toxic fraction of oil and are released to the environment through oil spills and discharge

Figure 50. Background levels of PAH in sediments in West Greenland



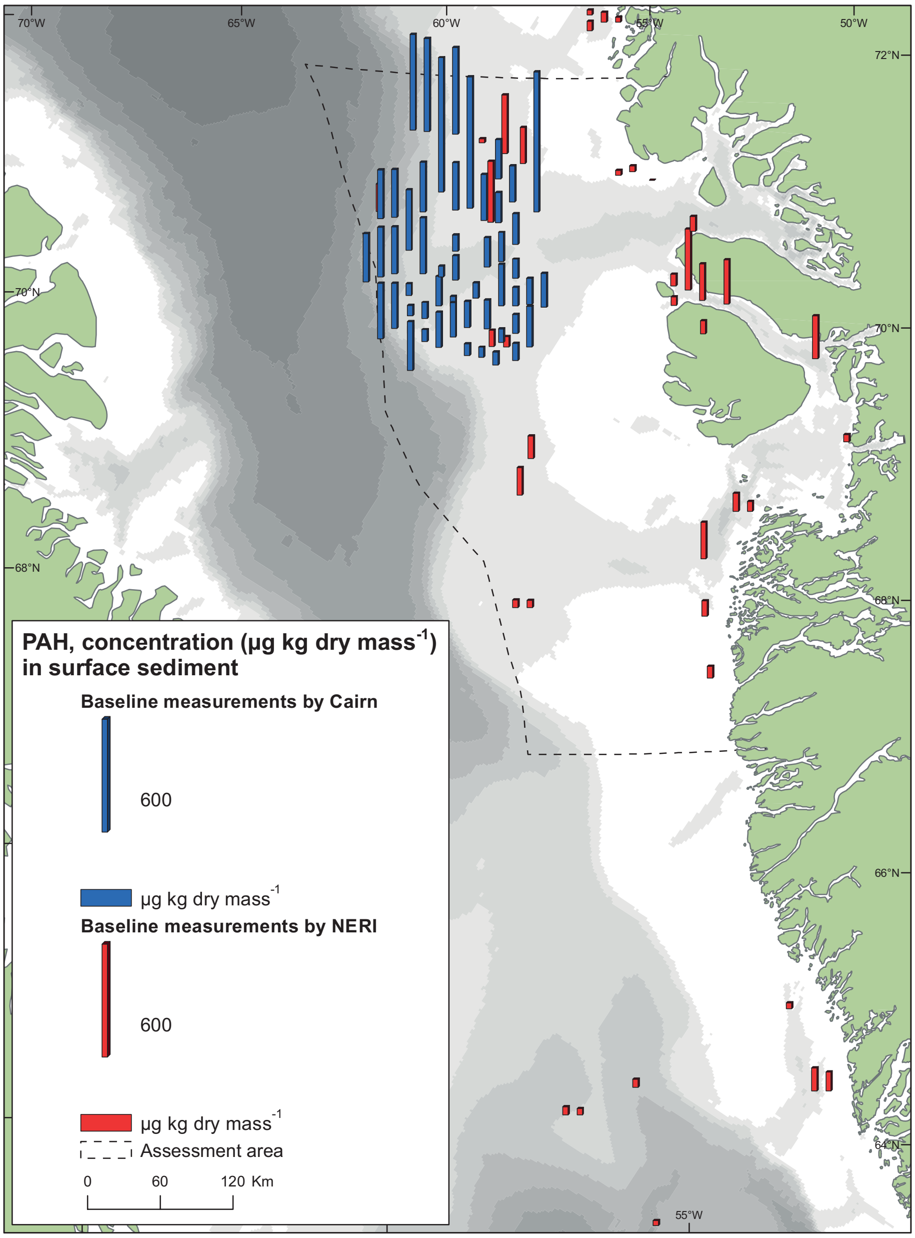
of produced water (see also Chapter 11). Sixteen PAHs are included on the lists of priority chemical contaminants by the World Health Organization and the U.S. Environmental Protection Agency (EPA).

Levels of petroleum hydrocarbons (incl. PAHs) are generally low in the Arctic marine environment and often close to background concentrations, except in areas with anthropogenic impact such as harbours. Presently, the majority of petroleum hydrocarbons in the Arctic originate from natural sources such as seeps (AMAP 2010).

From the studies performed so far in Greenland, including the assessment area, regarding PAH levels in biota and sediment (including sediments from offshore areas, municipal waste dump sites and sites with no known local pollution sources), levels of petroleum compounds in the Greenland environment appear to be relatively low and are regarded as background concentrations (Figure 50 and 51).

Total petroleum hydrocarbons (TPH) and PAH levels were measured near natural seeps at Marrat in the Disko Bay area in sediments and biota (blue mussels, shorthorn sculpins, Greenland cod) in 2005 (Mosbech et al. 2007b). TPH levels in the sediment were relatively low and therefore gave no real indication of oil seeps or

Figure 51. Background levels of PAHs in the assessment area



other local petrogenic sources. The PAH levels ranged from low values up to approx. 1600 µg/kg dry weight but there was no clear spatial pattern. However, samples from greater depths (200-400 m) and further away from the coast showed 3-4 times higher levels than those closer to the coast. The reason for this is presently not clear (Mosbech et al. 2007b).

As part of a baseline study performed by Capricorn in 2010 and 2011, PAH content in surface sediments were analysed offshore Disko Bay to document background level prior drilling. The PAH content in the sediment was usually low (Figure 51).

7.5 Conclusions on contaminant levels

In general, studies performed so far in Greenland (incl. AMAP activities) have revealed that levels of organochlorines in Arctic biota are highest in the marine organisms belonging to the top trophic level (e.g. polar bears, toothed whales and seals). This is particularly true for substances which are bio-magnificated such as PCBs and DDT. AMAP activities have also shown a decrease in the levels of some POPs (e.g. PCBs and DDT), as result of the introduction of bans and restrictions relating to their use in other parts of the world (Rigét et al. 2010). At the same time, however, new persistent pollutants, such as perfluorinated organic compounds and brominated flame retardants have increased in the last decades (Muir & de Wit 2010), also in animals from Greenland.

Levels of petroleum compounds, including PAHs, are relatively low in the Greenland environment and the assessment area (except for polluted areas such as harbours) and are regarded as background concentrations.

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

7.6 Biological effects of contaminants

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

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

This makes it difficult to estimate if threshold values determined in other species are valid for comparison with the contaminant levels found in Arctic species.

Species living in the Arctic have very specific life strategies and population dynamics as a result of their adaptation to the harsh environment. Moreover, their fat content and seasonal turn over differs compared to more temperate species (AMAP 2004). The lower temperatures in the Arctic are also likely to have an impact on the toxicity of contaminants.

The data basis is still limited allowing to determine whether cold adapted species are more (or less) sensitive to contaminants than temperate species and hence whether the relationships between contaminant concentrations and impacts derived from temperate species can be applied to the sub and high Arctic environment.

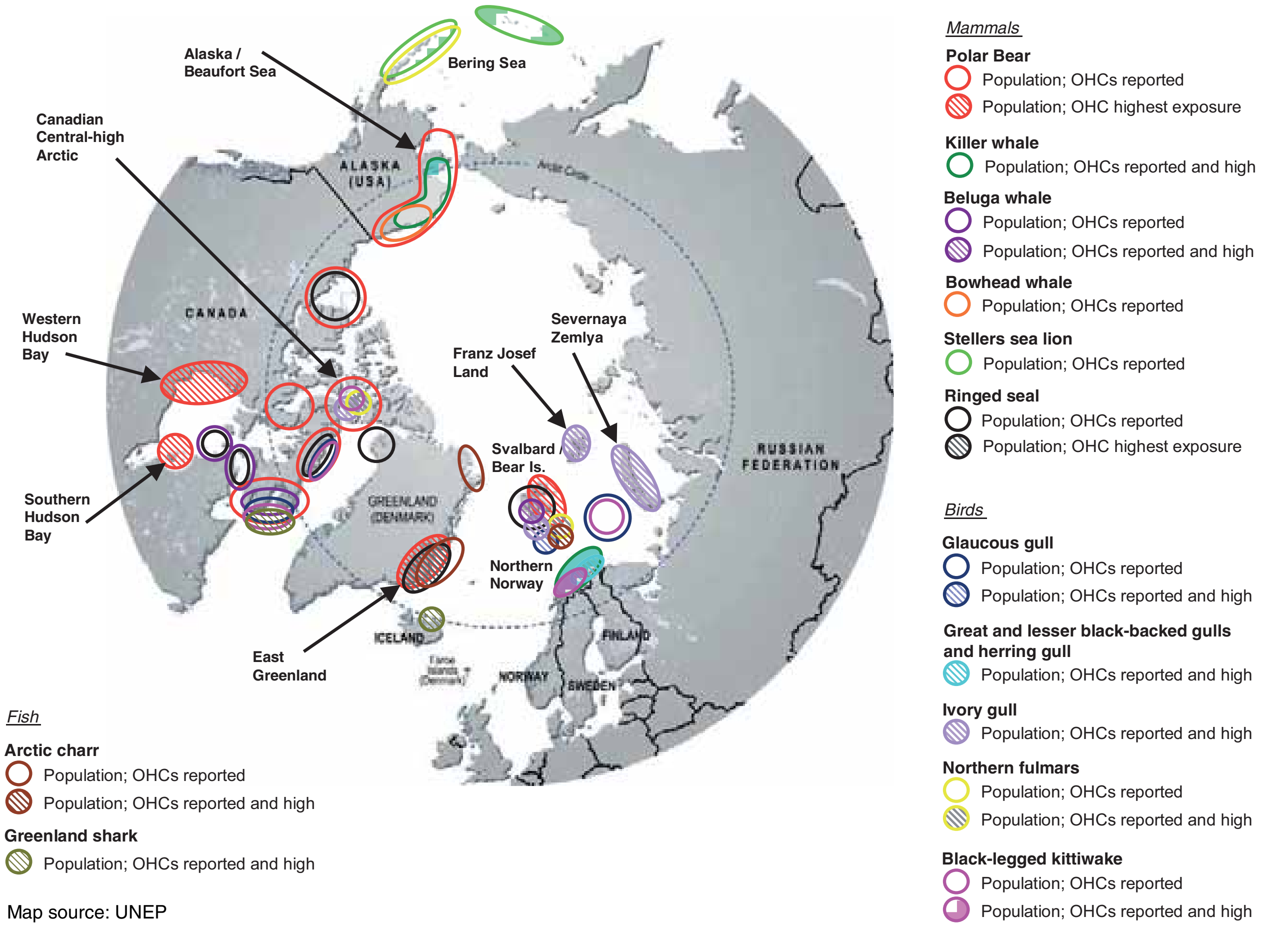


Figure 52. Based on the 'weight of evidence' from a range of studies performed on Arctic wildlife and fish, several key ('hotspot') species and populations have been analysed. Among those are East Greenland polar bear and ringed seals, Greenland shark from the Baffin Bay/Davis Strait and a few populations of freshwater Arctic char (Source: Letcher et al. 2010).

As part of the AMAP assessment in 2009, the most recent relevant studies have been reviewed and summarized in regard to biological effects and how they are related to organohalogen contaminants exposure (Letcher et al. 2010) and mercury contamination (AMAP 2011b). First attempts have been made to assess known tissue/body compartment concentration data in the context of possible threshold levels on top trophic level species, including seabirds (e.g. glaucous gull), polar bears and Arctic char.

There was only little evidence that organohalogen contaminants are having widespread effects on the health of Arctic organisms. However, on a smaller scale, effects have been documented. Based on the 'weight of evidence' found in different studies performed on Arctic and subarctic wildlife and fish, several key species and populations have been identified (Letcher et al. 2010). Among those are East Greenland polar bear and ringed seals, Greenland shark from the Baffin Bay/Davis Strait and a few populations of freshwater Arctic char (Figure 52)

Pollution effects on polar bear health caused by the complex, biomagnified mixture of the substances are summaries and assessed by Sonne (2010). The review shows that hormone and vitamin concentrations, liver, kidney and thyroid gland morphology as well as reproductive and immune systems of polar bears are likely to be influenced by contaminant exposure. An evaluation of climate change scenarios suggested that future polar bear health and population size may be impaired by energetic and physiological stress caused by a combination of sea-ice depletion and contaminant exposure.

Polar bears from Greenland, including the assessment area, also show considerable amounts of mercury in their tissues, particular in East Greenland (Sonne et al. 2007). Mercury is a potent neurotoxin. Its accumulation is associated with subtle neurological damage, as determined by measuring neurochemical biomarkers known to be disrupted by mercury. In a recent study it has been shown that East Greenland polar bears show decreased levels of NMDA receptors, which play a role in the neuronal signal transmission. In future studies this could serve as a sensitive indicator to assess sublethal and early effects of mercury in polar bears (Basu et al. 2009).

7.6.1 Polyaromatic Hydrocarbons (PAH) and possible effects on biota

At present, PAH levels are relatively low in Greenland biota though point sources in harbour areas are found (Figure 50). With increasing human activities, e.g. in relation to oil exploration, this may change and reliable environmental monitoring tools are required to identify any potential impact on the biota.

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

The effects of PAHs on organisms are extensive and occur on various levels, including biochemical and physiological and/or genotoxic effects (Hylland et al. 2006). The responses and tolerance to PAHs can vary considerably in organisms, depending on the geographical range of the species, but also on the particular PAH mixture. Effects in relation to PAH exposure have also been found at the population level, possibly reflecting the pre-exposure history and/or heritable, genetic changes in populations chronically exposed to PAHs.

Sources to PAH-contamination from exploration and exploitation activities can be oil based drilling mud, oil residues on cuttings and particularly release of produced water.

Inputs of effluents (including PAHs) from offshore oil and gas production platforms in the Norwegian sector of the North Sea have been monitored through an integrated chemical and biological effects programme since 2001 (Hylland et al. 2008). To test potential effects on organisms, cages with either Atlantic cod or blue mussels were positioned at various distances (0-5000 m) and different directions from the oil platforms. In addition, two reference locations were used, both 8000 m away from the respectively platform. PAH tissue residues in blue mussels ranged between 0-40 ng/g wet weight depending on the distance to the oil rigs. PAH bile metabolites in cod confirmed exposure to effluents, but levels were low when compared to those found in cod from coastal waters (Hylland et al. 2008). The found biological effects in the blue mussels reflect exposure gradients and that the mussels were affected by components in the produced water. The results also indicate synergistic and antagonistic interactions between low- and high-molecular-weight PAHs.

Some interesting studies have been carried out with Atlantic cod from the Barents Sea. Hydrocarbon uptake and effects on metabolites, enzymatic and genotoxic biomarkers were measured. Elimination of PAHs was demonstrated to be slower at the lowest temperatures. For some biomarkers the response was lower than in cod from the North Sea. The results show that several factors have to be taken into account when performing risk assessment for cold water fish species, and for example may recovery from exposure take longer time than in fish from temperate areas (Skadsheim et al. 2009).

The response of marine organisms to petroleum exposure via water, food or sediment has also been studied extensively in the laboratory by means of a number of biochemical, physiological and histological indicators. Their applicability and limitations in relation to ecological risk assessment after an oil spill has been assessed (Anderson & Lee 2006).

However, as pointed out before, most of these studies have been performed in temperate regions, and results may not apply to arctic conditions.

Possible effects on biota caused by PAHs are discussed in more details in Chapters 10 and 11. In general, it can be stated that exposure to PAHs cause effects on different biological levels and that the thresholds can differ depending on the species.

7.6.2 Conclusions

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

Studies performed in Norway on polar cod and other typical Artic species have documented that the application of a range of biomarkers should be considered when assessing biological effects (see also Chapter 11). Moreover, assessment criteria have to be established allowing assessing any unacceptable impact. Such criteria are based on ecotoxicological tests that cover the sensitivity range of relevant species at different trophic levels, e.g. OSPAR Environmental Assessment Criteria (EAC). Toxicological tests with relevant species from the Baffin Bay/Disko area are not available for establishing such criteria. Knowledge concerning species' sensitivity, assessment criteria as well as an adequate monitoring strategy, have to be available before increased drilling activities, e.g. during oil exploration or production will start in West Greenland.

8 Impacts of climate change

D. Schiedek and M. Dünweber

8.1 General context

The Arctic marine environment has changed over the past several decades, and these changes are part of a broader global warming that exceeds the range of natural variability over the past 1,000 years as documented in the Arctic Climate Impact Assessment (ACIA 2005).

Since the publication of the ACIA, several indicators have shown further and extensive changes at rates faster than previously anticipated. Air temperatures are increasing, sea-ice extend has decreased sharply with record low in 2007 and 2011 (Figure 53).

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

In September 2011 the sea-ice level reached with 4,240 million km^2 a new historic minimum (Figure 53). Already in July the new record minimum had been expected because in this month the sea-ice extent was minimum, compared with the same month in other years (Figure 53).

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 inflows 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

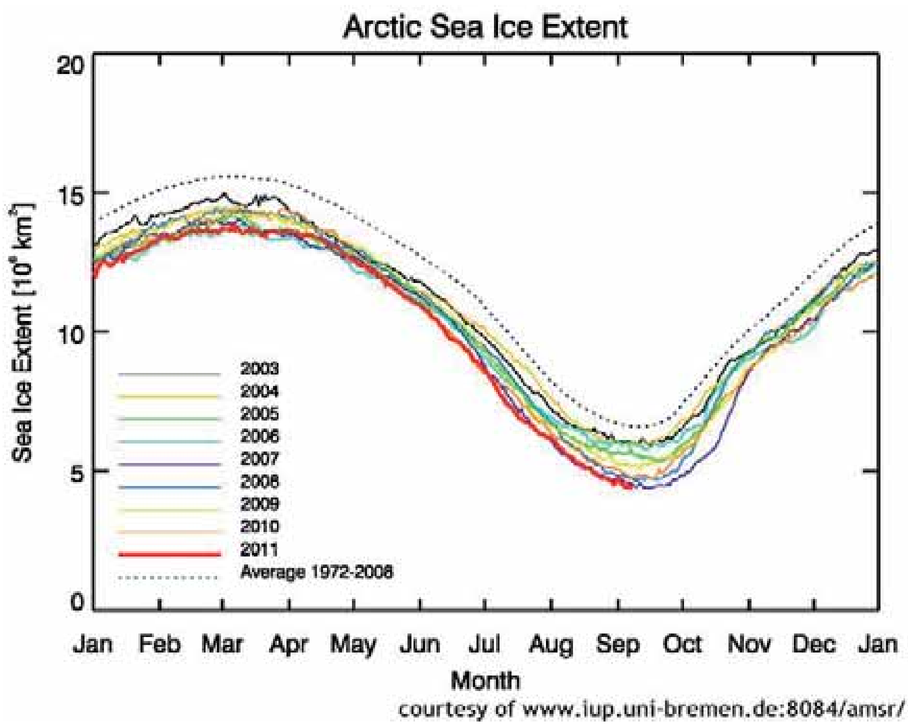


Figure 53. Sea-ice extent of the years 2003 to 2011 with minima in September and maxima in March (data from University of Bremen).

of the 2000s compared to 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, even though with considerable variation from year to year. A nearly ice-free summer is now considered likely for the Arctic Ocean by mid-century (AMAP 2011a).

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

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).

8.1.1 Sea-ice cover

The Davis Strait/South-eastern Baffin Bay experience strong annual variability in sea-ice extent and concentration, primarily driven by wind and current patterns and low winter temperatures. The variability in distribution of the sea-ice is primarily determined by the annual NAO-index. The annual NAO variability determines the current pattern of the Davis Strait which influences the north-south extent of sea-ice and the position of the sea-ice edge (Buch 2000, 2002, Heide-Jørgensen et al. 2007b).

In recent years sea-ice has shown high year to year variability or reduced extent for limited time periods in Disko Bay (Hansen et al. 2006), depending on atmospheric cooling (Buch 2000, 2002, Tang et al. 2004). Based on an yearly averages of ice free days during a 30 year period (1978 to 2008), the ice free days have increased by about 30 days during the last 8 years (2000–2008) in the assessment area (Hvidegaard et al. 2008).

8.1.2 Implications for the marine ecosystem

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

Changes in the oceanographic conditions will affect primary production and thus the timing, location and species composition of phytoplankton blooms. This will in turn affect zooplankton communities and the productivity of fish; i.e. mismatch in

Table 14. Summary of types of footprints of responses of marine organisms living in the Arctic region to climate change (Wassmann et al. 2011).

Responses	Nature of changes
Range shift	Northward displacement of 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

timing of phytoplankton and zooplankton production due to early phytoplankton blooms may reduce the efficiency of the food web. Food web effects could also occur through changes in the abundance of top-level predators, but the effects of such changes are more difficult to predict. Generalist predators are likely to be more adaptable to changed conditions than specialist predators. All in all, significant alterations are to be expected for the entire food web.

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

Marine ecosystems in the Arctic region, including Greenland, are already changing in response to a warming climate as documented by Wassmann et al. (2011). They found clear evidence for changes for almost all components of the marine ecosystems, also in West Greenland.

Their evaluation is based on several types of footprints of responses in biota to climate change, such as range shifts, including poleward range shift of subarctic species, changes in abundance, growth/condition, behaviour/phenology and community/regime shifts (Table 14).

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

8.2 Primary production and zooplankton

In order to describe the impacts of a reduction in sea-ice cover duration and thickness, future primary production was projected for the Canadian Beaufort Shelf. The results of the model runs show, that the relative contribution of the ice algal and spring phytoplankton blooms to the annual primary production will be reduced in the future owing to reduction in the length of the ice algal growth season (resulting from earlier snow and ice melt) and in the replenishment of nutrients to the mixed layer in winter. The model runs showed also an increase in the duration of the summer subsurface phytoplankton bloom, which favours the development of the main copepod species. This leads to an increase in export production that is greater than the increase in primary production (Lavoie et al. 2010).

During the last decades the physical forcing of the plankton succession in Disko Bay has changed. An acceleration of the melt water input from the Jakobshavn Isfjord glacier to the bay has been documented (Holland et al. 2008), which in combination with the general reduction of the sea-ice cover potentially impact stratification as well as light conditions for the plankton and consequently the timing and succession of the lower trophic levels of the food chain.

Climate change is likely to change primary production from strongly pulsed to a more prolonged and unpredictable production of diatoms (rich in polyunsaturated fatty acids) with consequences for the higher trophic levels (Kattner et al. 2007), and there is at least some evidence for earlier chl. *a.* maxima in Greenland waters (Kahru et al. 2011). Presently, Arctic ecosystems are dominated by the diatom-feeding copepod species *Calanus glacialis* and *C. hyperboreus*; both are favoured food for specialised Arctic seabirds and marine mammals. A prolonged production period could favour a mixed diatom-dinoflagellate community which could result in a food chain based on *C. finmarchicus-Metridia longa*, which are less valuable as food for Arctic planktivorous species (bowhead whale and little auk).

Depending on the species, a future warmer climate will cause a shift in the zooplankton community structure towards the smaller less energy rich *C. finmarchicus* as shown experimentally (Kjellerup et al. 2011). This scenario will presumably cause a trophic cascade due to less energy content per individual (Falk-Petersen et al. 2007). In addition, the share in biomass accounted for by *C. finmarchicus* will increase (Hirche & Kosobokova 2007) due to its higher growth rate and short life cycle (Scott et al. 2000). Thus, a regime shift towards *C. finmarchicus* could influence the little auk populations negatively (Karnovsky et al. 2003) and favouring certain intermediate species like herring (Falk-Petersen et al. 2007).

Other studies showed that depending on the species, reproductive success was improved with increased food availability and higher temperature, resulting from reduced ice cover. It was predicted that a climate-induced reduction in the duration of ice cover will favour the population growth of the predominant large calanoid copepods and *Pseudocalanus* on Arctic shelves (Ringuette et al. 2002).

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

8.3 Benthic fauna and flora

Climate change related changes in zoobenthic communities will mainly depend on the temperature tolerance of the present species and their adaptability. If warming continuous, sub-arctic and boreal species will become more frequent, causing changes in the zoobenthic community structure and probably its functional characteristics, especially in coastal areas.

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

In the review by Wassmann et al. (2011), 12 examples of changes are presented involving benthic communities, including species specific changes in growth, abundance and distribution ranges as well as on the community level, i.e. total species composition. The found changes can be regarded as indications what to expect in the assessment area where our knowledge is still very limited regarding temperature tolerance and adaptability of the benthic fauna.

The pattern of occurrence and recent changes in the distribution of macrobenthic organisms in fjords and coastal (nearshore) Arctic waters has also been reviewed and future changes have been hypothesized (Wesławski et al. 2011). The predicted temperature rise in itself, will likely cause minor problems for coastal benthos, since nearshore living organisms are often adapted to a wide temperature range. More important for the coastal benthos are variables associated with temperature rise: increase of coastal turbidity and sedimentation, changes in ice cover, increase in storminess, increasing coastal erosion and freshening of surface waters.

For the assessment of possible impact on coasts and fjords due to oil activities it is important to know that coastal and fjord diversity in the Arctic does not show a uniform pattern, thus the expected changes in relation to climate change will differ regionally and across ecosystem compartments (Wesławski et al. 2011).

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

8.4 Fish and shellfish

Fish communities form an essential link in Arctic food chains and they are also prey for many seabirds and mammal species in the Arctic, including the assessment area. Temperature changes may influence fish populations both directly, through shifts to areas with preferred temperature, and indirectly through the food supply and the occurrence of predators. Moreover, changes in temperature may have different effects on the various life stages of a species (Pörtner & Peck 2010).Changes in the distribution and abundance of fish populations will, therefore, have consequences for both fish prey as well as for predators depending on fish species.

Poleward extension in the distribution range of many fish species is very likely under the projected climate change scenarios. Some of the more abundant species likely to move northward due to the projected warming include Atlantic herring, Atlantic mackerel (*Scomber scombrus*) and Atlantic cod. The southern limits of colder water fish species, such as polar cod and capelin are likely to move northward. Greenland halibut possibly shifts its southern boundary northward or restrict its distribution more to continental slope regions (ACIA 2005) which is of relevance also for the assessment area.

Fish recruitment patterns are strongly influenced by oceanographic processes such as local wind patterns, mixing, and prey availability during early life stages; climate change impacts on these are difficult to predict. Recruitment success could be affected by changes in the timing of spawning, fecundity rates, larval survival rates, and food availability.

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

Changes in the distribution of polar cod have been modelled for a period of 30 years. Polar cod is a small, pelagic gadoid fish (less than 20 cm) which lives in Arctic waters including the assessment area. It is of great ecological importance since it feeds on zooplankton and is an important prey species for larger fish, seabirds and marine mammals. The modelling results indicate that both distribution and abundance of Arctic cod may be dramatically reduced (Cheung et al. 2008).

In general, it is to be expected that the loss of multi-year ice cover will profoundly affect Arctic ecology and but will probably also have positive effects on fisheries as already been documented for the Arcto-Norwegian cod distributions and abundance (MacNeil et al. 2010). This population shows stronger year classes in warm years and poor year classes in cold, and warming has led to a northern range expansion in Norway (Drinkwater 2006, 2009). As a result of warming, yields are predicted to increase by approximately 20 per cent for the most important cod and herring stocks in Iceland, and approximately 200 per cent in Greenland over the next 50 years (Arnason 2007). Climate-driven fish invasions into the Arctic are expected to exceed those of any other Large Marine Ecosystem (Cheung et al. 2010).

Since the last assessment concerning the fish species in Greenlandic waters (Nielsen & Bertelsen 1992), five species have been found originating from the southern regions (Atlantic) mainly from shallow waters (<400 m). Their arrival in Greenland is likely to be a result of increasing temperatures (Møller et al. 2010).

These species are common in Iceland and northern European waters, and it seems likely that they have been recruited from Iceland via the Irminger and West Greenland currents, which is a well-documented route for Atlantic cod (Wieland & Hovgaard 2002, Hovgaard & Wieland 2008).

Increasing temperatures have also caused growing stocks of commercial boreal species such as Atlantic cod and Haddock (*Melanogrammus aeglefinus*) (Stein 2007).

Despite the positive effects of climate warming predicted for Arctic fisheries, it is still not clear how invading species interact with native species and how this effects food web interactions.

8.5 Marine mammals and seabirds

The impacts of climate change on marine mammals and seabirds are likely to be profound, but not so easy to estimate since patterns of changes are non-uniform and highly complex (ACIA 2005). There is a limit to how far north High Arctic species can shift to follow the sea-ice. If the loss of sea-ice will be as dramatic (temporally and spatially) as projected by ACIA-designed models, negative consequences for Arctic mammals that depend on sea-ice for breeding and foraging can be expected within the next few decades.

Laidre et al. (2008) compared seven Arctic and four sub-Arctic marine mammal species in regard to their habitat requirements and evidence for biological and demographic responses to climate change. They found that hooded seal, polar bear, and narwhal appear to be the three most sensitive Arctic marine mammal species, primarily due to their reliance on sea-ice and specialised feeding behaviour. The least sensitive species were ringed seal and bearded seal, primarily due to large circumpolar distributions, large population sizes, and flexible habitat requirements. In using a conceptual model, Moore & Huntington (2008) estimated the impacts and resilience of marine mammal species to changes in sea-ice in combination with follow-up changes in benthic and pelagic communities. The response of the mammals on habitat loss (sea-ice) and change in food sources will differ depending on whether they are ice-obligate (e.g. polar bear, ringed seals), ice-associated (certain seals, white whale, narwhal, bowhead whale and walrus) or seasonally migrant species (i.e. fin and minke whales).

Polar bears appear to be at risk since their habitat is changing and there is limited scope for a northward shift in distribution. According to Derocher et al. (2004) spatial and temporal sea-ice changes will lead to shifts in trophic interactions involving polar bears through reduced availability and abundance of their main prey: seals. In the short term, climatic warming may improve polar bear and seal habitats if currently thick multi-year ice is replaced by annual ice with more leads, making it more suitable for seals. However, a cascade of impacts beginning with reduced sea-ice will be manifested in reduced adipose stores, leading to lowered reproductive rates. As sea-ice thins, it is likely to be more fractured and labile and more reactive to winds and currents. As a result, polar bears will need to walk or swim more and thus use greater amounts of energy to maintain contact with the remaining preferred habitats (Derocher et al. 2004).

The increased fragmentation and loss of sea-ice habitat, as a consequence of climate change, is the single most critical conservation concern for polar bears. Global warming has been amplified at high latitudes in the northern hemisphere and a number of studies have documented significant reductions in extent and duration. Recent predictions of continued climate warming show unidirectional, negative changes to sea-ice, although the timing and rate of change will not be uniform across the circumpolar Arctic. However, because of their dependence on sea-ice habitat, the impacts of continued climate change will increase the vulnerability and risk to the welfare of all polar bear subpopulations. Population and habitat modelling have projected substantial future declines in the distribution and abundance of polar bears and in thickness and age of sea-ice (Lunn et al. 2010).

Projections of polar bear sea-ice habitat distribution in the polar basin during the 21st century were developed to understand the consequences of anticipated sea-ice reductions on polar bear populations. Location data from satellite-collared polar bears and environmental data (e.g. bathymetry, distance to coastlines, and sea-ice and collected from 1985 to 1995) were used to describe habitats that polar bears preferred in summer, autumn, winter and spring (Durner et al. 2009). Monthly maps of 21st-century sea-ice concentration projected by 10 general circulation models

(GCMs) used in the Intergovernmental Panel of Climate Change Fourth Assessment Report, indicated habitat losses in the polar basin during the 21st century. Mean loss of optimal polar bear habitat was greatest during summer; from an observed 1.0 million km^2 in 1985-1995 (baseline) to a projected mean of 0.32 million km^2 in 2090-2099 which presents a reduction of 68 %. Projected winter losses of polar bear habitat were less: from 1.7 million km^2 in 1985-1995 to 1.4 million km^2 in 2090-2099 (−17 % change). Durner et al. (2009) concluded that reduction in the total amount of optimal habitat will likely reduce polar bear populations, but exact relationships between habitat losses and population demographics are not known. The projected change in habitats will probably affect specific sex and age groups differently and may ultimately preclude bears from seasonally returning to their traditional ranges.

For widely distributed seabirds, such as the thick-billed murre, changes in the extent and timing of sea-ice cover over the past several decades are leading to changes in phenology and reproduction with adverse consequences for nestling growth (Gaston 2010). The direct response of common eiders, another important seabird for the Arctic ecosystem including the assessment area, to climate change is currently under investigation in several countries. In Iceland, local weather conditions appear to affect nesting dates and clutch sizes, although not consistently between colonies. The North Atlantic Oscillation Index was found to have no effect on the survival of eider females in Finland. The management of human harvest of eiders or their products, and the management of introduced predators such as foxes and mink (*Mustela vison*), will remain important (Merkel & Gilchrist 2010). In East Greenland common eiders have expanded their breeding range over several 100 km towards north in recent decades as a response to more open waters along the coasts (Boertmann & Nielsen 2010).

The ivory gull is a sea-ice obligate species, which face the same threats as the polar bear and there is concern for the future of the species (Gilg et al. 2009, 2010).

More and more information has been gathered in the past years to provide evidence that change in Arctic climate has a large potential to modify the marine ecosystems, either through a bottom-up reorganization of the food web by altering the nutrient or light cycle, or top-down reorganization by altering critical habitat for higher trophic level (Macdonald et al. 2005). At present, we have only started to understand the possible impacts and consequences of climate change for the Arctic marine environment. Complexity arising from alterations to the density, distribution or abundance of keystone species at various trophic levels, such as polar bears and polar cod, could have significant and rapid consequences for the structure of the ecosystems in which they currently occur.

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

8.6 Interactions between climate change and other stressors

Climate change will have profound impacts on the ecosystems and their components in the Arctic, and it will act on populations in combination with the human induced stressors such as oil spill, contaminants (see below) and hunting. Most true Arctic species populations such as polar bear, ivory gull and little auk, will most likely suffer from the changes becoming much more sensitive to the other human induced stressors. This will make it important to consider all the stressors in combination when assessing impacts of especially major oil spills in the future.

8.6.1 Climate change and contaminants

The Arctic environment is now clearly affected by climate change, but also by human releases of contaminants as indicated in Chapter 7 of this SEIA.

Climate change will affect contaminant exposure and toxic effects (Macdonald et al. 2005) and both forms of stress will impact aquatic ecosystems and biota in many ways (Schiedek et al. 2007, Noyes et al. 2009). An overview of possible changes and consequences is given in Table 15.

Pathways, distribution patterns and / or toxicity of certain contaminants are likely to change; native organisms are likely to become less tolerant to contaminant exposure due to higher temperatures (Macdonald et al. 2005, Schiedek et al. 2007). Species distribution ranges will change, and some will be displaced by temperate species which might differ in their contaminant tolerance. Additional possible risks could be caused by oil contamination due to offshore oil and gas resources being developed as well as increased ship traffic (AMAP 2010, PAME 2009). Climate change may also lead to increased pollution loads resulting from an increase in precipitation bringing more river borne pollution northward (Macdonald et al. 2005).

Toxicology and toxico-kinetics of persistent organic pollutants (POPs) could be altered as a direct result of changes in temperature. Climate change will also alter other environmental features, such as salinity or ocean acidification which alone or in combination could enhance the toxic effects of POPs on wildlife, and species vulnerability (AMAP 2011b).

Bio-magnification of many persistent organic pollutants (POPs) is particularly high for higher trophic levels (i.e. mammals); these animals are also among the most vulnerable to climate change as described above. Relationships between various POPs and hormones in Arctic mammals and seabirds imply that these chemicals pose a threat to the endocrine systems of these animals, in particular the thyroid hormone system, but effects have also been seen in sex steroid hormones and cortisol (Jenssen 2006). Different endocrine systems are important for enabling animals to respond adequately to environmental stress, and endocrine-disrupting chemicals may interfere with the adaptation to increased stress, e.g. that induced

Table 15. Climate change-induced toxicological effects of contaminants on wildlife (after Noyes et al. 2009s and references therein).

Climate changes induced effects	Relationships / Interactions
Altered uptake and elimination	• increasing temperature = increasing uptake of toxicants • increasing temperature = increasing elimination • increasing temperature = remobilization of bioaccumulated POPs
Increased toxicity	• increasing temperature = increasing toxicity • increasing temperature = increasing metabolism and potentially altered metabolite profiles • toxicant exposure may limit capacity of species and populations to acclimate to altered temperatures • pollutant-exposed ectotherms and species at the edge of their physiological tolerance range may be especially sensitive to temperature increases
Altered environmental salinity	• decreasing solubility and increasing bioavailability of pesticides / POPs (“salting out effect”) • increasing salinity + increasing POP / pesticide exposure may alter ossmoregulation due to altered enzymatic pathways
Altered ecosystems	• altered POP sequestration and / or remobilization through shifts in food sources and starvation events • shifts in disease vector range and severity coupled with toxicant exposure inhibiting immune response may leave wildlife more susceptible to disease • low level exposures may impair organism acclimation to ecosystem alterations induced by climate change • climate change induced changes in trophic food webs may alter POP bioaccumulation and biomagnification

by climate change (Jenssen 2006). Presently, possible interactions between climate change and contaminants have not been studied in great detail and therefore our knowledge is still very limited.

Climate change is expected to alter environmental distribution of contaminants and their bio-accumulation due to changes in transport, partitioning, carbon pathways and bio-accumulation process rates. Magnitude and direction of these changes and overall bio-accumulation in food webs is currently not known. In a study performed by Borgå et al. (2010) a first attempt has been made to quantify the effect of climate change (i.e. increased temperature and primary production). It was assumed that there were no changes in food web structure and in total air and water concentrations of organic contaminants. To determine the effect of climate change, a bio-accumulation model was used on the pelagic marine food web of the Arctic. The effect of climate change on model parameters and processes and on net bio-accumulation, were quantified for three substances (g-hexachlorocyclohexane (HCH), polychlorinated biphenyl (PCB)-52, and PCB-153) and for two possible climate scenarios. It was found that increased temperature and primary production reduced the overall bio-accumulation of organic contaminants in the Arctic marine food web, with the largest change being for PCB-52 and PCB-153 (Borgå et al. 2010). In future studies other aspects such as altered contaminant transport or food web structure have to be addressed.

The influence on recent changes in feeding ecology (1991-2007) in polar bears from the western Hudson Bay subpopulation on the exposure and accumulation of contaminants was reported by McKinney et al. (2009). Differences in timing of the annual sea-ice breakup explained a significant proportion of the diet variation among years which resulted in increases in the tissue concentrations of several chlorinated and brominated contaminants. The increased levels coincided with an increase in the consumed proportions of open water-associated seal species compared to ice-associated seal species in years of earlier sea-ice breakup. This demonstrate that climate change is a modulating influence on contaminants in this polar bear subpopulation and may pose an additional and previously unidentified threat to northern ecosystems through altered exposures to contaminants (McKinney et al. 2009).

8.7 Conclusions

Climate change may alter patterns of POP bio-accumulation and bio-magnification by altering bottom-up or top-down mechanisms controlling trophic food webs (Braune et al. 2005, Schiedek et al. 2007). Climate change-induced alterations in bottom-up controlling mechanisms, such as altered nutrient and primary production, may lead to the addition or removal of trophic levels (MacDonald et al. 2005). This in turn could shift predators higher or lower in the aquatic food web, leading to a respective increase or reduction of POPs. Top-down alterations in trophic structures elicited by the changing climate, for example, could involve the loss or diminished populations of higher trophic level species leading to consumption further down the food chain and reduced POP bio-magnification potential.

Increased temperature and salinity linked to climate change could enhance the toxicity of some POPs and other pesticides in aquatic biota. Altered bio-transformation of contaminants to more bioactive metabolites appears to be an important mechanism by which climate change enhances chemical toxicity. Moreover, these climate change and contaminant interactions could compromise homeostasis and physiological responses, potentially impairing species fitness, reproduction, and development (Heugens et al. 2001, Schiedek et al. 2007, Brian et al. 2008).

The complex interactions between climate change and pollutants may be particularly problematic for species living at the edge of their physiological tolerance range. For most species, there are optimum ranges of temperature, salinity, pH, moisture, etc., and organisms living under conditions that approach their tolerance limits are often more vulnerable to additional stressors, such as climate change and chemical pollution (Noyes et al. 2009, and references therein). Species with narrow ranges of tolerance to changing environmental conditions may have difficulty acclimating to climate change.

Altered habitats caused by the rapidly changing climate also could trigger species migrations that ultimately push populations into suboptimal regions where they may experience reduced overall fitness and diminished tolerance to toxicant exposures (Schiedek et al. 2007).

The Disko West assessment area includes the southern limit of present winter sea-ice cover in West Greenland. It can therefore be seen as a transition area, and the biota living there are likely to be affected by the expected changes, with significant consequences for the ecosystem and the living resources.

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

9 Impact assessment

D. Boertmann, D. Schiedek, A. Mosbech and S. Wegeberg

9.1 Methodology and scope

The following assessment is based on available information compiled from studies published in scientific journals and reports, as well as from previous NERI/DCE technical reports (e.g. Mosbech et al. 1996, Boertmann et al. 1998, Mosbech 2002, 2007a) and information obtained from the oil spill sensitivity atlases prepared for the region (Clausen et al. 2012, Stjernholm et al. 2011). Another source of data are those collected by Marine Mammals and Seabird Observers (MMSO) during seismic surveys and other geophysical studies for the oil companies in relation to on-going and planned oil exploration activities. All this knowledge has been summarised in the previous Chapters 3 to 8. Finally, results of the different studies initiated specifically for the present assessment have been included (see Chapter 12).

9.1.1 Boundaries

The assessment area covers the area described in the introduction (Figure 1). It is the region which potentially can be impacted by activities performed in relation to oil exploration and exploitation activities. Particularly large and long-lasting oil spills have the potential to impact extensive areas and far from the spill site.

However, it cannot be excluded that the area affected might be even larger including coasts both north and south of the assessment area and also areas along the Canadian coast, e.g. Baffin Island.

The assessment includes, as far as possible, all activities associated with the 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 ice coverage in winter and spring. Production activities, if decided upon and initiated, are likely to take place throughout the year. How production facilities eventually will be established is presently not known. A setup is described in Section 2.6.

9.1.2 Impact assessment procedures

The first step in an 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 often not possible to evaluate all ecological components in the area, the concept of Valued Ecosystem Components (VEC) has been applied.

VECs can be species, populations, biological events or other environmental features that are important for the ecosystem or to the human population, have a national or international profile, can act as indicators for environmental change, or can be the focus of management or other administrative efforts. VECs can also be important flora and fauna groups, habitats (also temporary and dynamic ones such as the marginal ice zone or polynyas) and processes such as the phytoplankton spring bloom indicating intensive primary production.

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 16, 17, 19). The tables are based on worst-case scenarios for impacts, under the assumption that current (2012) 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 (e.g. migratory birds), or a large part of a regional population (e.g. a large seabird colony).

It should be emphasized that quantification of the impacts on ecosystem components is difficult and in many cases impossible. The spatial overlap of the expected activities can only be assessed to a limited degree, as only the initial oil activities are known at this point. Furthermore, the physical properties of potentially spilled oil are likewise not known. Moreover, there is still a lack of knowledge concerning important ecosystem components and how they interact. In addition, climate change now impacting ecosystem functioning, potentially alters many of the interactions.

Relevant research regarding toxicology, ecotoxicology of petroleum related compounds and their effects and sensitivity of organisms to disturbance has been used, and 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, as well as the Norwegian assessment of hydrocarbon activities in the Lofoten-Barents Sea (Anon 2003b) have been drawn upon.

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

10 Impacts of the potential routine activities

D. Schiedek, D. Boertmann, A. Mosbech, S. Wegeberg, O.A. Jørgensen, K. Sünksen and F. Ugarte

10.1 Exploration activities

In general all activities related to oil exploration are temporary and will be terminated after a few years if no commercial discoveries are being made. Another important aspect in relation to oil exploration is that the activities are limited to a period when the sea is more of less free of ice. However, some activities may take place in ice covered waters, as a company in 2010 carried out 2D-seismic surveys in lightly ice covered waters off Northeast Greenland, with the aid of a large ice breaker.

Environmental impacts of exploration activities relate to:
- Noise from seismic surveys and drilling
- Cuttings and drilling mud
- Disposal of various substances
- Emissions to air
- Placement of structures.

In connection with oil exploration only the most significant impacts (i.e. noise, cuttings and drilling mud) will be considered in the assessment. The other listed issues will be 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.

10.1.1 Assessment of noise

Noise from seismic surveys

The main environmental concerns relates to effects on biota caused by the generation of sound 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).

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

In Arctic waters there are certain special conditions which have to be considered. Owing to ray bending caused, for instance by a strongly stratified water column, it cannot be assumed that there is a simple relationship between sound pressure levels and distance to source. This makes it difficult to base impact assessments on simple transmission loss models (spherical or cylindrical spreading) and to apply results from assessment 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, which is particularly evident in stratified Arctic waters. This has also been documented by means of acoustic tags attached to sperm whales, which recorded high sound pressure levels (160 dB re μPa, peak to peak) more than 10 km from a seismic array (Madsen et al. 2006).

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

In the following potential impacts on different ecosystem components are discussed and assessed.

Impact of seismic noise on zoo- and ichtyoplankton

Zooplankton (e.g. copepods such as *Calanus* and larvae of benthic crustaceans) and fish larvae and eggs (= ichtyoplankton) cannot avoid the pressure wave from the airguns and can be killed within a distance of less than 2 m and sublethal injuries may occur within 5 m (Østby et al. 2003). The relative volume of water affected in this way by a seismic survey will be small and population effects, if any, are considered to be very limited, according to Norwegian and Canadian assessments (Anon 2003b). However, in Norway, specific spawning areas in certain periods of the year may have very high densities of fish larvae in the uppermost water layers. Therefore the Lofoten-Barents Sea area is closed for seismic activities during the cod and herring spawning period in May-June (Anon 2003b). In the previous assessment of seismic activities and their impacts in the Disko West area it was concluded that impacts due to seismic activities (3D) were negligible for the recruitment of fish stocks in West Greenland waters (Mosbech et al. 2007a). Densities of fish eggs and larvae are generally low in the upper 10 m and most fish species spawn in a dispersed manner in winter or spring, which minimise the temporal overlap with seismic activities. It is therefore most likely that impacts of seismic activity (even 3D) on zooplankton and thus on fish recruitment are negligible in the assessment area.

Impact of seismic noise on fish

There is agreement among experts that adult fish will generally avoid seismic sound waves, in seeking towards the bottom, and thus not being harmed. Young Atlantic cod and redfish (30-50 mm long), are able to swim away from the mortal zone near the airguns (comprising of a few meters) (Nakken 1992).

It has been estimated that adult fish can react to an operating seismic array at distances of more than 30 km, and that intense avoidance behaviour can be expected within 1-5 km (see below). Norwegian studies measured declines in fish density at distances more than 10 km from sites of intensive seismic activity (3D). Negative effects on fish stocks may therefore occur if adult fish are scared away from localised spawning grounds during the spawning season. Outside 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 μPa peak to peak) down to 5-15 m distance sustained extensive ear damage, with no evidence of repair nearly 2 months after exposure (McCauley et al. 2003). It was estimated that a comparable exposure could be expected at ranges <500 m from a large seismic array (44 l) (McCauley et al. 2003). It appears that the fish avoidance behaviour demonstrated in the open sea protects the fish from damage. In contrast to these results, marine fish and invertebrates monitored with a video camera in an inshore reef did not move away from airgun sounds with peak pressure level as high as 218 dB (at 5.3 m relative to 1 μPa peak to peak) (Wardle et al. 2001). The reef fish showed involuntary startle reactions (C-starts), but did not swim away unless the explosion source was visible to the fish at a distance of only about 6 m. Despite a startle reaction displayed by each fish every time the gun was fired, continuous observation of fish in the vicinity of the reef using time-lapse TV and tagged individuals did not reveal any sign of disorientation, and fish continued to behave normally in similarly quite large numbers, before, during and after the gun firing sessions (Wardle et al. 2001). Another study 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 during night when sand eels were buried in the sediment (Hassel et al. 2004).

The studies described above indicate that behavioural and physiological reactions to seismic sounds among fish vary between. 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 of short term and catches would return to normal after the studies. The effect was more pronounced for large fish compared to smaller fish.

In a recent study, impacts of 3D seismic survey on gillnet and longline fisheries were investigated, showing some 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 catches in gillnet showed a tendency to decrease (but not statistically significant) during the shooting. However, also acoustic surveys of fish densities indicated that saithe left the shooting area.

An analysis of the official catch statistics from an area with seismic surveys in Norway in 2008 showed very different results (Vold et al. 2009): Catch rates of Atlantic cod, ling (*Molva molva*), tusk (*Brosme brosme*) and Atlantic halibut had not changed significantly. Catch rates of redfish and monkfisk (*Lophius piscatorius*) seemed to increase, while catch rates of saithe and haddock caught in gillnet decreased and catches with other gear was not affected. The majority of the seismic surveys included in the analysis were 2D and scattered in time and space.

A Canadian review (DFO 2004) concluded that the ecological effect of seismic surveys on fish is low and that changes in catchability probably are species dependent in line with the Norwegian studies.

In Greenland waters, including the assessment area, the commercial fisheries which 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 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 was found in the gillnets. There are also other examples for 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) and mentioned above cannot be applied to other fish species and to fisheries taking place at other water depths, such has the Greenland halibut fishery.

In summary it can be stated that there will be a risk of reduced catches of Greenland halibut in areas with intensive seismic activity, but probably only during a certain period. The trawling grounds within the assessment area are, however, spatially restricted at depths of approx. 1,500 m and on the narrow continental slope; thus alternative fishing grounds might be limited. Local fishery companies operating there have so far not recorded reduced catches in periods when fishery and seismic surveys took place at the same time (Frans Heilmann, Polar Seafood pers. comm.).

Regarding possible effects of seismic shooting on invertebrates, there is in general very little knowledge, 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, emphasizes the lack in information to evaluate the effects on crustacean 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). Behaviour associated with hearing has so far 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 (Andriguetto-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 or fishery on this resource were evaluated, and both the population and the fishery on it were considered as relatively robust to 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.

Almost nothing is known about underwater hearing of diving sea birds 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 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 damages in the ear. Behavioural responses include changes in surfacing, diving and heading patterns, and may result in displacement from the affected area or reduced feeding success. Low frequency sounds may effectively mask the calls of baleen whales, thus interfering with their social activities and/or navigation and feeding activities. Acoustic responses to masking by anthropogenic noise include changes in type or timing of vocalisations. In addition, there may be indirect effects associated with altered prey availability (Gordon et al. 2003).

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 temporary reduced hearing ability is considered unimportant by Canadian researchers; unless it develops into permanent threshold shift (PTS, permanent heraing loss) or occurs in combination with other threats normally avoided by acoustic means (DFO 2004).

In the USA a sound pressure level of 180 dB re 1 µPA) (rms) or higher has been adopted by the US National Marine Fisheries Service as a mitigation standard to protect whales from exposures considered capable of inducing temporary or permanent damage to their hearing (NMFS 2003, Miller et al. 2005). This exposure criterion is poorly defined from a measuring point of view 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 discussions and it is to be seen if and how they will be implemented in future 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 re 1 µPA 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). 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). Stone & Tasker (2006) showed a significant reduction in marine mammals sightings during seismic surveys in the UK during periods of shooting compared with non-shooting periods.

In the Alaskan Beaufort Sea it was shown that bowhead whales change their behaviour when exposed to low frequency sound from airgun arrays (e.g. Reeves et al. 1984, Richardson et al. 1986, Ljungblad et al. 1988). Humpback whales have been observed to consistently change course and speed in order to avoid close encounters with operating seismic arrays (McCauley et al. 2000).

Di Iorio & Clarck (2010) documented that blue whales increase their calling rate during seismic surveys, probably as a compensatory behaviour to the elevated ambient noise. Fin whales can also change the acoustic characteristics of their sounds (Castellote et al. 2010). On the other hand, Dunn & Hernandez (2009) tracked blue whales that were at 15-90 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 also been observed as close as 100 m from operating airgun arrays (NERI 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 and Madsen et al. (2006) found no reaction of sperm whales to a seismic survey tens of km away).

The ecological significance of displacement is generally unknown. If alternative areas are available the impact will probably be low. The temporary character of seismic surveys will also allow displaced animals to return after the surveys. However, if the area is critical to the survival of the population, displacement could lead to population decline. Such critical areas can be difficult to identify, but a good example are the summer grounds for narwhals (outside the assessment area), cf. the SEIA for Baffin Bay (Boertmann & Mosbech 2011).

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 study based on cetacean and prey surveys showed that rorquals (fin, sei, blue, minke and humpback whale) and krill aggregate in three high density areas on the West Greenland banks (Laidre et al. 2010). One of these important feeding areas covers an area south of the assessment area. Displacement from such important feeding areas may have a negative impact on the energy uptake of the rorquals that are in West Greenland to feed before their southward migration. Given the extent of 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 at the same time be excluded from both key habitats and alternative foraging grounds.

The US National Marine Fisheries Service defines the radii about a seismic ship with received sound levels of 160 dB (re 1 μPA) as the distances within which some cetaceans are likely to be subject to behavioural disturbance (NMFS 2005 in Dunn & Hernandez 2009). Actual distances would depend on the source levels of the airgun array, the salinity and temperature layers of the water and the depth of the observation.

A few studies have observed lack of measurable behavioural changes by cetaceans exposed to the sound of seismic surveys taking place several kilometres away. In the above mentioned blue whale study it was estimated that the whales experienced sounds of less than 145 dB (re 1μPA) and it was concluded that their study supported the current US-NMFS guidelines, but also that further studies with more detailed observations are needed (Dunn & Hernandez 2009).

A behavioural effect widely discussed in relation seismic surveys and whales is the masking effect of communication and echolocation sounds.

There are, however, very few studies which document such effects (but see Castellote et al. 2010 and Di Iorio & Clark 2010), mainly because the experimental setups are extremely challenging. Masking requires overlap in frequencies, overlap in time and sufficiently high sound pressures. The whales and seals in the assessment area use a wide range of frequencies (from <10 Hz to >100 kHz, Figure 24), why the low frequency sounds of seismic surveys are likely to overlap in frequency with at least some of the sounds produced by these marine mammals.

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 which have 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 would be the marine mammals most affected by auditory masking from seismic surveys (Gordon et al. 2003) and it has been demonstrated that blue whales increase their calling rate during seismic surveys, perhaps as a compensatory behaviour to the elevated ambient noise (Di Iorio & Clark 2010).

Sperm whales showed diminished forage effort during air gun emission. It is not clear if this was due to masking of echolocation sounds or to behavioural responses of the whales or the prey (Jochens et al. 2008).

The most noise-vulnerable whale species in the assessment area will be white whale, narwhal and bowhead whale. But they are mostly absent from the area when seismic surveys usually are carried out (summer and autumn). There is, however, a risk of overlap with seismic operations in late autumn in some specific areas: Narwhals have well-defined migration routes and winter habitats within the assessment area, and here there is a risk of displacement especially caused by 3D surveys. The migration areas are those where the animals could be exposed to seismic noise, whereas the winter quarters are the most critical; however no seismic surveys will take place there in winter.

Seismic activities are currently regulated in the assessment area in order to minimise overlap with the occurrence of narwhals (Kyhn et al. 2012).

Other whales occurring in summer and autumn will also be vulnerable, but their occurrence in the assessment area is less regular and no concentrations areas are known.

Seals, on the other hand, display considerable tolerance to underwater noise (Richardson et al. 1995), confirmed by a study in Arctic Canada, where ringed seals showed only limited avoidance to seismic operations (Miller et al. 2005), and in many areas they have also habituated to industrial noise (Blackwell et al. 2004). Walruses may be disturbed and displaced by seismic activity (especially when hauled out on ice) and not so much by the seismic noise. The important winter feeding and mating ground for walrus in the assessment area (Figure 20) will be sensitive to such disturbance, but seismic activities are not carried out when walruses are present.

Mitigation of impacts from seismic noise

Mitigation measures generally recommend a soft start or ramp up of the airgun array each time a new line is initiated (review by Compton et al. 2008). Although not verified by experiments or observations, this approach is commonly considered 'best practice'. A soft start will allow marine mammals to detect and avoid the sound source before it reaches levels dangerous to the animals.

Secondly, it is recommended to have skilled marine mammal observers onboard 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 can be more efficient, depending on species, if supplemented by the use of hydrophones for recording whale vocalisations (Passive Acoustic Monitoring – PAM), although whales not necessarily emit sounds, when present.

But visual observation in Arctic waters may not preclude effects on whales. For example may very high sound pressures occur far from the sound source and out of sight of the observer, and visual observation can be hampered by fog and darkness late in the season.

A third mitigating measure is to close areas during sensitive periods. In the Lofoten-Barents Sea, for instance, spawning grounds for herring and Atlantic cod are closed for seismic surveys during the spawning season of these two species.

Finally, it is recommended to inform local authorities and the hunters' organisations before seismic activities take place. 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 the subsistence hunting on these (Miller et al. 2005). Some are identical to those mentioned above, while the most important was a delay in 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 even were completely closed for surveys.

DCE has issued a set of guidelines for conducting seismic surveys in Greenlandic waters and protection areas (where seismic surveys are regulated) are designated for specific species (Kyhn et al. 2012).

In these guidelines following best practice is recommended (in line with the JNCC 2010 recommendations):

- The airgun array should not be larger than needed for the specific survey.
- Use of mitigation gun. The mitigation gun is the smallest airgun in the array in terms of energy output (dB) and volume (in^3). Output from the array should be reduced to the mitigation gun as outlined below.
- A safety zone of 500 m from the airgun array shall be applied.

- An injury zone of 200 m shall be applied. If marine mammals are observed within 200 m during full power, the output shall be reduced to the mitigation gun until the mammal has left the zone.
- A pre-shooting search shall be conducted before commencement of any use of the airguns. If waters are less than 200 m deep, this search shall last 30 min. When operating in waters with a depth of more than 200 m, it shall be extended to 60 min. If marine mammals are spotted within the safety zone, the ramp-up procedure shall be delayed 20 minutes, from the time when the animal has left the safety zone (or the ship has moved so far that the animal is outside). The pre-shooting search can be initiated before the end of a survey line, while the airguns are still firing.
- The array shall not be started at full power, but individual airguns should be added one by one or if not possible, output of each airgun slowly increased by manipulation of pressure (ramp-up or soft start procedure).
- The ramp-up procedure shall occur over a period of about 20 min and can be carried out while the survey ship is en route to the starting point of the transect line.
- Ramp-up should not be initiated if marine mammals are inside the array or within the safety zone (500 m) of the array. If marine mammals are discovered within this safety zone during the ramp-up procedure, the airguns shall be reduced to the mitigation gun, and a new ramp-up procedure initiated when the mammal has left the safety zone – i.e. at least 20 min. after the last sighting.
- If proper ramp-up cannot be performed for technical or other reasons, other measures should be taken to assure that no animals are within the safety zone at start up.
- Passive Acoustic Monitoring (PAM) of vocalizing whales shall be deployed for monitoring purposes during start up at night or during periods when the sea state is above 3; especially in areas with bowhead whales.
- If the array is shut down for any reason while on the transect line it can be re-initiated at full power given that the silent break is no longer than 5 min. Otherwise a full ramp-up procedure should be followed.
- During line changes the array output should be reduced to the mitigation gun, if the transit time is longer than the time it takes to conduct a ramp-up and a full ramp-up should be initiated prior to arrival at the next line. If transit time is less than 20 min the array can be operated during transit, preferably at reduced power output (the mitigation gun).
- At least two Marine Mammal and Seabird Observers (MMSO) shall be posted on the source vessel (where the airguns are deployed from) and minimum one should be continuously on the look-out particularly for whales and seals during the pre-shooting search and when airguns are operated.
- Observation of marine mammals during shooting and inside the safety zone may not lead to shutdown, but if marine mammals are observed within the 200 m injury zone of the array, output should be reduced to the mitigation gun until the marine mammals are outside the 200 m zone again.
- A log of marine mammal observations should be kept on the ship and reported as part of the cruise report.
- Airguns should not be used outside the transect lines, except in the cases mentioned above (ramp-up prior to arrival and on short transit lines) and for strictly necessary testing purposes. Testing the array at full power shall be initiated with a ramp-up procedure as above.
- When planning seismic surveys it should be aimed at to minimise the overall exposure to the most possible degree in using the smallest airgun array necessary to obtain the data needed. The total exposure is a complex function of a) number of animals exposed, b) duration of exposure for each animal and c) the sound level each of them is experiencing. Nevertheless, reducing any of the three parameters will also reduce the total exposure. Thus the possibility to limit one or more of these factors should be considered in the planning.

Conclusions on disturbance from seismic noise (Table 16)

Regarding noise from seismic activities, the most sensitive VECs in the Disko West assessment area are bowhead whales, narwhals, white whales and walrus. The occurrence of these species usually does not overlap with the season for seismic surveys. However, late in the season (October/November) there is a risk for overlap with migrating white whales and narwhals, a risk which increases if seismic surveys are facilitated by the use of icebreaker.

There is also a risk of displacement from important/critical habitat of other species, such as fin, blue, humpback and especially minke whale.

Displacement of hunted species may also impact the availability (for hunters). If the affected areas include traditionally hunting grounds there will be a risk of reduced availability of quarry species.

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

The offshore fishery for Greenland halibut may encounter reduced catches for a period during and after intensive seismic shooting, due to displacement of the fish although this has so far not been observed.

Noise from drilling units

Noise from drilling units has two sources, 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 the seismic airguns.

Generally, drill ships generate more noise than a semi-submersible platform, which in turn produces more noise than a jack-up. The latter 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 drilling 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

Table 16. Overview of potential impacts from single seismic 2D and 3D surveys on VECs in the Disko West assessment area. See Section 4.9 for a summary of the VECs. It is important to note that a single seismic survey is temporary and that cumulative impacts by several simultaneous or consecutive surveys may be more pronounced. This assessment assumes the application of current (2012) mitigation guidelines, see text for details.

		Population impact* – worst case			
VEC	Typical vulnerable organisms	Displacement 2D	Displacement 3D	Sublethal effect	Direct mortality
Pelagic hotspots	copepods, fish larvae	–		insignificant(L)	insignificant(L)
Tidal/subtidal zone	none	–		–	–
Demersal fish & offshore benthos	Gl. halibut	short term(L)		insignificant	none
Seabirds (breeding)	none	–		–	–
Seabirds (non-breeding)	none	–		–	–
Marine mammals (summer)	baleen- & toothed whales	short term(L)	short term(L)	insignificant(R)	none**
Marine mammals (winter)	bowhead, white whale, narwhal	short term(L)	short term(L)	insignificant(R)	none**

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

measured noise levels were similar to those known from other drill ships and were above those reported from semi-submersibles and drill rigs. It corresponded to fast moving merchant ships with source levels of up to 184-190 dB re 1 μPa during drilling and maintenance work. Both drilling and maintenance work results in tones that are higher than the background noise levels at ranges of 16-38 km from the ship and can be regarded as a substantial noise source (Kyhn et al. 2011).

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 it is assumed that 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). Auditory masking from boat noise has been demonstrated for white whales and killer whales in Canada (Foote et al. 2004, Scheifele et al. 2005). In Alaskan waters migrating bowhead whales avoided an area with a radius of 10 km around a drill ship (Richardson et al. 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).

Bowhead whales' usually occur in the assessment area late in the winter and in spring until early June. The migration corridor across Baffin Bay seems to be wide enough to provide alternative routes and displacement of single animals similar to that described from the Beaufort Sea has probably no significant effect here.

Other whales living on the shelf – such as fin, minke, humpback and blue whale as well as white beaked dolphins and harbour porpoises – and whales living in deep waters on the continental slope could also be displaced by drilling operations. However, there is no knowledge so far on critical habitats for these species in the assessment area.

Conclusion on noise from exploration drilling rigs (Table 17)

Exploration activities are temporary, and displacement of marine mammals caused by noise from drilling rigs will also be temporary. The most vulnerable species in the assessment area are narwhal, white whale, bowhead whale and walrus, but the temporal overlap between these species and exploration drilling will be short and restricted to late autumn. The other species are less vulnerable, but if several rigs operate in the region, there is a high risk for cumulative effects for example displacement from alternative habitats.

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.

Table 17. Overview of potential impacts of noise and discharges from a single exploration drilling on VECs in the Disko West assessment area. See Section 4.9 for a summary of the VECs. This assessment assumes the application of current (2012) mitigation guidelines, see text for details.

		Population impact* – worst case		
VEC	**Typical vulnerable fauna**	**Displacement**	**Sublethal effect**	**Direct mortality**
Pelagic hotspots	plankton, zooplankton	–	insignificant (L)	insignificant (L)
Tidal/subtidal zone	none	–	–	–
Demersal fish &	Gl. halibut, sandeel	short term(L)	minor (R1)	minor (L)[2]
offshore benthos	filter feeders (e.g. bivalves)	short term(L)	minor (L)	minor (L)
Seabirds (breeding)	none	–	–	–
Seabirds (non-breeding)	king eider	short term (L)	insignificant (R)	none
Marine mammals (summer)	baleen- & toothed whales	short term (L)	minor (L)	none
Marine mammals (winter)	bowheads, bearded seal, walrus, narwhal	short term (L)	minor (L)	none

*L = local, R = regional; [1]tainting of commercial fish, [2]sandeels could be directly affected by discharges, since they are buried in the sediment most of the time.

10.1.2 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 have to be disposed of in some way.

The liquid base of the drilling mud may be water (WBM – water based mud) or synthetic fluids (SM – synthetic mud; ethers, esters, olefins, etc.) or oil (OBM – oil based mud).

The practice in Norway was until 1993, to dispose all the waste to the seafloor. However, release of OBM was, due to environmental concerns, 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 compounds.

OBMs are still used in Norway, mainly for special drillings under difficult conditions, and cuttings and mud are afterwards either reinjected or transported to land for treatment in specialised facilities.

The experience from Norway is that the environmental impacts on the seabed from OBM cuttings are widespread and long term (e.g. 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 depositions 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 after use of OBMs (Jensen et al. 1999). 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.

New studies in Norway (Research Council of Norway 2012) 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). The effects of cuttings sedimentation was shown to be less than expected, although long term effects and cumulative effects of sedimentation was not addressed, but such may be detected and prevented by the monitoring programmes.

The use of WBM may move some of the effects on the seafloor to the water column, where especially suspension of particles gives some reason for concern (Bechmann et al. 2006), but Research Council of Norway (2012) concludes that impacts will be local and short term on fauna in the water column.

Finally, is it important to be aware of the contents of heavy metals, esp. lead and mercury in the barite used in the drilling mud, as these metals have proved to be bioavailable from the released mud (Research Council of Norway 2012). This problem is of special concern in Greenland, where mercury in the environment has been in focus for many years (see Chapter 7).

For the Disko West assessment area knowledge concerning the seafloor fauna has been collected by the studies described in Box 3 (Benthic studies) and during environmental baseline surveys performed by Capricorn in 2009 and 2010. However, a full assessment of the potential impact of drilling mud and cuttings on benthic animals is presently not possible.

Multiple drilling carried out when a field is developed may cause more widespread effects on the benthos. Discharges of cuttings with water-based drill fluids are likely to disperse widely in the water column before reaching the seabed and may also impact pelagic organisms such as plankton (Røe & Johnsen 1999, Jensen et al. 2006).

The most sensitive organisms to suspended particles and sedimentation of cuttings are cold water corals such as the reef-forming hard corals *Lophelia* and sponges (Freiwald et al. 2004, SFT 2008). New research in Norway have 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 sediments was persistent, the underlaying tissues would die (Larsson & Purser 2011).

The Northwest Atlantic Fisheries Organisation (NAFO) considers coldwater corals and sponge fields, similar to seamounts and hydrothermal vents, as vulnerable marine ecosystems (VMEs). However, the particular sensitive habitats for these organisms (reefs and sponge gardens) have not been documented (so far) from the assessment area. But they have been located as close as the Canadian part of the Davis Strait near the border to Greenland (Campbell & Simms 2009, Kenchington et al. 2011).

The prescribed drill site surveys should make it possible to locate such reefs and sponge gardens before activities are initiated in order to avoid impacts.

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 and treatment in specialised facilities. This is usually the way to treat OBMs as described above. However, it creates other environmental impacts such as increased emissions of greenhouse gasses in relation to transport and pumping and problems with treatment or re-use on land (SFT 2008), which has to be balanced against the impacts on the water column and on the sea-floor (NEBA).

Impacts can be further reduced by application of environmentally safe drilling chemicals, such as those classified by OSPAR (HOCNF) as PLONOR (Pose Little Or No Risk to the Environment). However, in general these chemical have not been evaluated under Arctic conditions regarding degradation and toxicity, why all chemicals to be discharged should be assessed and evaluated before they are approved for release.

In Norway, releases to the marine environment of environmentally hazardous substances ('red' and 'black' chemicals) have been reduced by 99% during 1997-2007 by applying international standards, BAT and BEP (SFT 2008). In Greenland the use of 'black' chemicals is not allowed and the use of 'red' requires specific approval.

Impacts from oil contaminated drill cuttings shall be mitigated by keeping them on board for deposition or cleaning on land in specialised treatment facilities. Finally shall the companies carry out monitoring of the seabed (BACI-studies) a.o. to mitigate impacts

Conclusion on discharges from exploration drilling
Within the Disko West assessment area local effects on the benthos (e.g. sandeels or bivalves) are to be expected from the discharge of water-based muds (WBM) during exploration drilling (Table 17). Potential impacts on benthic feeders, such as king eider, walrus and bearded seal will probably not be significant. However, baseline studies shall be conducted in the vicinity of the proposed drill site to evaluate if there are unique communities or species that could be harmed and environmental monitoring should be performed to document spatial and temporal effects in relation to discharge of drilling materials.

10.2 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.

10.3 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 in the following way:

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

10.3.1 Produced water

During production several by-products and waste products occur which need to be treated or disposed in one way or the other. In this respect, 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 has the discharges during the 5% 'off normal time' in the Lofoten-Barents Sea 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). There is particularly concern regarding Poly Aromatic Hydrocarbons (PAHs), hormone-disrupting phenols, radioactive components and nutrients in relation to toxic concentrations, bio-accumulation, fertilisation, etc. (Rye et al. 2003).

Recent Norwegian studies reviewed by Research Council in Norway (2012) conclude that produced water have effects on fish and other marine fauna. These effects include damage on 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.

Impacts on the marine environment from produced water can be reduced by re-injecting it into wellbores. This is not always possible (SFT 2008) and when discharging produced water, international standards (OSPAR) must then be applied, i.e. the oil content may not be higher than 30 mg/l. In Norway released produced water had an average oil content of 11 mg/l in recent years (Anon 2011a).

Nutrient concentrations can be high in produced water (e.g. ammonia up to 40 mg/l). When released to the environment nutrients may act as fertiliser, which could impact especially 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 e.g. seabirds (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 respectively 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).

10.3.2 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 should at least be applied to minimise impacts. In addition, waste water of different kinds will be released. The environmental impacts of such 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 which 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 (Anon 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 which have impacted fisheries in a negative way (e.g. the comb jelly *Mnemiopsis* in the Black Sea (Kideys 2002)).

At present, the Arctic Ocean is the least severely affected areas 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 risk 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 (incl. Denmark/Greenland) to enter into force. This is expected to occur soon, and within a few years the convention hopefully will apply to all ships. All vessels and drilling units involved in hydrocarbon activities in Greenland have to follow the IMO guidelines or the relevant Canadian regulations.

Besides ballast water, invasive species can also be transported to the Arctic attached to the hull of the ships.

10.3.3 Placement of structures

The construction of subsea wells and pipelines has the potential to destroy parts of important habitats on the seafloor. Such 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 10.1.2).

Important habitats in this respect are also feeding grounds for bearded seal, walrus and king eider, which feed on benthic mussels and other invertebrates. Such an important feeding ground is the shallow part (50 m) of Store Hellefiskebanke.

An assessment of the impact of subsea constructions must wait until locations for oil exploration and production are known and site-specific EIAs and site specific studies have been carried out.

Structures may also have a disturbance effect particularly on marine mammals. Most vulnerable in this respect are the walruses, narwhals, white whales and bowhead whales.

Illumination and flaring attract birds during the night (Wiese et al. 2001). In West Greenland this relates in particular to eider ducks. Under certain weather conditions (e.g. 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 (Merkel & Johansen 2011).

A related problem is known from the North Sea, which millions of song birds cross at night time during their autumn and spring migrations. Under certain weather conditions large numbers of song 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-time migrating little auks has recently been expressed (Fraser et al. 2006). The highest densities of this species were, during the September 2009 survey, however found in the Canadian part of the Davis Strait (Box 7). It was recently shown that the attraction of birds can be mitigated by changing the illumination to colours not attracting birds, e.g. green (Poot et al. 2008).

Placement of structures will affect the fisheries due to exclusion (safety) zones. These areas, however, are small compared to the total fishable area. A drilling platform with an exclusion zone with a radius of 500 m covers approx. 7 km^2. In the Lofoten-Barents Sea area the effects of exclusion zones on the fisheries are generally estimated as 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 vessels will trawl across subsea structures and pipelines, while small often choose to avoid the crossing of such structures (Anon 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 shall also be considered in this context. They may impact habitats for unique coastal flora and fauna, and for example obstruct rivers with migrating Arctic char.

Aesthetic aspects are also important to include in this context. Landscape conservation can be important, especially for the tourist industry, as one of the main assets is the unspoiled nature. Background studies in the field combined with careful planning can reduce such impacts on the landscape.

10.3.4 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 to 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 away km from the sailing route (Davis et al. 1990).

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

Helicopters produce a strong noise which can scare marine mammals as well as birds. Particularly walruses hauled out on ice are sensitive to this activity, and there is risk of displacement of the walruses from critical feeding grounds. Walruses have a narrow foraging niche restricted to the shallow parts of the shelf (e.g. Store Hellefiskebanke). Activities in these areas may displace the walruses to suboptimal feeding grounds or to coastal areas where they are more exposed to hunting.

Seabird concentrations are also sensitive to helicopter flyovers. The most sensitive species is thick-billed murre at breeding sites. They will often abandon their nests for long periods of time and when scared off from their breeding ledges they may push eggs or small chicks off the ledge, resulting in a failed breeding attempt (Overrein 2002). There is only one breeding colony of thick-billed murre in the assessment area (in Disko Bay), and it is declining, why it is particularly sensitive to disturbance. Also concentrations of feeding birds can be sensitive, as they may lose feeding time due to the disturbance.

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

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

Concentrations of moulting sea ducks especially king eiders occur at many sites along the coasts of the assessment area, especially the west coast of Disko Island (Figure 14). The effects of disturbance can be mitigated by applying specific flight altitudes and routes, as many birds will habituate to regular disturbances as long as these are not associated with other negative impacts such as hunting.

Other activities could include blasting, which have potential to cause behavioural disturbance and physical damage in marine mammals (Lien et al. 1993, Ketten 1993, 1995, Nowacek et al. 2007).

10.3.5 Air emissions

The large amounts of greenhouse gases released from an oil field will increase the total Greenland emission significantly. The CO_2 emission from Statfjord in Norway, for example, is twice the total current Greenland CO_2 emission, which in 2008 was 685,500 t (Nielsen et al. 2010). Such amounts will have a significant impact on the

Greenland greenhouse gas emission in relation to the Kyoto Protocol (to the United Nations Framework Convention on Climate Change) and its expected successor. Another very active greenhouse gas is methane (CH_4) which is released in small amounts together with other VOCs from produced oil during trans-shipment or from vented gas.

The subsequent combustion and use of produced oil will also contribute to the global increase of CO_2 in the atmosphere.

Emissions of SO_2 and NOx 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 t NOx in 1999. In the Norwegian strategic EIA on petroleum activities in the Lofoten-Barents Sea area it was concluded that NOx emissions even from a large-scale scenario would have insignificant impact on the vegetation on land. It was, however, also stated that there was no knowledge about tolerable depositions of NOx and SO_2 in Arctic habitats where nutrient-poor habitats are widespread (Anon 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 increasing the melt. Emission of BC is particularly problematic when using heavy fuel oil. Heavy fuel oil is, however, 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, but when Denmark signed the protocols covering NOx and SO_2 some reservations were taken in relation to Greenland.

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 include also activities, such as hunting and fishing, and climate change is often considered in this context (National Research Council 2003).

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 licence blocks may exclude, for instance, 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 contents of PAH, trace metals and radionuclides 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. seabird 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 2010), while the murre population is still decreasing in most of the colonies in West Greenland including the one inside the assessment area. 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). An oil spill in the season for the swimming migration of the thick-billed murres (Box 5) could be very significant in this respect.

10.3.6 Mitigating impacts from development and production

As a consequence from previous experience, e.g. from the North Sea, the Arctic Council guidelines (PAME 2009) recommend to prevent discharges as far as possible. When water-based muds are used, additives containing oil, heavy metals, or other bio-accumulating substances should be substituted with environment friendly substances or criteria for the maximum concentrations should be established (PAME 2009). Only chemicals registered by HOCNF and the Danish product register PROBAS or similar shall be 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 Council 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 shall at least follow the standards described by OSPAR, applying a sound environmental management based on the Precautionary Principle, Best Available Techniques (BAT) and Best Environmental Practice (BEP).

Based on knowledge concerning site-specific biological, oceanographic and sea-ice conditions, discharges of drilling mud and cuttings should occur at or near the seafloor or at a suitable depth in the water column to prevent large sediment plumes. Such plumes have the potential to affect benthic organisms, plankton and productivity and may also impact higher trophic levels such as fish and mammals. The discharges should be evaluated at on a case-by-case basis.

Disturbance can be mitigated by careful planning of 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.

10.3.7 Conclusions on development and production activities

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

If these substances are released to the seabed (only in case of WBM), impacts must be 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.

The release giving most reason for environmental concern relates to produced water. Recent studies have indicated that the small amounts of oil and nutrients can impact birds and primary production, and there is also evidence for effects of several of the other components in the produced water. These effects shall be mitigated by regulation, monitoring of the sites and application of latest technology, i.e. to clean the water or by re-injection.

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 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 walruses. 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 include mainly permanent displacement from critical habitats – walrus being the most sensitive. Aesthetic impacts primarily include impacts on the pristine 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 ground. But the impact on the fishery will probably be relatively low.

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

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, e.g. OSPAR (HOCNF) and guidelines (e.g. Arctic Council) can contribute to reduce emissions to air and sea. Furthermore, a discharge policy, as for example planned for the Barents Sea, will contribute substantially to minimise impacts. Finally, monitoring of impacts at the sites and the surrounding environment is essential.

10.4 Decommissioning

Possible impacts from decommissioning activities are mainly related to noise at the sites and from traffic, assuming that all material and waste are removed and transported out of the assessment area and deposited at a safe site. There will also be 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.

11 Impacts from accidental oils spills

D. Schiedek , D. Boertmann, A. Mosbech, S. Wegeberg, O.A. Jørgensen, K. Sünksen and F. Ugarte

11.1 Oil spills

The potentially most harmful impact on the environment from oil activities are large oil spills (AMAP 2010). The probability of such events are 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 Disko West.

Several factors increase the potential for severe impacts of a large oil spill in the assessment area. Owing to the specific Arctic conditions (e.g. low temperature) 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 make it even impossible.

According to the AMAP oil and gas assessment, tankers are the potential primary source for an spill (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 or weeks. The deep-water blow-out from the *Macondo*-well, for instance, lasted 87 days before it was stopped.

11.1.1 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 t would occur once every 4,600 years (small-scale development scenario) and once every 1,700 years in an intensive development scenario (Anon 2003b). The likelihood of a large oil spill from a tanker ship accident is generally estimated to be higher than for an oil spill due to a blowout (Anon 2003b). Another study estimated that the probability for 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[2] and ultra-deep waters[3] increase the risk for a long lasting oil spill, due to the high pressures encountered in the well and due to the difficulties of operating at in such deep waters. The water depth was among the many factors contributing to the long time it lasted (almost 3 months) to cap the *Macondo*-well in 2010 (Graham et al. 2011).

11.1.2 The fate and behaviour of spilled oil

Previous experience with spilled oil in the marine environment gained in other parts of the world shows that fate and behaviour of the oil vary considerably, depending on the physical and chemical properties of the oil (light oil or heavy oil),

---

[2] >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).

[3] >5000 feet ~1524 m according to US authorities (cf. Graham et al. 2011)

how it is released (surface or subsea, instantaneous or continuous) and on the sea conditions (e.g. temperature, ice, wind and current).

Fate of oil spills in West Greenlandic waters have been modelled by DMI at several occasions in relation to the preparation of strategic environmental impact assessments: Disko West (Nielsen et al. 2006), Baffin Bay (Nielsen et al. 2008) and 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, and some of the oil will be dispersed in the upper water column where it usually will stay in the upper 10 m (Johansen et al. 2003). However, oil dispersed due to a sub-sea blowout, may accumulate at any depth.

Low temperature and the presence of sea-ice can hamper the dispersal process considerably.

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 particle are typical for Greenland waters in areas where the melt water from the glaciers can disperse widely into the open sea.

Subsurface spills

Blowouts on a platform will initially cause a surface spill, but may continue as a subsurface spill if the riser from the wellhead collapses. The risk of such a collapse is greater 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. if 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 not known for the assessment area, the behaviour of the oil cannot be predicted with any certainty. 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 *Macondo*-well oil spill in the Mexican Gulf in 2010 was unusual in size, location and duration, but in many ways similar to the *Ixtoc* blow out in 1979 also in the Mexican Gulf. It revealed new and so far undescribed ways spilled oil could be distributed in the environment, although this probably also happened during the *Ixtoc* spill (Jernelöv 2010). The unusual dispersion of the oil was mainly caused by the spill site on the seabed at more than 1500 m water depths. Dispersants were applied at the well head and huge subsea plumes of dispersed oil were formed in different depths and they moved long distances with the water currents (Diercks et al. 2010, Thibodeaux et al. 2011). Oil also settled on the ocean floor far from the spill site (Schrope 2011).

From studies of deepwater blowout events it was predicted that a substantial fraction of the released oil and gas will be suspended in pelagic plumes, and this may occur even in the absence of added dispersant agents (Johansen et al. 2001). The fate of oil in deep water is likely to differ much 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 estimated 140,000 t oil annually (Kvenvolden & Cooper 2003), why there should be an intrinsic potential for microbial degradation (presence of the relevant organisms). Bio-degradation rates faster than expected in the deep plumes have been reported in accordance with this hypothesis (Hazen et al. 2010).

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).

The oil spill from the *Macondo*-well has been estimated at 840,000 t, making it the largest recorded peace time spill. The oil dispersed at the well head had a very slow buoyant migration towards the surface, allowing volatile hydrocarbon to be dissolved in the water column. Adding dispersants at the well head contributed to the formation of huge plumes of dispersed oil in different depths between 800 and 1200 m (Hazen et al. 2010, Valentine et al. 2010). It was estimated that 50 % of the oil 'remained' dispersed, sank to the seabed or was degraded in the water column (Kerr 2010).

There are indications of severe and unexpected deep sea impacts (Schrope 2011), but until the environmental impacts of the *Macondo*-spill are really understood or described (Graham et al. 2011), it will not be possible to include any final conclusions in this SEIA. A natural resource damage assessment is under preparation (Graham et al. 2011), and the consequences of the *Macondo* subsea blowout will be discussed in more detail in a later version of this assessment. In this context it should be mentioned that a Norwegian review of the environmental impacts of the *Macondo* 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 which also will apply to Greenland.

11.2 DMI oil spill simulations

As part of the first SEIA assessment for Disko West different oil spill scenarios were carried out by DMI (Nielsen et al. 2006) using a 3-D hydrodynamic model and a number oil drift and fate simulations; for details on the model see Mosbech et al. (2007).

The model covered the region 65º-75º N, 72º-50º W, with an original resolution of approx. 10 km, refined to approx. 1 km (1/120° latitude by 1/48º longitude). Vertically, the particle cloud was resolved into a 0.05 m surface (skin) layer and 12 subsurface layers located between 1, 5, 10, 15, 20, 30, 50, 75, 100, 500, 1000 and 1500 m depths. Vertical extent of each particle was in the order of millimetres or less and therefore each particle was assumed to be located in one single layer. Each particle may cover more or less than one grid cell. Thickness of each surface layer grid cell was calculated based on accumulating all particles covering the grid cell, weighted by the fraction of the coverage of each particle.

Simulations were carried out for seven hypothetical spill locations all located in the shelf area west of Disko Island: locations 1-5 were selected by GEUS representing potential sites for offshore well drilling or oil production platforms and locations 6-7 were selected for simulating spills from tankers near a potential oil terminal. The crude oil *Statfjord*, a medium type crude oil (API density 886.3 kg/m³), was selected by GEUS among 8 types in the DMI database as the most representative oil to potentially be discovered in the assessment area. This is a medium oil type, lighter than seawater, which will evaporate by around one third during the first 24 hours of a surface spill period.

For continuous spills a release at a constant rate during the first ten days of the simulation period was assumed. The amount of oil released was fixed at 3,000 t/day, totalling 30,000 t. For instantaneous spills the chosen amount of oil released was 15,000 t.

Six 10-day 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 included spells of a strong southerly wind. A total of 114 one-month oil drift simulations were carried out (Mosbech et al. 2007a).

Some the main results of these scenarios are summarised in Table 18 and some examples are presented in Figure 54.

The DMI scenarios indicated that spills reaching the coastal waters, eventually stranding on the shorelines, have the potential to cause severe short term impacts

Table 18. The impacts from the seven scenarios and alternative scenarios summarised (see Appendix 1). R = reversible, r = slowly reversible, No = no significant impacts expected. No* = No immediate impacts expected, but impacts possible following spring during ice melt. L = low impacts expected, M = moderate impacts expected, H = high impacts expected, ? = possible. For further details see Mosbech et al. (2007).

Scenario	Scenario alternative	Extent sq. km	Duration years	Season	Marine mammals	Birds	Fish	Benthos	Primary prod. plankton	Shorelines	Local use	Commercial use	Long-term effects likely
1		9000	>10	summer	L R	H r	M r	H r	L R	H r	H R	H R	yes
1	alt. drift	13000	>10	summer	L R	H r	L r	H r	L R	H r	H R	H R	yes
1	Mar. alt.	9000	>10	spring	M R	H r	H r	H r	M R	H r	H R	H R	yes
2		1500	>10	autumn	L R	M R	L R	H r	L R	H r	L R	H R	yes
3		22000	1	winter	L R	L R	H? R	No	L R	No	No	L R	
3	Sept. alt.	22000	1	autumn	L R	H R	No	No	L R	No	No	H R	
4		8000	1	winter	M R	L R	H? R	No	No*	No	L R	L R	
4	alt. drift	10000	>5	winter	M R	H R	L R	No	L R	No	L R	L R	yes
5		10000	>10	summer	L R	H r	M R	H r	L R	H r	H R	H R	yes
6		30000	1	winter	M R	L R	H? R	No	No*	No	L R	L R	
6	Aug. alt.	30000	1	autumn	M R	H r	L R	No	L R	No	L R	H R	
7		unknown	1	spring	L R	L-M R	H? R	No	M R	No	L R	L R	

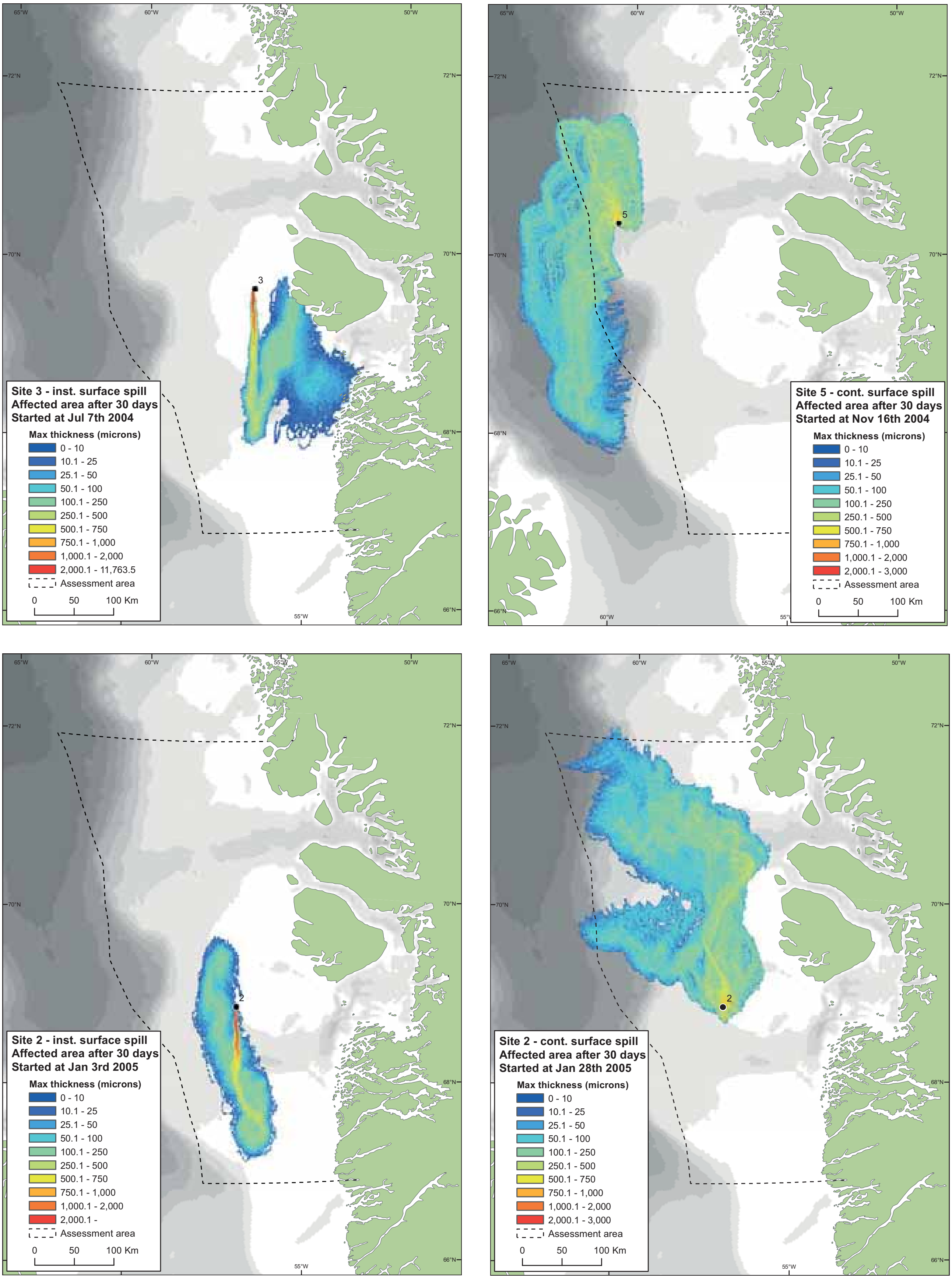


Figure 54. Examples of the DMI oil spill trajectory simulations.

on the coastal ecosystem as well as long-term effects. Spawning stocks of capelin and lumpsucker can be impacted; breeding, moulting and wintering seabird populations will be exposed; and some fisheries will be closed to avoid contamination of catches. Oil spills far from the coast, on the other hand, may under fortunate circumstances cause very small impacts. However, offshore fisheries for deep-sea shrimp risk closure to avoid contaminated catches, important feeding grounds for walrus may also be hit, and some very vulnerable and concentrated bird occurrences are also at risk. Oil spills in ice-covered waters are very difficult to evaluate as the oil may be trapped for long periods of time and released during melt far from the spill site. The results of the modelling also clearly showed that depending on the season and the prevailing hydrographical conditions, effects on the coastal or offshore habitats will differ.

The impacts of an instantaneous oil spill in the summer period from spill at Site 3 (Scenario 1), for instance, will be high if the oil moves as indicated by the DMI spill drift model (Figure 54). Some of the effects will be reversible, but for specific coast types and at seabird breeding colonies effects are likely to be apparent for decades.

If this oil spill is continuous instead of instantaneous, the modelling shows that oil also will drift northwards and hit the coasts of northwest Disko and the western Nuussuaq peninsula. The region northeast of the spill location is a very important moulting area for king eiders, and large concentrations will be exposed. The long coast lines of western Disko and Nuussuaq will be contaminated with oil. The northwards drift of oil will also pass the important deep-sea shrimp fishing grounds at Hareø. An oil spill in late autumn or in the winter may have very different impacts in this area. In summary, it should be pointed out that predictions are difficult. However, DMI has developed operational models, also covering the Disko West area, which could support management and application of the best combat measures in case of an oil spill.

11.3 Oil spill in ice-covered waters

Due to the roughness of the subsurface of the ice, oil will not move as far away from the spill site in ice-covered waters as in open waters at least as long as the ice do not move. If an oil slick is 1 cm thick on average, a spill of 15,000 m^3 will cover approx. 1.5 km^2 below the ice, and less if thicker. This also means that very high oil concentrations may occur and persist for prolonged periods. Fauna under the ice or in leads and cracks may therefore risk exposure to highly toxic hydrocarbon levels. However, the drift ice in the licence blocks is very dynamic and moves with the currents. Spilled oil will follow the movements of the ice and may be released far from the spill site.

11.4 Dissolution of oil and toxicity

Total oil concentration in water is a combination of the amount of small dispersed oil droplets and the dissolved oil components. The process of dissolution is of particular interest as it increases the bio-availability of the oil components. The rate and extent to which oil components dissolve in seawater depends mainly on the amount of water-soluble fractions (WSF) of the oil. The degree of natural dispersion is also important for the rate of dissolution, although surface spreading and water temperature may also have some influence.

PAHs are among the toxic components of crude oil (see also Section 7). The highest PAHs concentration found in the water column in Prince William Sound within a six-week period after the *Exxon Valdez* spill was 1.59 ppb, at 5 m depth. This is well below levels considered to be acutely toxic to marine fauna (Short & Harris 1996).

SINTEF (Johansen et al. 2003) reviewed available standardised toxicity studies and found acute toxicity down to 0.9 mg oil /l (0.9 ppm or 900 ppb) and applied a safety factor of 10 to reach a PNEC (Predicted No Effect Concentration) of 90 ppb oil for 96-hour exposure. This is based on fresh oil which leaks a dissolvable fraction, most toxic for eggs and larvae. Later, after weathering, oil will be less toxic.

The so far published concentrations of oil components in the waters at the *Macondo*-well blowout in the Mexican Gulf in 2010 were >50 µg/l (50 ppb) BTEX (benzene, toluene, ethylbenzene and xylene, constituting only a fraction of the oil) measured in a subsea plume of oil 16 km from the well site (Camilli et al. 2010) and total PAH concentrations up to 189 µg/l near the well site (Diercks et al. 2010). The latter study found PAH concentrations associated with acute toxicity in discrete depth layers between 1000 and 1400 m extending at least as far as 13 km from the well head.

Water soluble components (WSC) could leak from oil encapsulated in ice. Controlled field experiments with oil encapsulated in first-year ice for up to 5 months have been performed in Svalbard, Norway (Faksness & Brandvik 2005). The results show that the concentration of water-soluble components in the ice decreases with ice thickness, but that the components could be measured even in the bottom ice core. A concentration gradient as a function of time was also observed, indicating migration of water-soluble components through the porous ice and out into the water through the brine channels. The concentration of water-soluble components in the bottom 20 cm ice core was reduced from 30 ppb to 6 ppb in the experimental period. Although the concentrations were low, the exposure time was long (nearly four months). This might indicate that the ice fauna could be exposed to a substantial dose of toxic water-soluble components, and at least in laboratory experiments with sea-ice amphipods sub-lethal effects have been demonstrated (Camus & Olsen 2008, Olsen et al. 2008). Leakage of water-soluble components to the ice is of special interest, because of a high bio-availability to marine organisms, relevant both in connection with accidental oil spills and release of produced water.

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

11.5 Oil spill impacts on the environment

There are generally two types of effects from oil in the marine environment: physical smothering (e.g. of birds, plumage and fish eggs) and intoxication from ingestion, inhalation and contact. Smothering is an acute effect, while intoxication can be long lasting. The effects of an oil spill on the VECs in Disko West will be different, as shown in Table 19 and further described in the following.

Table 19. Overview of potential impacts of a large oil spill on VECs in the Disko West assessment area. See Section 4.9 for a summary of the VECs.

VEC	Typical vulnerable organisms	Population impact* - worst case		
		Displacement	Sublethal effect	Direct mortality
Pelagic hotspots	halibut larvae, zooplankton, juvenile polar cod	–	moderate (L)	major (L)
Tidal/subtidal zone	capelin, bivalves , crustaceans	long term (L)	major (L)	major (L)
Demersal fish & offshore benthos	sandeel, Grl. halibut, shrimp, shelf benthos	short term (L)	moderate (L)	moderate (L)
Seabirds (breeding)	auks, c. eider	short term (L)	major (R)	major (R)
Seabirds (non-breeding)	auks, eiders	short term (L)	major (R)	major (R)
Marine mammals (summer)	baleen- & toothed whales	short term (L)	moderate (R)	minor (R)
Marine mammals (winter)	bowheads, hooded seal, walrus, narwhal, white whale, polar bear	short term (L)	moderate (R)	major(R)

*L = local, R = regional

11.5.1 Oil spill impact on plankton and fish (incl. larvae) and crustaceans

Adult fish and shrimp

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

Adult shrimps live on or near the bottom in relatively deep waters (100-600 m), where oil concentrations from a surface spill will be very low, if detectable at all. No effects were seen on the shrimp stocks (same species as in Greenland) in Prince William Sound in Alaska after the large oil spill from *Exxon Valdez* in 1989 (Armstrong et al. 1995). Regarding subsea blowouts, a simulation study in the Davis Strait concluded that high oil concentrations would most likely occur only in a restricted area (Johansen 1999). However, the lessons learned from the deep sea blowout from the *Macondo*-well in the Mexican Gulf in 2010, where large subsea oil plumes occurred in the water column down to more than 1200 m, questions this conclusion and in such a case shrimp populations may be impacted over large areas.

Snow crabs live in deep waters where surface spill are not like likely to impact them. However, subsurface spills, as seen from the *Macondo*-well, may hit snow crab grounds and impact populations here.

Key locations for capelin include spawning areas close to the beach. These are numerously present in most of the fjords in the assessment area from the head of fjords to the outer coastal regions. An oil spill hitting spawning areas wiping out eggs and larvae may have the potential to impact local capelin stocks, because no or few adult fish survive the spawning to spawn the subsequent years (Clausen et al. 2012). The recovery time from such an event is not known, as it is still unknown whether local fjords hosts separate genetically isolated capelin populations or if they mix.

Another oil spill sensitive fish in the coastal zone is the lumpsucker, which spawn in shallow coastal waters in spring.

Capelin and lumpsucker spawning areas have been mapped in the assessment area using local knowledge from fishermen and others. Both species spawn along extensive coastlines in the assessment area.

A third oil spill sensitive coastal fish in the assessment area is the Arctic char. They assemble at river mouth's before they move upstream to spawn and winter and will be sensitive to oiling in such sites, where local stock may be reduced. Arctic char distribution in the assessment area has been mapped based on local knowledge from fishermen and others (Olsvig & Mosbech 2003, Clausen et al. 2012).

Fish- and shrimp larvae

Eggs and larvae of fish and shrimp are more sensitive to oil than adults, and low levels of dissolved oil hydrocarbons are for example documented to produce sub-lethal effects on the early cod larval stages (Tilseth et al. 1984).

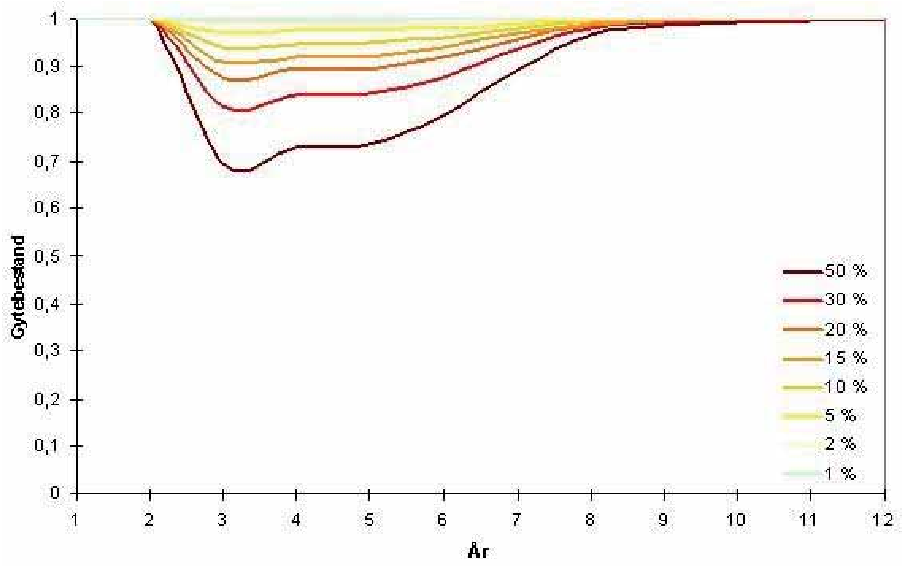
Theoretically impacts on fish and shrimp larvae may be significant and reduce the annual recruitment strength with some effect on subsequent populations and fisheries for a number of years. However, such effects are extremely difficult to identify/filter out from natural variability and they have never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

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

In general, species with distinct spawning concentrations and with eggs and larvae in distinct geographic concentrations in the upper water layer will be particularly vulnerable to surface spills. Eggs and larvae of Atlantic cod in the Barents Sea can be highly concentrated in the upper 10 m in limited areas. Based on oil spill simulations for different scenarios and different toxicities of the dissolved oil, the individual oil exposure and population mortality has been calculated. The population impact is to a large degree dependent on whether there is a match or 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 be present for weeks or a few months, and be concentrated in surface water in calm weather). For combinations of unfavourable circumstances and using the PNEC with a safety factor of times 10 (Johansen et al. 2003), there could be losses in the region of 5%, and in some cases up to 15%, for a blowout lasting less than 2 weeks, while very long-lasting blowouts could give losses of eggs and larvae in excess of 25%. A 20% loss in recruitment to the cod population is estimated to cause a 15% loss in the cod spawning biomass and to last approx. eight years to recover fully (Figure 55).

Hjermann et al. (2007) reviewed the above described impact assessment of Barents Sea stock of Atlantic cod, herring and capelin by Johansen et al. (2003), and suggested improvements by emphasising more on oceanographic and ecological variation in the modelling. They also concluded that it is not possible to assess long-term effects of oil spills due to the general variation in the ecosystem. At best, ecological modelling could provide 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.

Figure 55. Estimated reduction and recovery time 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: Anon (2003b), Johansen et al. (2003).



Compared to the Lofoten-Barents Sea-area, there is much less knowledge available on concentrations of eggs and larvae from West Greenland and particularly in the assessment area. However, the highly localised spawning areas with high concentrations of egg and larvae for a whole stock near the surface as seen in the Lofoten-Barents Sea have not been reported from the assessment area. The overall picture here is that fish larvae are widespread, although occurring in patches which may hold relatively high concentrations. Another factor of importance is the risk of overlap between an oil spill and the spawning seasons (when eggs and larvae are most concentrated). Most fish spawn in late winter and spring, at a time when exploration drilling will not take place minimising the likelihood of overlap. This will be higher during a production phase, when the risk of oil spills is apparent year round.

Larvae of shrimp and Greenland halibut (also eggs) are found deeper in the water column than cod egg and larvae, and would therefore be less exposed to harmful oil concentrations from an oil spill at the surface. Eggs and larvae of Greenland halibut drift for example slowly though the assessment area at 13-40 m depth (Stenberg 2007, Gundersen et al. 2010). This implies that an oil spill will most likely impact a much smaller proportion of a season's production of eggs and/or larvae of these species than modelled for cod in the Barents Sea. Impacts from a surface spill on recruitment to Greenland halibut and northern shrimp stocks therefore most likely will be insignificant. However, a subsea blowout with the properties and quantities of the *Macondo*-well spill in 2010, when huge plumes of dispersed oil occurred in the water column, may expose eggs and larvae over much larger areas and depth ranges, and may cause a more significant impact on the recruitment and stock size of these bottom-living species.

Copepods and other zooplankton

Copepods are very important in the food chain and can be affected by the toxic oil components in the water below an oil spill. They can for example ingest dispersed oil droplets.

Recent exposure studies performed on natural plankton communities (Hjorth et al. 2007, Hjorth et al. 2008) and copepods (Hjorth & Dahllöf 2008, Jensen et al. 2008b, Hjorth & Nielsen 2011) with pyrene (as a proxy for crude oil) have shown several negative effects on primary production, reproduction and food uptake among *Calanus* species and on survival of females, feeding status, and nucleic acid content in *Microsetella* spp. from Western Greenland. The species were affected differently by pyrene and also to the combination of pyrene and temperature, indicating that the larger lipid stores in *C. glacialis* had a buffer effect. The pyrene concentrations applied were, however, difficult to compare to actual spill situations. Negative effects of combined temperature changes and PAH exposure on pellet production, egg production and hatching of *Calanus finmarchicus* and *C. glacialis* have also been demonstrated (Hjorth & Nielsen 2011, Grenvald et al. 2012).

In Arctic marine habitats, the most severe ecological consequences of a large oil spill on plankton communities are to be expected when the biological activity is high, and that is primarily in spring: April to June and in the upper 50 m. Later in the season, when the temperature is higher and the majority of grazers have migrated down to their overwintering depths above the bottom (Dünweber et al. 2010), the biological activity is lower or concentrated at the pycnocline much deeper, and impacts on plankton communities will probably be less severe (Söderkvist et al. 2006). Modelling studies of the potential effects of oil spills on copepods in the Barents Sea (Melle et al. 2001) showed that populations were distributed over such large areas that a single surface oil spill would only impact a minor part and not pose a major threat to the population (Anon 2003b). Again, the lessons learned from the *Macondo*-well oil spill, where huge subsea plumes of dispersed oil were found at different depths, may change these conclusions of relatively mild impacts from a surface spill to more acute and severe impacts in case of a large sub-surface spill.

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

A study of the density and distribution of chlorophyll (as a measure of primary productivity) in the Disko Bay area in spring 2006 (Mosbech et al. 2007a) indicated wide spatial and temporal variability in chlorophyll levels and that high chlorophyll levels (spring bloom) are distributed over large areas. Moreover, areas of high importance for primary production vary both between seasons and between years, depending for example on ice conditions. An oil spill therefore has at least the potential to impact small and localised primary production sites, while primary production as a whole will only be slightly impacted even during a large spill in open waters. This may, however, not apply to an oil spill of the *Macondo*-well type, due to the huge subsea plumes of dispersed oil.

11.5.2 Oil spill impacts on benthic flora

The direct impact of an oil spill on macroalgae will most likely be mass mortality on the 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 pheromones. This has been observed in *Fucus vesiculosus* (Derenbach & Gereck 1980) with negative consequences for reproduction.

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 the *Fucus* cover in these areas and some areas are still considered as recovering (NOAA 2010). This variation may be a result of the dynamics between grazers and the macroalgae, as was shown after the *Torrey Canyon* accident at the coast of Cornwall, UK (Hawkins et al. 2002). Regarding Prince William Sound, the variations were considered as a result of homogeneity of the evolving *Fucus* population (e.g. genetics, size and age), which made it more vulnerable to natural environmental impacts (e.g. no adult *Fucus* plants to protect and assure recruitment), thus resulting in a longer time span to restore *Fucus* population heterogeneity (Driskell et al. 2001).

In contrast, no major effects were observed in a study on impact of crude and chemically dispersed oil on shallow sub-littoral macroalgae at northern Baffin Island (the BIOS study), which was conducted by Cross et al. (1987).

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

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

How pyrene might affect natural algae and bacteria communities in Arctic sediment was studied near Sisimiut (West Greenland). 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 growth and degradation of organic matter.

11.5.3 Oil spill impacts on benthic fauna

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

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

Effects of the sub-surface spill from the *Macondo*-well have been detected on benthic fauna (Schrope 2011), but no conclusions have been drawn so far.

Many benthos species, especially bivalves, accumulate hydrocarbons, which may cause sub-lethal effect (e.g. reduced reproduction). Such bivalves may act as vectors of toxic hydrocarbons to higher trophic levels, particularly bearded seals, walruses and eiders.

In broad terms, the shallow water (down to 50 m) communities have high species richness (bivalves, macro algae etc.) and the fauna is available to higher trophic levels as eiders and walrus (see Box 3). Another feature is that individuals of several species have an estimated maximum age of more than 25 years (the bivalves, *Mya* spp., *Hiatella arctica*, *Chlamys islandica* and the sea urchin *Strongylocentrotus droebachiensis*). This indicate that the benthic communities may be very slow to recover after any type of disturbance that cause mortality of these old individuals that often constitute the majority of the biomass. From a biodiversity perspective the high prevalence of species found at only one site and of species represented only by a single specimens also suggest that mortality induced from oil spills potentially can cause a significant reduction in the total species richness for a long time.

11.5.4 Oil spill impacts on ice habitats

There is very little knowledge available on oil spill impacts on the sea-ice ecosystem (Camus & Dahle 2007, AMAP 2010). If oil accumulates under the ice it may stay there until break-up and melt in spring. When caught under and even in the ice, weathering processes are hampered which means that the toxicity of the oil may persist much longer than in open waters.

At least in laboratory experiments with sea-ice amphipods, sub-lethal effects of exposure to WSF have been demonstrated (Camus & Olsen 2008, Olsen et al. 2008).

The sea-ice ecosystem is however very resilient as it necessarily has to re-establish each season when new ice is formed, at least in areas dominated by first-year ice. However, polar cod could be particularly sensitive, due to the fact that their eggs stay for a long period just below the ice, and hatching occurs when the ice starts to disintegrate and melt. As oil spilled under ice will tend to accumulate in the same space (AMAP 2010), there is a potential risk for overlap and impacts on the recruitment at least on a local scale.

Baseline levels, seasonality and responsiveness to oil compounds in polar cod have been studied both in the field and in laboratories. The studies provided first insights into the general eco-physiological responses of polar cod to PAH exposure during periods of e.g. reproduction and feeding. The studies also resulted in a range of baseline values of the selected biomarkers and their seasonal amplitude for sound interpretation of field-based toxicity assessments (Christiansen et al. 2010, Jonsson et al. 2010, Nahrgang et al. 2009, 2010a, 2010b, 2010c, 2010d).

11.5.5 Oil spill impacts in coastal habitats

One of the lessons learned from the *Exxon Valdez* oil spill was that the near-shore areas were the most impacted habitats (NOAA 2010). 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 (e.g. McCay 2003).

Many of the animal populations living in this habitat in Prince William Sound have now recovered (birds, fish), but certain populations are still under recovery (several bird species, clams, mussels) and a few were recently assessed as ‘not recovered’ (pigeon guillemot – a close relative to the black guillemot in Greenland, and also Pacific herring) (NOAA 2010).

An oil spill resulting from an activity in the assessment area and reaching the coast, has the potential to reduce stocks of important fish species (capelin and lump-sucker) spawning here 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 in sediment, among boulders and imbedded in crevices in rocks. This was the case in Prince William Sound, where oil in 2010 was still lingering in buried patches in the affected shores, and here is a source for continued (chronic) exposure for sea otters and birds that seek food in sediments (NOAA 2010). Many coastlines in the assessment area are similar to those of Prince William Sound, and similar effects must be expected if oil hit these coasts. See also below in Section 11.5.9 on long-term effects.

In a study performed 12 years after the oil spill, it was estimated how much oil remained on the beaches of Prince William Sound. Oil was found on 78 of 91 beaches, randomly selected according to their oiling history. The analysis revealed that over 90 % of the surface oil and all of the subsurface oil located 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 Shetland Islands spray with oil was carried by wind and impacted fields and grasslands close to the coast.

Similar effects could be expected in the coastal habitats in the Disko West area.

11.5.6 Oil spill impacts on seabirds

It is well documented that birds are extremely vulnerable to oil spills in the marine environment (Schreiber & Burger 2002). Birds which rest and dive from the sea surface, such as auks, seaducks, cormorants and divers (loons), will be highly exposed to floating oil, compared to birds that spend more time in the air. Nevertheless, all seabirds face the risk of being fouled with spilled oil on the surface. This particular vulnerability is attributable to their plumage. Oil soaks easily into the feathers and they stick together destroying their insulating and buoyancy properties. Oiled seabirds readily die from hypothermia, starvation or drowning. Birds may also ingest oil by cleaning their plumage and by feeding on oil-contaminated food. Oil irritates the digestive organs, damages the liver, kidneys and salt glands and causes anaemia. Sub-lethal and long-term effects may be the result. However, the main cause of seabird losses following an oil spill is direct oiling of the plumage.

Many 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. The high concentrations of seabirds found at coasts, e.g. breeding colonies, moulting areas or in offshore waters at important feeding areas in the assessment area (see Chapter 4) are particularly vulnerable.

Oiled birds which have drifted ashore are often the focus of the media when oil spills occur, witnessing the high individual sensitivity to oil spills. However seen from an ecological point of view, the concern must be the case where populations suffer from such oiling. To assess this issue, extensive studies of the natural dynamics of the affected populations and the surrounding ecosystem are necessary (Figure 56).

Analysis for assessment and mitigation

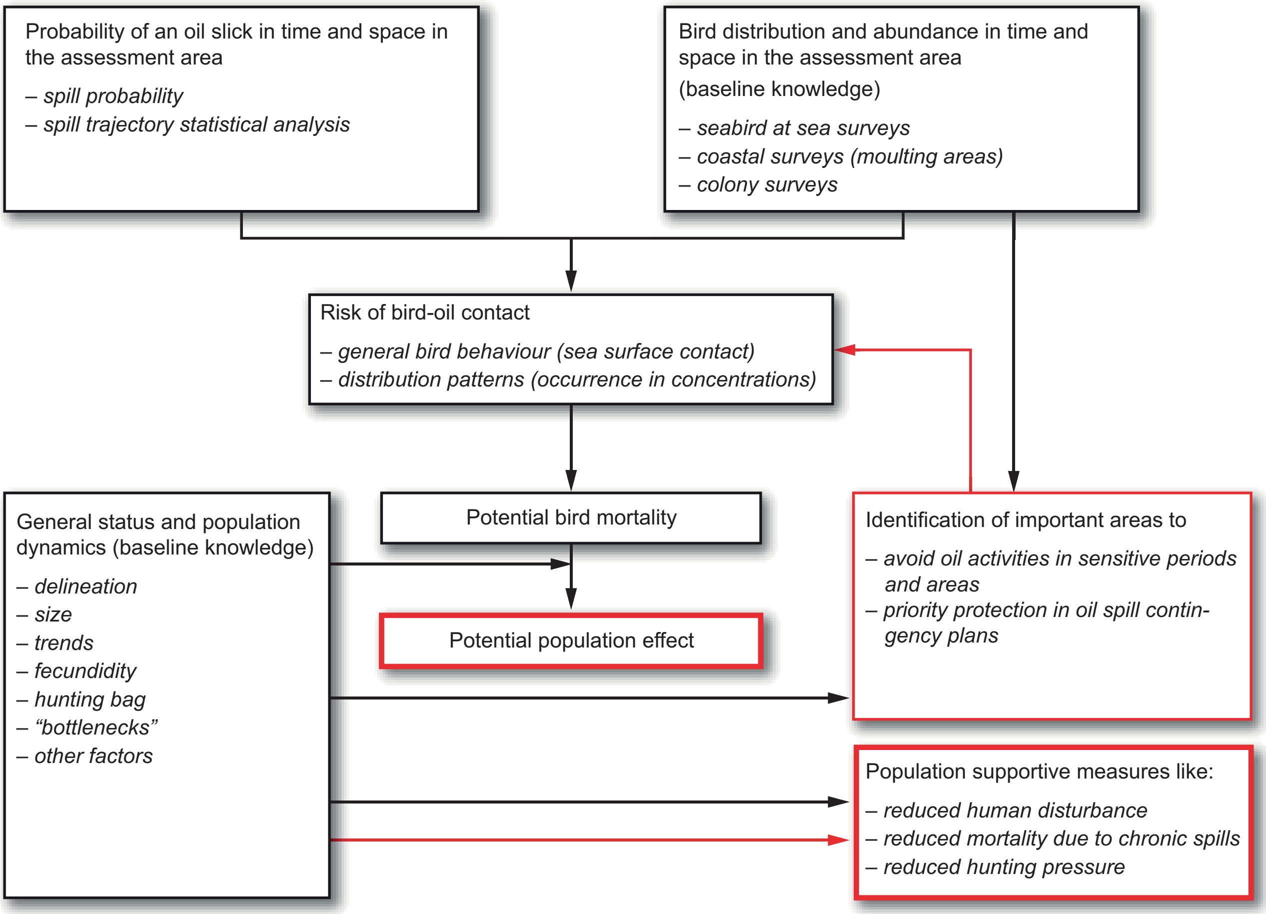


Figure 56. Basic principles of assessing vulnerability of seabird populations to oil spills. Black lines indicate main analysis of effects on bird populations, red lines analysis of potential mitigation measures. Indirect effects are not included.

The seabirds most vulnerable to oil spills are those with low reproductive capacity and a corresponding high average lifespan (low population turnover). Such a life strategy is found among auks, fulmars and many seaducks. Thick-billed murres (an auk), for example, do not breed before 4-5 years of age and a pair 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 seabirds are therefore particularly vulnerable to adult mortality caused, for example, by an oil spill.

If a breeding colony of birds is completely wiped out by an oil spill it must be recolonised 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).

Breeding birds

A large number of seabird species breed in the assessment area (cf. Section 4.7) and a majority is associated with habitats (sea-facing cliffs or on low islets) along the outer coastline where they will be 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. Eider ducks will usually stay in sheltered in-shore waters while murres will move offshore and disperse over extensive areas (Box 6).

There is only one breeding colony of thick-billed murre in the assessment area. This is situated in the inner part of Disko Bay and an oil spill from the current licence blocks is not likely to drift this far. However, as the adult birds feed far from the breeding site e.g. off the outer coast, the breeding population at this colony could be seriously affected if an oil spill sweep the feeding areas. Another risk situation is when the chicks and flightless adults leave the colony on a swimming migration. The satellite tracking studies of birds from this colony in 2005 and 2006 showed that these swimming birds may move both south and north of Disko and thereafter stay in the waters west of Disko for some weeks (Box 6). These birds are most concentrated during the first weeks when a substantial number move out through the Vaigat. When they arrive in the open sea they disperse over extensive areas (Figure 33). The population is therefore most vulnerable to oil spills occurring in the Vaigat in late July. This particular population is declining and therefore especially sensitive to additional mortality.

Other important bird colonies where the population could be severely impacted by an oil spill in the assessment area include an Arctic tern colony at Kitsissut/Grønne Ejland, which is the largest in Greenland (and one of the largest in the world) with about 20,000 pairs, and the small colonies of Atlantic puffin on the islands south of Disko Island could even be exterminated.

Moulting and wintering areas

Important and very vulnerable concentrations of moulting seaducks are found along the coasts throughout the entire assessment area in late summer and autumn. Concentrations of primarily common and king eiders are shown in Figure 14.

In winter seabirds are mainly located to the south of Disko Bay, in the drift ice of Store Hellefiskebanke and in the fjord mouths. Here huge, very important and oil spill vulnerable concentrations of mainly king eiders and common eiders are found (Box 5).

Migration concentrations

The number of thick-billed murres occurring in the assessment area in spring is also very high. The aerial survey in April/May 2006 resulted in an estimate at 400,000 birds with large concentrations at the northeast corner of Store Hellefiskebanke (an important upwelling area) and in the southern part of Disko Bay (Figure 32). These birds most likely proceed northwards to breeding sites in Upernavik and perhaps further north. Such concentrations are particularly vulnerable to oil spills because the birds rest and stage in the restricted (by ice) open-water areas, where oil also will tend to accumulate in case of a spill.

The survey in September 2009 showed that particularly thick-billed murres may occur in large concentrations within the assessment area (Box 6 and 7), while the majority of the little auks occurred to the west of the assessment area on the Canadian side of Davis Strait (Box 7). These murre-concentrations are very vulnerable, as significant numbers may be affected by a large oil.

In general a large oil spill has the potential to deplete seabird populations in the assessment area, but it is not likely that entire populations (except for some small and local colonies) can be wiped out.

11.5.7 Oil spill impacts on marine mammals

Marine mammals are relatively robust and can generally survive short periods of fouling and contact with oil, except for polar bears and seal pups, for 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 conditions suitable for necropsies. Nevertheless, increased mortality of killer whales, sea otters and harbour seals exposed to the *Exxon Valdez* event in Prince William Sound has been well documented (e.g., Spraker et al. 1994, Matkin et al. 2008). In the Gulf of Mexico, the rate of stranded cetaceans increased after the *Macondo*-well event in 2010, from a 2003-2007 mean observed rate of 17 strandings per year to 101 in 2010. However, the monitoring effort has probably also been increased (Williams et al. 2011).

Marine mammals has to breathe at the surface. Inhalation of vapours from an oil spill is therefore a potential hazard. Some of the marine mammal mortality after the *Exxon Valdez*-spill has been ascribed this kind of exposure. The loss of killer whales was probably related to inhalation of oil vapours from the spill (Matkin et al. 2008, see details below), and the death of harbour seals were also related to oil vapours (Spraker et al. 1994, see details below). In periods with ice-coverage when oil can fill the spaces between the ice floes, the risk of inhalation of toxic vapours may be elevated, 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 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 lactation and weaning period and can not move away from oil spills. They are protected against the cold by a thick coat of woolly hair (lanugo) and oil will have a strong negative effect on the insulating properties of this fur. The mother seals recognize their pups by smell and a changed odour caused by oil might therefore affect the mother's ability to find its pup. Although the sensory abilities of seals should allow them to detect oil spills though sight and smell, seals have been observed swimming in the midst of oil slicks, suggesting that they may not be aware of the danger posed by oil (St. Aubin 1990). Harbour seals found dead shortly after the *Exxon Valdez* oil spill had evidence of brain lesions caused by oil vapour 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 oil vapours (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, why 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 limited open-water areas. Walruses will also be sensitive to oil spills in ice covered waters where they may be forced to surface in oil spills and thereby to inhale oil vapours (see above).

The population of walruses wintering in the assessment area (Store Hellefiskebanke) is especially sensitive as it is the only regular, large occurrence in West Greenland and because the population is declining.

Whales

There are several reports of whales which have repeatedly moved directly into oil slicks (e.g., Harvey & Dalheim 1994, Smultea & Würsig 1995, Anon 2003a, Matkin et al. 2008). Whales are therefore probably not able to detect oil and do not avoid oil-contaminated waters (Goodale 1981, Harvey & Dalheim 1994, Anon 2003a).

If whales have direct contact with oil slicks, immediate contact with the oil will be 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 causing a toxic effect.

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 will likely depend on factors such as the quality of the oil and the water temperature (Werth 2001).

The 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 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. After 16 years they had not recovered at all or had recovered at rates lower than those for groups not affected by the oil.

The most sensitive whales in the assessment area are the winter whales; narwhal, white whale and bowhead whale. They are all subjected to hunting and they are more or less confined to ice covered waters. Moreover is the assessment area particularly important too all three species (Table 19).

In the summertime another set of whales occur in the assessment area: fin whale, humpback whale, minke whale, harbour porpoise, white beaked dolphin, bottlenose whale, sperm whale and pilot whale. Their surfacing is at least not restricted by ice cover, why they probably are less subjected to inhalation of oil vapours.

Polar bear

Polar bears are very sensitive to oiling as they are dependent on the isolative properties of their fur and also because they will ingest the oil as part of their grooming behaviour (Øritsland et al. 1981, Geraci & St. Aubin 1990). Polar bears have died from ingesting oil this way (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 2012) due to climate change, which reduce their habitat, the ice-covered Arctic waters.

While moving on pack ice they 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.

Among the two subpopulations occurring within the assessment area, the Davis Strait population probably will not be impacted by oil activities including oil spills, due to the low occurrence. However, for the Baffin Bay subpopulation the assessment area is more important as winter and spring habitat and oil activities (including oil spills) may have a higher probability of negatively impacting the population. It is however not possible to assess the fraction of the total population that may be impacted by an oil spill in the Disko West area. Future decrease of sea-ice in the Baffin Bay area will reduce the number of polar bears in the assessment area and consequently also the degree of overlap between bears and oil activities.

11.5.8 Oil spill impacts on fisheries

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

A very important issue in this context is the reputational damage an oil spill will cause on fish products from 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 societies 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 of fisheries usually will last some weeks in offshore areas, while 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 *Macondo*-well spill 230,000 km^2 were closed for both commercial and recreational fishing; in September 2010 c. 83,000 km^2 were still closed (Graham et al. 2011) and in April 2011 after a year, the last of the closed areas was reopened for fishery (NOAA 2011). Both commercial fishery and subsistence harvest and fishery in the Prince William Sound was in 2010 still considered as 'recovering' since the oil spill in 1989 (NOAA 2010).

Some of the main fishing grounds for Greenland halibut in the Baffin Bay are located in the assessment area (annual catch on app. 13,000 t, equally split between Canada and Greenland). If tainted fish show up in the commercial catches, severe economic consequences must be expected. Greenland halibut at West Greenland often migrate over long distances in short time (unpublished GINR) and tainted fish may show up in the commercial catches further south in the Davis Strait (where the annual catches constitute approx. 14,000 t).

The largest Greenland halibut fishery in Greenland takes place near Ilulissat, very far from the license-areas in Disko West. However, the drift modelling carried out by DMI indicates that under certain conditions oil may drift this far (Appendix 1, Figure 7).

11.5.9 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 documents 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 is sufficiently bio-available to induce chronic biological exposure and has caused long-term impacts at the population level. Heavily oiled coarse sediments formed subsurface reservoirs of oil where it was protected from loss and weathering in intertidal habitats. In these habitats several bird populations, e.g. harlequin ducks, preying on intertidal benthic invertebrates, showed clear signs of impacts from contamination. At oiled coasts they displayed the detoxification enzyme CYP1A nine years after the spill. 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 with un-oiled shores (Peterson et al. 2003). The oil still lingers in the environment and both the harlequin duck and other populations of coastal birds are still assessed as 'recovering' (NOAA 2010).

Many coasts in West Greenland including the assessment area have a similar morphology as the coasts of Prince William Sound, where the oil was trapped. This indicates that similar long-term impacts must be expected in the assessment area if spilled oil hit the coasts. The Arctic conditions in the assessment area may even prolong the impact period compared to Prince William Sound, where effects are still detectable after more than 20 years.

Another possible long-term effect in Prince Williams Sound was the collapse of the herring stock in 1993, which was related to sub-lethal effects of PAH exposure of the eggs during the spill in 1989 (Hjermann et al. 2007).

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

11.5.10 Oil spill impacts on tourism

The tourism industry may be impacted by a large oil spill hitting the coasts. Tourist travelling to Greenland to encounter the pristine, unspoilt Arctic environment will most likely avoid oil-contaminated areas. In this context it is notable that recreation and tourism are still considered as 'recovering' from the effects of the *Exxon Valdez* oil spill in 1989 in Alaska (NOAA 2010).

11.5.11 Mitigation of oil spills

The primary task is to prevent oil spills from happening. This is done by application of high HSE standards, BAT, BEP and a high level of oil spill preparedness. When it happens, impacts shall be minimised by an effective oil spill response, including contingency planning and response strategies. However, an effective oil spill response in the assessment area is hampered especially during winter and spring by ice, winter darkness and harsh weather.

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, and includes also offshore areas. The application of this tool is further discussed in the following Section (11.6).

A supplementary way to mitigate potential impacts on animal populations that are sensitive to oil spills, e.g. seabirds, is to manage populations by regulation of other population stressors (such as hunting), in order to increase their ability to compensate for extra mortality due to an oil spill (see Figure 56).

11.6 Oil spill sensitivity mapping

K. Johansen, D.S. Clausen, D. Boertmann and A. Mosbech

The coast of the assessment area has been mapped according to its sensitivity to oil spills (Stjernholm et al. 2011, Clausen et al. 2012). The two atlases integrate all knowledge presently available concerning coastal morphology, archaeology, biology and resource use. The coast was divided into segments approx. 50 km long, and they were classified according to their sensitivity to marine oil spills. This classification is shown on map sheets, and other map sheets show coast types, logistics and information relevant in an oil spill countermeasure context. Included are also descriptions of ice conditions, climate and oceanography.

The atlases are available on the following websites:
http://www2.dmu.dk/Pub/SR44.pdf and http://www2.dmu.dk/Pub/FR828.pdf

An overview of the sensitivity classification is shown in Figure 57. A larger part of the coast-line has been classified as highly or extremely sensitive to oil spills, particularly in the inner part of the Disko Bay and the northern part of the assessment area.

11.6.1 Seasonal summary of offshore oil spill sensitivity

In relation to this assessment the classification of the offshore areas is particularly relevant. 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 using the newest available data (Figure 58). 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, water depth, slope of seabed and distance to coast (for details see Clausen et al. 2012).

For each season and offshore area various symbols are shown representing important species or species groups according to their relative abundance (explanation of symbols see Figure 58). The relative sensitivity to oil spill has been calculated for each offshore area and season, ranging from low to extreme sensitivity. This classification is based on the relative abundance of resources, but also on species', specific sensitivity values, an oil residency index, a human use factor and a few other parameters. Note that the sensitivity ranking shown in Figure 58 is relative for each season and therefore cannot be directly compared between seasons.

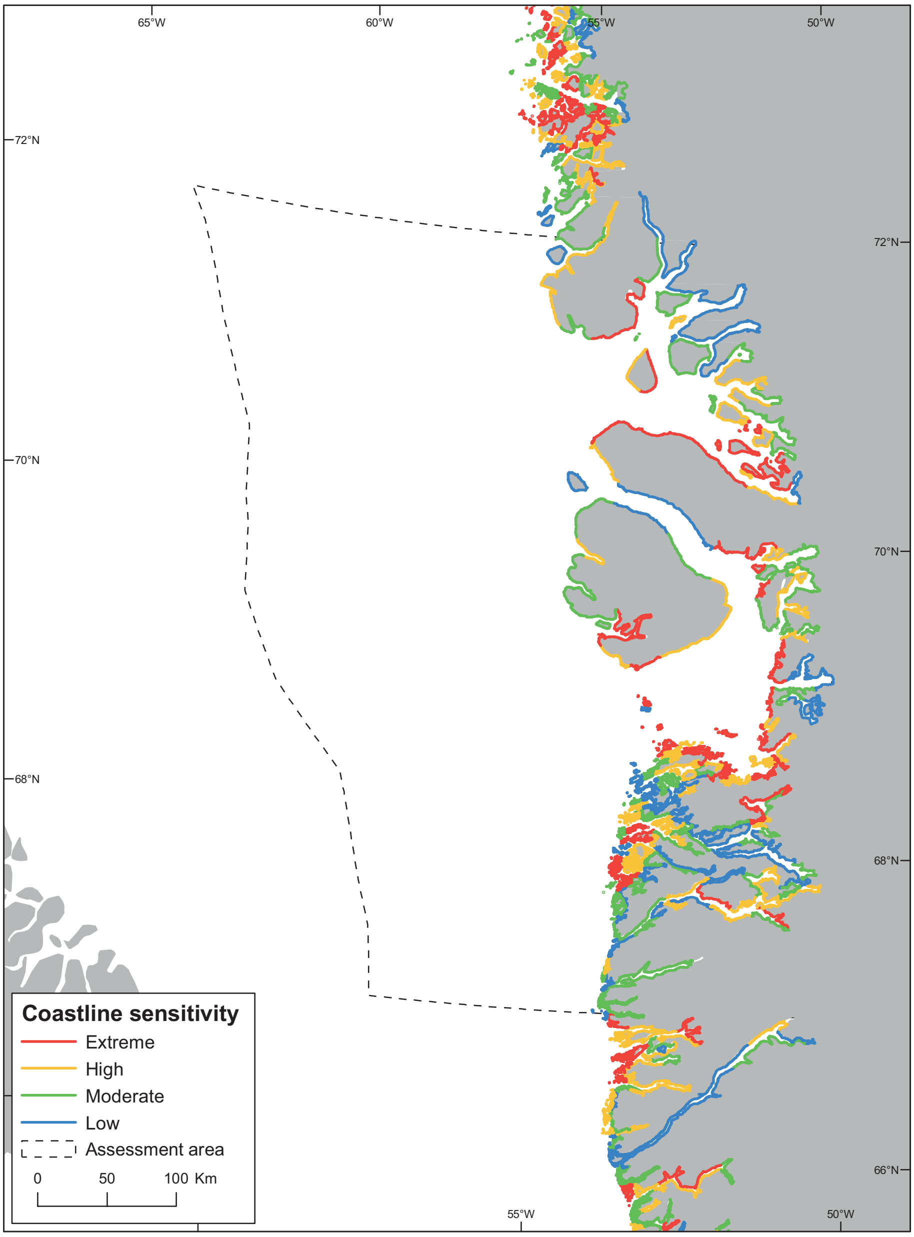


Figure 57. Oil spill sensitivity of coast lines in the assessment area according to the oil spill sensitivity atlases issued by NERI (Clausen et al. 2012, Stjernholm et al. 2011).

Spring (April/May–June)

The sea-ice gradually disintegrates and retreats towards north and west and open-water areas increase, e.g. in polynyas and along fast ice edges. In coastal habitats the shore lead opens and gradually becomes wider. Ice may still be present in the central part of the Baffin Bay in late June. The spring bloom is initiated in these open waters, and many seabirds assemble along the fast-ice edges and other open waters, especially close to the large breeding colonies. Many seabirds breeding further north or in Canada still occur in April/May and may be assembled in large concentrations in the archipelagos along the outer coast.

Bowhead whales, white whales, narwhals, walrus, and bearded seals move northwards in the leads and cracks which opens. Polar bears are also leaving the assessment area, moving north and west. As open water becomes available; fin, minke and humpback whales, and harp and hooded seals move in from the south.

The presence of the various marine mammals as well as large numbers of wintering/migrating birds results in a sensitivity classification of the near-coastal offshore areas as highly sensitive or extremely sensitive to oil spills during spring, including the Store Hellefiskebanke in the southern part of the assessment area (Figure 58, Spring).

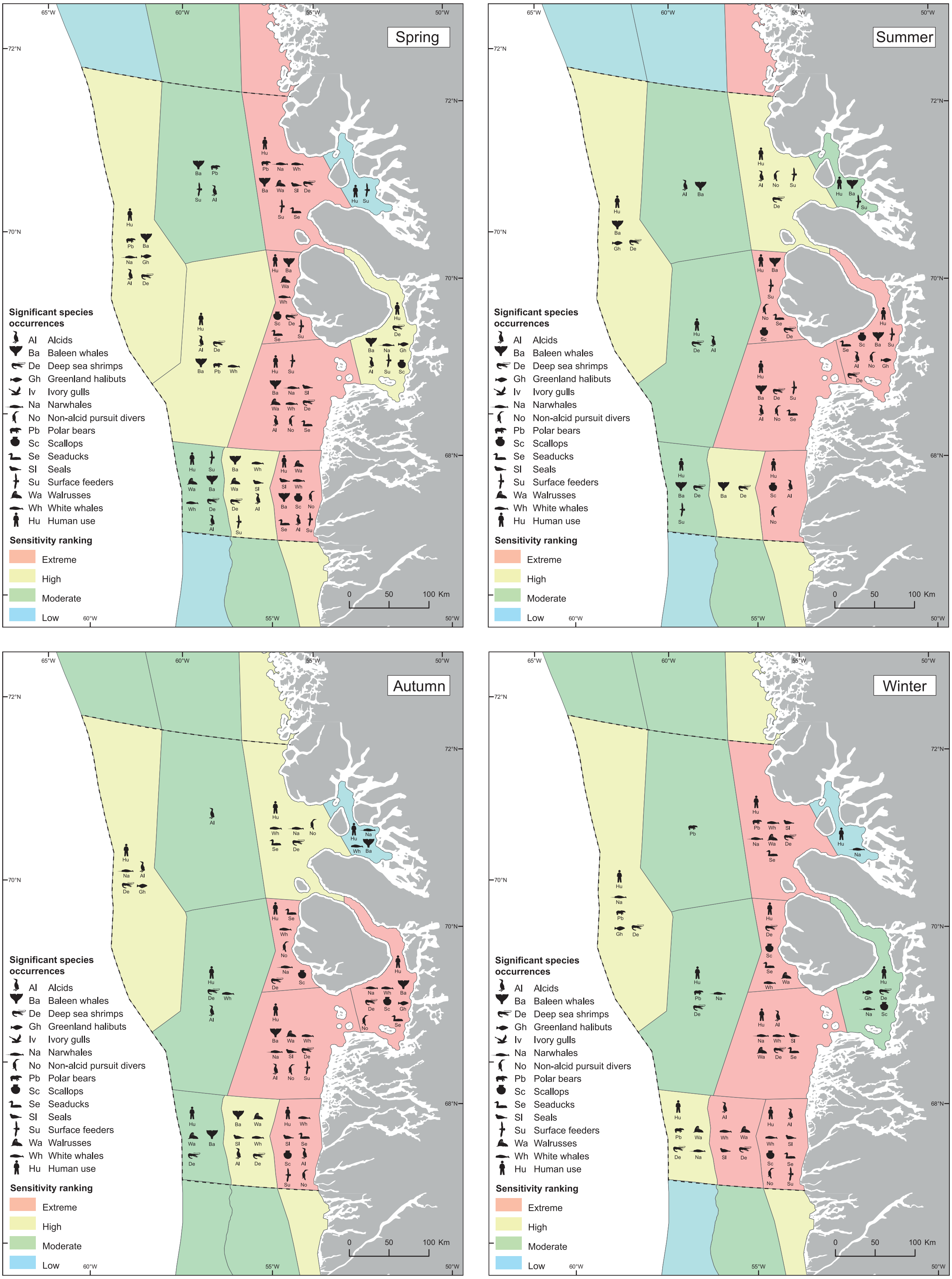


Figure 58. Oil spill sensitivity of offshore areas in the assessment area based on the oil spill sensitivity atlases issued by NERI (Stjernholm et al. 2011, Clausen et al. 2012).

The sensitivity of the north-western part of the assessment area is high, mainly due to fishing activities (i.e. Greenland halibut).

Summer July–August

This is the open-water season, when the assessment area usually is ice free except for icebergs.

Seabirds occupy the many breeding colonies, and they feed in the offshore waters close to the colonies. King eiders from breeding areas in Arctic Canada assemble in high numbers in certain fjords, esp. on the west coast of Disko and Svartenhuk. Bowhead whales, white whales, walrus and several narwhal stocks have left the assessment area following the ice towards north and northwest. Fin, minke, blue and humpback whales move in from south and feed in different parts of the assessment area.

As in spring larger parts of the near-coastal waters are extremely sensitive, particular around Disko Island (Figure 58, Summer).

Autumn September–November

Local breeding seabirds move out of the areas and seabirds breeding outside move in from the north and migrate through the assessment area. Particularly important are the thick-billed murres, while the studies in September 2009 indicated that the majority of the little auks migrate to the west of the assessment area. Narwhals and white whales arrive from the north and walruses from the west. Minke, fin and humpback whales move out of the assessment area.

The presence of these species makes large parts of the offshore waters extremely sensitive to oil spills in autumn (Figure 58, Autumn).

Winter (December–April)

The ice moves from west and northwest into the offshore areas and usually covers most of the assessment area by late December. However open waters are found in the shear zone between the drift ice and the fast ice along the coast. Narwhals, white whales, bowhead whales, walrus, ringed seals and bearded seals occur in or near these open-water areas, while narwhals and walrus also occur inside the drift ice. Polar bears walk over the sea-ice and swim across open water in search of seals. These marine mammals are highly dependent on the open-water areas and they are sensitive to disturbance and will be highly exposed to oil spills in such open waters.

Wintering seabirds – mainly the two species of eider duck – are found high numbers on the shallow part of Store Hellefiskebanke and along the coast south of Disko Bay, especially in the mouth of the fjords, where tidal currents are keeping the waters ice free.

Polar cod spawn under the ice in late winter and the eggs accumulate under the ice, at least in the northern part of the assessment area, where they are particularly exposed to oil spills.

The presence of the marine mammals and seabirds in larger part of the coastal and offshore area in combination with human use (e.g. hunting and commercial fishery for Greenland halibut) make most of the near-coastal areas and some parts of the offshore area extremely sensitive and other offshore areas towards the Canadian border highly sensitive to oil spills (Figure 58 - Winter).

In summary, it can be stated that the larger parts of the coastal area, including the waters around Disko Island and the banks, especially Store Hellefiskebanke are during all seasons extremely or highly sensitive to oil spills. High sensitivity has also been documented for offshore areas close to the Canadian border (north-west part of the assessment area), partly due to human use, e.g. commercial fishery and the presence of polar bears and narwhals in winter.

12 Background studies and information needs

D. Boertmann, A. Mosbech , S. Wegeberg and F. Ugarte

12.1 Background studies

Based on knowledge gaps identified in relation to the previous Disko West SEIA (Mosbech et al. 2007a), a number of background studies were carried out as part of a programme designed to improve knowledge and provide data needed as baseline for future assessments and for planning, monitoring and regulatory purposes. These studies have been completed by now and main results are included in the present assessment.

The background study programme funded by the Bureau of Minerals and Petroleum and carried out since the previous SEIA for the Disko West area had following components:

A. Studies of benthic macrofauna and macroalgae

- A.1 Studies of benthic macrofauna and macroalgae in the coastal areas in 2009 and 2012 (main results of the 2009 study are presented in Box 2).
- A.2 Studies of benthic macrofauna and habitat mapping of Store Hellefi skebanke and shelf area (main results are presented in Box 3).

B. Studies of seabird autumn migration and marine ecology

- B.1 Airplane and ship based survey autumn 2009 – (main results are presented in Box 1).

C. Marine mammal studies

- C.1 Occurrence and sensitivity of bowhead whales and narwhal (main results are presented in Box 9).
- C.2 Area occupancy of polar bears (main results are presented in Box 8).

D. Ritenbenk seabird colony follow-up study (results are presented in Box 6).

E. Underwater noise from the drillship Stena Forth operating in the Disko West area (presented in report by Kyhn et al. (2011)).

F. Updated SEIA with integrated data analysis (this report).

G. Updated oil spill sensitivity mapping (presented in Chapter 11.6)

12.2 Future information needs and development of a monitoring framework

Having completed the initial background studies it is clear that environmental background studies are still required both on a regional strategic level and on a project specific level. Environmental data is especially required for the planning of oil spill contingency strategies and of oil spill counter measures. Such studies are also needed to provide adequate data for future site-specific EIA-reports, data to designate 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 is a confounding factor that needs to be included in the baseline and monitoring.

To accommodate future information needs DCE and GINR propose a plan for the next two years (2014-2015) with three components: (1) Development of an integrated monitoring plan to support ecosystem based management of oil activities in the future; (2) Initiation of studies on selected generic issues of oil in the Arctic to support oil spill preparedness and (3) Conduction of specific studies of biodiversity to support oil spill preparedness , regulation of activities and preparation of future EIAs.

(1) Development of an integrated monitoring plan to support ecosystem based management of oil activities in the future

The Disko West assessment area is subject to an increase in human activity, including offshore hydrocarbon exploration (and perhaps future exploitation) in combination with a changing climate. Major changes in the environment are expected as a result of these drivers. A robust environmental data series spanning decades will be invaluable for understanding these changes, and therefore a coordinated long-term monitoring program for the Disko West area should be initiated, especially if oil will be produced. Such a program should be based on a number of selected parameters for a wide range of pre-defined ecosystem components (e.g. abundance of marine mammals, diversity of benthic organisms, density of sandeels, seabird breeding success etc.). Data should be collected by the 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 and to apply and monitor mitigation measures of human impacts. A program of this kind could take advantage of existing monitoring programs of fisheries and hunting resources carried out by GINR. The program could for example include:

- Benthic flora and fauna – establishment of a baseline (diversity, spatial variation, biomass, primary production),
- Baseline seabird colony studies,
- Marine mammals – distribution and abundance.

(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 them 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 secure that specific Greenland perspectives are addressed. The most 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 which are not necessary 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 (e.g. polar cod) under Arctic conditions,
- Degradation rates and toxicity of oil and degradation products in water and sediments under Arctic conditions,
- Impacts from subsea oil spills on concentrations of dia-pausing copepods (*Calanus*).

In relation to oil spill response and fate and behaviour of oil spills in ice:

- The effects of the *in situ* burn residues on the arctic environment, in order to assess if and when *in situ* burning can be allowed as an operational response.
- 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 optimized discharge depth of the drilling mud.

In relation to produced water there are similar questions:

- Fate, behaviour 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 (e.g. polar cod).

(3) Specific studies of biodiversity to support oil spill preparedness, regulation of activities and future EIAs

Here are listed some biodiversity information needs, which shall supply data to future oil spill preparedness and response to regulation of oil activities in the assessment area and the companies preparation of future specific EIAs. The list is not comprehensive and more needs may be identified.

<u>Shrimp larvae distribution, drift and settling</u>

Northern shrimp fishery is the single most important industry in Greenland. Shrimp larvae move passively in the upper part of the water column, where they can be exposed to oil spills and produced water.

Applied methods will include dedicated field studies, drift buoys and modelling covering the Disko West assessment area (origin) and Baffin Bay (area of potential settling of larvae).

<u>Benthic flora and fauna – identification of sensitive areas and establishment of a baseline (diversity, spatial variation, biomass, primary production)</u>

Benthic flora and fauna is sensitive to oil spill, to placement of structures and to release of drilling mud, i.e. sedimentation of mud particles and drill cuttings. Sensitive benthic areas and habitats (e.g. 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.

Dedicated strategic field surveys, including studies of food web impacts of oil to identify cascading effects as well as modelling of oil dispersal in the water column in the coastal region, combined with environmental baseline studies carried out by the licensees during site surveys.

<u>Fish – biology, spawning areas, stock relationships of important species (esp. Greenland halibut, polar cod and capelin)</u>

Fish, especially egg and larvae, can be sensitive to oil spills and produced water (e.g. tainting) and adult fish can be displaced by noisy activities. Knowledge on fish biology is therefore important to mitigate impacts on fish stocks and on fisheries.

These issues shall be addressed by dedicated surveys, tagging of fish, 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 (e.g. bearded seals, bottlenose whales), reactions to seismic pulses

Marine mammals (seals, walrus, baleen whales, toothed whales and polar bears) are sensitive to oil spills and to noisy activities. To mitigate impacts, knowledge of their biology and behaviour as specified above is important.

These issues shall be addressed by telemetry, dedicated surveys, passive acoustic monitoring, photo-identification and molecular analyses of tissue samples.

Ecology of shelf banks

The shallow banks, including the Store Hellefiskebanke, are especially vulnerable to oil spills because of their high concentrations of marine organisms at several trophic levels. These shallow banks are also important fishing and hunting grounds and have thus high economic importance for the Greenland society. A better understanding of the ecological interactions and dynamics of the bank fauna is needed.

This understanding shall be strengthened by food web interaction studies, including all benthic and pelagic components (e.g. benthic invertebrates and -microbes, phytoplankton, copepods, krill, sandeels) and the top predators (e.g. marine mammals and sea birds).

Baseline seabird colony studies

In order to establish a monitoring programme for assessing the impacts of hydrocarbon activities, baseline ecological knowledge on breeding seabirds (especially those not addressed in the previous studies) is required. For example cormorants breeding on the west coast of Disko Island are among the populations most exposed to potential oil spills. Background knowledge on population size, breeding success and foraging ecology would allow a quick assessment of potential ecological effects.

The status of the Ritenbenk-colony is critical as the main species (thick-billed murre and kittiwake) are declining. Monitoring of this site will be an essential part of future baseline seabird colony studies. The two colonies of Atlantic puffins on the islands Rotten and Brændevinsskær are also relevant for inclusion in monitoring programmes as they are very important in a national conservation context.

Such programmes shall include direct observations, photographic monitoring and application of data loggers.

13 References

Aars J, Andersen M, Fedak M (2007). Swimming and diving behavior of female polar bears. 17th Biennial Conference on the Biology of Marine Mammals, Cape Town, December 2007.

ACIA (2005). Impacts of a warming Arctic: Arctic Climate Impact Assessment (ACIA). Cambridge University Press, Cambridge, UK.

Acona (2012). Blowout risk evaluation in the Labroador Sea. Report No. AFT-2011-0444-02.3, Acona Flow Technology AS, Skien.

Acquarone M, Born E, Speakman J (2006). Walrus (*Odobenus rosmarus*) field metabolic rate measured by the doubly labeled water method. Aquatic Mammal 32: 363-369.

Ajiad AM, Gjøsætter H (1990). Diet of polar cod, *Boreogadus saida*, in the Barents Sea related to fi sh size and geographical distribution. International Council for the Exploration of the Sea, Council Meeting 1990/G: 48. 9 p.

Akvaplan-niva, Acona (2003). Muligheder for og konsekvenser ved deponering av borekaks på land og konsekvenser ved reinjektion. Akvaplan-niva. Tromsø. Unpublished Report.

Albert TF (1981). Some thoughts regarding the possible effects of oil contamination on the bowhead whale, *Balaena mysticetus*. In: Albert TF (ed): Tissue structural studies and other investigations on the biology of endangered Whales in the Beaufort Sea. Final Report for the period April 1, 1980 through June 30, 1981, Vol. 2. Prepared for U.S. Department of the Interior, Bureau of Land Management, Alaska OCS Office, p. 945-953.

Allen RC, Keay I (2006). Bowhead whales in the Eastern Arctic, 1611-1911: Population reconstruction with historical whaling records. Enviro. Hist. 12: 89–113.

Alonso-Alvarez C, Munilla I, Lopez-Alonso M, Velando A (2007). Sublethal toxicity of the Prestige oil spill on yellow-legged gulls. Environment International 33: 773-781.

AMAP (2004). AMAP Assessment 2002: Persistent organic pollutants in the Arctic. Arctic Monitoring and Assessment Programme (AMAP) Oslo, Norway. 310 pp.

AMAP 2009. Update on selected climate issues of concern. Arctic Monitoring and Assessment Programme, Oslo.

AMAP (2010). Assessment 2007: Oil and Gas Activities in the Arctic – Effects and Potential Effects. Vol. 1 and Vol. 2. Arctic Monitoring and Assessment Programme (AMAP), Oslo, vii+277 pp. http://www.amap.no/oga/.

AMAP (2011a). Snow, Water, Ice and Permafrost in the Arctic (SWIPA) - Executive Summary. AMAP Secretaria. Oslo, Norway. Assessment summary 17 pp.

AMAP (2011b). Arctic Pollution 2011. Arctic Monitoring and Assessment Programme (AMAP), Oslo vi+ 38pp, ISBN-978-82-7971-066-0Ambrose W, Renaud P (1995). Benthic response to water column productivity patterns: Evidence for benthic-pelagic coupling in the Northeast water polynea. Journal of Geophysical Research 100: 4411-4421.

Amstrup SC, Marcot BG, Douglas DC (2007). Forecasting the rangewide status of polar bears at selected times in the 21st century. USGS Alaska Science Center. Anchorage. Administrative Report.

Andersen OGN (1985). Forsøgsfiskeri efter tobis i Vestgrønland 1978. Biologiske resultater. Grønlands Fiskeri- og Miljøundersøgelser. Copenhagen. Fiskeri- og Miljøundersøgelser i Grønland serie III, 54+174 pp.

Andersen LW, Born EW (2000). Indications of two genetically different subpopulations of Atlantic walruses (*Odobenus rosmarus rosmarus*) in west and northwest Greenland. Canadian Journal of Zoology 78: 1999-2009.

Andersen LW, Born EW, Gjertz I, Wiig O, Holm LE, Bendixen C (1998). Population structure and gene flow of the Atlantic walrus (*Odobenus rosmarus rosmarus*) in the eastern Atlantic Arctic based on mitochondrial DNA and microsatellite variation. Molecular Ecology 7: 1323-1336.

Andersen LW, Born EW, Dietz R, Haug T, Oien N, Bendixen C (2003). Genetic population structure of minke whales *Balaenoptera acutorostrata* from Greenland, the North East Atlantic and the North Sea probably reflects different ecological regions. Marine Ecology Progress Series 247: 263-280.

Andersen JB, Böcher J, Guttmann B, Johnsen I, Kampp K, Skov H, Wegeberg S (2005). Baseline Ecological Survey – Thule Air Base. Zoological and Botanical Inventory of the Thule Air Base and north Star Bay. DHI Water & Environment. 181 pp.

Andersen LW, Born EW, Doidge DW, Gjertz I, Wiig Ø, Waples RS (2009a). Genetic signals of historic and recent migration between sub-populations of Atlantic walrus (*Odobenus rosmarus rosmarus*) west and east of Greenland. Endangered Species Research. Doi:10.3354/esr002. 42: 1-15.

Andersen LW, Born EW, Stewart REA, Dietz R, Doidge DW, Lanthier C (2009b). A genetic comparison of West Greenland and Baffin Island (Canada) walruses: management implications. NAMMCO Scientific Committee Working Group on Walrus Stock Status of Atlantic walrus in Greenland and adjacent seas. Copenhagen, Denmark. 23-26 November 2009. NAMMCO Working Paper SC/17/WWG/06.

Andersen JM, Wiersma YF, Stenson G, Hammill MO, Rosing-Asvid A (2009c). Movement patterns of hooded seals (*Cystophora cristata*) in the Northwest Atlantic ocean during the post-moult and pre-breed seasons. Journal of Northwater Atlantic Fish Science 42: 1-11.

Anderson JW, Lee RF (2006). Use of biomarkers in oil spill risk assessment in the marine environment. Human and Ecological Risk Assessment 12: 1192-1222.

Andriguetto-Filho JM, Ostrensky A, Pie MR, Silva UA, Boeger WA (2005). Evaluating the impact of seismic prospecting on artisanal shrimp fisheries. Continental Shelf Research 25: 1720-1727.

Anker-Nilssen T (1987). Metoder til konsekvensanalyser olje/sjøfugl. Norsk Institutt for Naturforskning. Trondheim. Vildtrapport No. 44, 114 pp.

Anon (1978). Bundinvertebrater på Store og Lille Hellefiskebanke og i Holsteinsborgdybet. Marine Identification Agency Aps. Skodsborg, Denmark. Rapport til Ministeriet for Grønland, 102 pp.

Anon (2003a). Cumulative Environmental Effects of Oil and Gas Activities on Alaska's North Slope. National Research Council. The National Academes Press, Washington, D.C.

Anon (2003b). Utredning av konsekvens av helårlig petroleumsvirksomhet i området Lofoten-Barentshavet. Olje- og Energiministeriet. Oslo. Sammendragsrapport.

Anon (2009). Hjemmestyrets bekendtgørelse nr. 8 af 2. marts 2009 om beskyttelse og fangst af fugle. Executive order by the Government of Greenland.

Anon (2010a). Hvalroskvoter 2010 (Walrus quotas 2010). Government of Greenland. http://dk.nanoq.gl/Emner/Landsstyre/Departementer/Departement_for_fiskeri/Nyhedsforside/Nyheder_fra_dep_fiskeri/2010/07/hvalroskvoter.aspx.

Anon (2010b). Hvalroskvoter 2011 (Walrus quotas 2011). Tusagassiorfinnut nalunaarut/Pressemeddelelse (Press release), 30 December 2010. Government of Greenland. Department of Fishery, Hunting and Agriculture, Nuuk.

Anon (2010c). Selvstyrets bekendtgørelse nr. 11 af 16. juli 2010 om beskyttelse og fangst af store hvaler. Executive order by the Government of Greenland.

Anon (2011a). Miljøteknologi. Delutredning til sektorutredning Petroleum og energi. Helheltlig forvaltningsplan for Nordsjøen. Kartleggning av tilgjengelig miljøteknologi. Oljedirektoratet. http://www.npd.no.

Anon (2011b). Selvstyrets bekendtgørelse nr. 7 af 29. marts 2011 om beskyttelse og fangst af hvid- og narhvaler. Executive order by the Government of Greenland.

Anon (2011c). Isbjørnekvoter 2011/ 2011-mi nannuttassiissutit. Naalakkersuisut har d. 4. januar 2011 godkendt isbjørnekvote for 2011. Sagsnr. 2010-041367. Dok. Nr. 536539. Aalisarnermut, Piniarnermut Nunalerinermullu Naalakkersuisoqarfik, Departementet for Fiskeri, Fangst og Landbrug, Nuuk: 2.

APA (2003). Greenland offshore (West Disko) oil development feasibility assessment. Project no. 10166. APA Petroleum Engeneering Inc. Unpublished Report.

APNN (2011a). Kvoter for fangst af hvid- og narhval. Press release from the Government of Greenland. http://dk.nanoq.gl/Emner/Landsstyre/Departementer/Departement_for_fiskeri/Nyhedsforside/Nyheder_fra_dep_fiskeri/2011/03/hvid_narhval.aspx.

APNN (2011b). Regionale kvoter for fangst af store hvaler 2011. Press release from the Government of Greenland. http://dk.nanoq.gl/Emner/Landsstyre/Departementer/Departement_for_fiskeri/Nyhedsforside/Nyheder_fra_dep_fiskeri/2011/03/regional_fangst_store_hvaler.aspx.

Arboe NH, Kingsley M (2010). The Fishery for Northern Shrimp (*Pandalus borealis*) off West Greenland, 1970-2010. Report of Scientific Council Meeting. Northwest Atlantic Fisheries Organization (NAFO).

Armstrong DA, Dinnel PA, Orensanz JM, Armstrong JL, McDonald TL, Cusimano RF, Nemeth RS, Landholt ML, Skalski JR, Lee RF, Huggett RJ (1995) Status of selected bottomfish and crustaceans species in Prince William Sound following the *Exxon Valdez* oil spill. In: Wells PG, Buttler JN, Hughes JS (eds): The *Exxon Valdez* oil spill: fate and effects in Alaskan waters. American Society for Testing and Materials STP1219, Philadelphia, p. 485-547.

Armsworthy SL, Cranford PJ, Lee K (2005). Offshore oil and gas environmental effects monitoring. Approaches and technologies. Batelle Press, Columbus, Ohio.

Arnason R (2007). Climate change and fisheries, assessing the economic impact in Iceland and Greenland. National Resource Modelling 20: 163–197.

Atkinson S, Born EW, Laidre K (2011). A Research Plan for re-Assessment of the Baffin Bay and Kane Basin polar bear sub-populations. Unpublished research plan submitted 22 July 2011 to the Canada-Greenland Joint Commission on Polar Bears: 28.

Au WWL, Carder DA, Penner RH, Scronce BL (1985). Demonstration of adaptation in beluga whale echolocation signals. Journal of the Acoustical Society of America 77: 726-730.

Bach L, Forbes VE, Dahllöf I (2009). The amphipod *Orchomenella pinguis* – A potential bioindicator for contamination in the Arctic. Marine Pollution Bulletin 58: 1664-1670.

Bach L, Fischer A, Strand J (2010). Local anthropogenic contamination affects the fecundity and reproductive success of an Arctic amphipod. Marine Ecology Progress Series 419: 121-128.

Baird RW (2000) The killer whale, foraging specializations and group hunting In: Mann J, Connor RC, Tyack PL, Whitehead H (eds): Cetacean societies, field studies of dolphins and whales. University of Chicago Press, Chicago, p. 127-154.

Baird RW, Dill LM (1995). Occurrence and behaviour of transient killer whales: seasonal and pod-specifi c variability, foraging behaviour, and prey handling. Can. J. Zool. 73: 1300-1311.

Basu N, Scheuhammer AM, Sonne C, Letcher RJ, Born EW, Dietz R (2009). Is Dietary Mercury of Neurotoxicological Concern to Wild Polar Bears (*Ursus maritimus*)? Environmental Toxicology and Chemistry 28: 133-140.

Barrett-Lennard LG (2000). Population structure and mating patterns of killer whales, *Orcinus orca*, as revealed by DNA analysis. PhD thesis, University of British Columbia, Vancouver.

Barrett RT, Chapdelaine G, Anker-Nilssen T, Mosbech A, Montevecchi WA, Reid JB, Veit RR (2006). Seabird numbers and prey consumption in the North Atlantic. ICES Journal of Marine Science 63: 1145-1158.

Bechmann RK, Westerlund S, Baussant T, Taban C, Pampanin DM, Smit M, Lowe D (2006). Impacts of drilling mud discharges on water column organism and filter feeding bivalves. IRIS report 2006/038.

Becker S, Walter B, Bischof K (2009). Freezing tolerance and photosynthetic performance of polar seaweeds at low temperatures. Botanica Marina 52: 609-616.

Belikov RA, Bel'kovich VM (2006). High-pitched tonal signals of beluga whales (*Delphinapterus leucas*) in a summer assemblage off Solovetskii Island in the White Sea. Acoustical physics 52: 125-131.

Belikov RA, Bel'kovich VM (2007). Whistles of beluga whales in the reproductive gathering off Solovetskii Island in the White Sea. Acoustical physics 53: 528-534.

Berge JA, Brevik EM, Bjorge A, Folsvik N, Gabrielsen GW, Wolkers H (2004). Organotins in marine mammals and seabirds from Norwegian territory. Journal of Environmental Monitoring 6: 108-112.

Bergström B (2000). The biology of *Pandalus*. Advances in Marine Biology vol. 38: 55-245.

Bergström B, Vilhjalmarsson H (2007). Cruise report and preliminary results of the acoustic/pelagic trawl survey off West Greenland for capelin and polar cod 2005. Pinngortitaleriffik, Greenland Institute of Natural Resources. Nuuk. Technical Report No. 66, 71 pp.

Bertness MD, Leonard GH, Levine JM, Schmidt PR, Ingraham AO (1999). Treating the relative contribution of positive and negative interactions in rocky intertidal communties. Ecology 80: 2711-2726.

Berzin AA (1971). The sperm whale. Translated into English in 1972, Israel Program for Scientific Translations, Jerusalem. 394 pp.

Best PB (1979) Social organization in sperm whales, *Physeter macrocephalus*. In: Winn HE, Olla BL (eds): Behaviour of marine animals, Vol 3. Plenum Press, New York, p. 227-289.

Bigg MA, Olesiuk PF, Ellis GM, Ford JKB, Balcomb III KC (1990). Social organization and genealogy of resident killer whales (*Orcinus orca*) in the coastal waters of British Columbia and Washington State. Report of the International Whaling Commission (Special Issue 12): 383-405.

Blackwell SB, Lawson JW, Williams MT (2004). Tolerance by ringed seals (*Phoca hispida*) to impact pipe-driving and construction sounds at an oil production island. Journal of the Acoustical Society of America 115: 2346-2357.

Blicher ME, Rysgaard S, Sejr MK (2010). Seasonal growth variation of *Chlamys islandica* (Bivalvia) in sub-Arctic Greenland is linked to food availability and temperature. Marine Ecology Progress Series 407: 71-86.

Boertmann D (1994). An annotated checklist to the birds of Greenland. – Meddr. Grønland Biosc. 38: 64 pp.

Boertmann D (2006). Optælling af ridekolonier i Disko Bugt, Arfersiorfik Fjord og Nordre Strømfjord. – Arbejdsrapport fra DMU, nr. 225.

Boertmann D (2008). Grønlands Rødliste 2007. Grønlands Hjemmestyre & Danmarks Miljøundersøgelser, Nuuk.

Boertmann D, Mosbech A (1997). Breeding distribution and abundance of the great cormorant *Phalacrocorax carbo* carbo in Greenland. Polar Research 16: 93-100.

Boertmann D, Mosbech A (2001). Important summer concentrations of seaducks in West Greenland. An input to oil spill sensitivity mapping. National Environmental Research Institute (NERI). Copenhagen. NERI Technical Report No. 345, 48 pp.

Boertmann D, Mosbech A (2002). Molting Harlequin ducks in Greenland. Waterbirds 25: 326-332.

Boertmann D, Mosbech A (2011). Eastern Baffin Bay. A strategic environmental impact assessment of hydrocarbon activities. DCE – Danish Centre for Environment and Energy, Aarhus University, Roskilde. DCE Scientific Report No. 9, 270 pp.

Boertmann D, Nielsen RD (2010). Geese, seabirds and mammals in North and Northeast Greenland. Aerial surveys in summer 2009. NERI Technical Report no. 773. Aarhus University. 65 pp.

Boertmann D, Mosbech A, Falk K, Kampp K (1996). Seabird colonies in western Greenland. National Environmental Research Institute (NERI). Copenhagen, Denmark. NERI Technical Report No. 170, 98 pp.

Boertmann D, Mosbech A, Frimer O (1997). Autumn migration of light-bellied Brent geese *Branta bernicla hrota* through North-west Greenland. Wildfowl 48: 98-107.

Boertmann D, Mosbech A, Johansen P (1998). A review of biological resources in West Greenland sensitive to oil spills during winter. National Environmental Research Institute (NERI). Copenhagen. NERI Technical Report No. 246, 74 pp.

Boertmann D, Lyngs P, Merkel FR, Mosbech A (2004). The significance of SW Greenland as winter quarters for seabirds. Bird Conservation International 14: 87-112.

Boertmann D, Mosbech A, Merkel FR (2006). The importance of Southwest Greenland for wintering seabirds. British Birds 99: 282-298.

Boertmann D, Tougaard J, Johansen K, Mosbech A (2010). Guidelines to environmental impact assessment of seismic activities in Greenland waters. 2nd edition. National Environmental Research Institute, Aarhus University. Roskilde. NERI Technical Report No. 785.

Boje J (2002). Intermingling and seasonal migrations of Greenland halibut (*Reinhardtius hippoglossoides*) populations determined from tagging studies. Fishery Bulletin 100: 414-422.

Booth JA (1984). The epontic algal community of the edge zone and its significance to the Davis Strait ecosystem. Arctic: 234-243.

Borgå K, Salorante TM, Ruus A (2010). Simulating climate change-induced alterations in bioaccumulation of organic contaminants in an Arctic marine food web. Environmental Toxicology and Chemistry 29: 1349-1357.

Born EW (2001). Reproduction in female Atlantic walruses (*Odobenus rosmarus rosmarus*) from Northwest Greenland. Journal of Zoology 255: 165-174.

Born EW (2003). Reproduction in male Atlantic walruses (*Odobenus rosmarus rosmarus*) from the North Water (N Baffin Bay). Marine Mammal Science 19: 819-831.

Born E (2005). An assessment of the effects of hunting and climate on walruses in Greenland. Greenland Institute of Natural Resources and Oslo University, Nuuk, Greenland.

Born E, Dietz R, Heide-Jørgensen MP (1982). Catch and distribution of walrus (*Odobenus rosmarus*) in West Greenland International Council for Exploration of the Sea (ICES). Copenhagen. ICES Report C.M. 1982/N:10, 27 pp.

Born EW, Heide-Jørgensen MP, Davis RA (1994). The Atlantic walrus (*Odobenus rosmarus rosmarus*) in West Greenland. Meddelelser om Grønland, Bioscience 40: 1-33.

Born EW, Heide-Jørgensen MP, Larsen F, Martin AR (1994). Abundance and stock composition of narwhals (*Monodon monoceros*) in Inglefield Bredning (NW Greenland). Meddr. om Grønland, Bioscience 39: 51-68.

Born E, Gjertz I, Reeves RR (1995). Population assessment of Atlantic walrus. Norsk Polarinstituts Meddelser 138: 1-100 pp.

Born EW, Andersen LW, Gjertz I, Wiig O (2001). A review of the genetic relationships of Atlantic walrus (*Odobenus rosmarus rosmarus*) east and west of Greenland. Polar Biology 24: 713-718.

Born E, Rysgaard S, Ehlmé G, Sejr M, Acquarone M, Levermann N (2003). Underwater observations of foraging free-living Atlantic walruses (*Odobenus rosmarus*) and estimates of their food consumption. Polar Biology 26: 348-357.

Born EW, Acquarone M, Knutsen LØ, Toudal E (2005). Homing behaviour in an Atlantic walrus (*Odobenus rosmarus rosmarus*). Aquatic Mammals 31: 23-33.

Born EW, Kingsley MCS, Riget FF, Dietz R, Møller P, Haug T, Muir DCG, Outridge P, Øien N (2007). A multi-elemental approach to identification of subpopulations of North Atlantic minke whales *Balaenoptera acutorostrata*. Wildlife Biology 13: 84-97.

Born EW, Sonne C, Dietz R (2010) Research on polar bears in Greenland 2005-2009. pp. 135-148 in M. E. Obbard GWT, E. Peacock & T. DeBruyn (ed): Proceedings of 15th Working Meeting of the Polar Bear Specialist Group IUCN Occassional Papers of the IUCN Species Survival Commission No 43. Gland, Switzerland and Cambridge, UK, Copenhagen, Denmark.

Born EW, Laidre K, Wiig Ø (2012). Genetic mark-recapture assessment of the Bafffin Bay and Kane Bassin polar bear subpopulations. Greenland Institute of Natural Ressources.

Borum J, Pedersen MF, Krause-Jensen D, Christensen PB, Nielsen K (2002). Biomass, photosynthesis and growth of Laminaria saccharina in a high-arctic fjord, NE Greenland. Marine Biology 141: 11-19.

Bossi R, Riget, FF, Dietz R (2005). Temporal and Spatial Trends of Perfluorinated Compounds in Ringed Seal (*Phoca hispida*) from Greenland. Environ. Sci. Technol, 39, 7416-7422.

Bourne WRP (1979). Birds and gas flares. Marine Pollution Bulletin 10: 124-125.

Bowering WR, Chumakov AK (1989). Distribution and relative abundance of Greenland halibut (*Reinhardtius hippoglosoides*, Walbaum) in the Canadian Northwest Atlantic from Davis Strait to the Northern-Grand-Bank. Fisheries Research 7: 301-327.

Box JE, Cappelen J, Decker D, Fettweis X, Mote T, Tedescoand M, van de Wal RSW (2010). Greenland [in Arctic Report Card 2010], NOAA, http://www.arctic.noaa.gov/reportcard.

Boye TK, Simon M, Madsen PT (2010). Habitat use of humpback whales in Godthaabsfjord, West Greenland, with implications for commercial exploitation. Journal of the Marine Biological Association of the United Kingdom 90: 1529-1538.

Bradstreet MSW (1982). Occurrence, habitat use, and behavior of seabirds, marine mammals, and Arctic cod at the Pond Inlet ice edge. Arctic 3: 28-40.

Braithwaite LF, Aley MG, Slater DL (1983). The effects of oil on the feeding mechanism of the Bowhead whale. Report AA851-CTO-55, prepared for the Department of the Interior, from Brigham Young University, Provo, UT.

Braune BM, Outridge PM, Fisk AT, Muir DCG, Helm PA, Hobbs K, Hoekstra PF, Kuzyk ZA, Kwan M, Letcher RJ, Lockhart WL, Norstrom RJ, Stern GA, Stirling I (2005). Persistent organic pollutants and mercury in marine biota of the Canadian Arctic: An overview of spatial and temporal trends. Science of the Total Environment 351-352: 4-56.

Breuer EAG, Stevenson AG, Howe JA, Carroll JC, Shimmield GB (2004). Drill cutting accumulations in the Northern and Central North Sea: a review of environmental interactions and chemical fate. Marine Pollution Bulletin 48: 12-25.

Breuer E, Shimmield G, Peppe O (2008). Assessment of metal concentrations found within a North Sea drill cutting pile. Marine Pollution Bulletin 56: 1310-1322.

Brewer K, Gallagher M, Regos P, Isert P, Hall J (1993). Exploration Prospect: Site Specific Monitoring Program. Final Report Prepared by Coastal and Offshore Pacific Corporation, Walnut Creek, CA, for ARCO Alaska, Inc., Anchorage, AK. Kuvlum #1, 80 pp.

Brian JV, Harris CA, Runnalls TJ, Fantinati A, Pojana G, Marcomini A, Booy P, Lamoree M, Kortenkamp A, Sumpter JP (2008). Evidence of temperature-dependent effects on the estrogenic response of fish: Implications with regard to climate change. Science of the Total Environment 397: 72-81.

Bryan TL, Metaxas A (2006). Distribution of deep-water corals along the North American continental margins: Relationships with environmental factors. Deep Sea Research Part I: Oceanographic Research Papers 53: 1865-1879.

Buch E (2000). A monograph on the physical oceanography of the Greenland waters. Danish Meteorological Institute (DMI). Copenhagen. Scientific Report No. 00-12, 405 pp.

Buch E (2002). Present oceanographic conditions in Greenland Waters. Danish Meteorological Institute (DMI). Copenhagen. Scientific Report No. 02-02, 39 pp.

Buch E, Nielsen MH, Pedersen SA (2003). On the coupling between climate, hydrography and recruitment variability of fishery resources off West Greenland. ICES Marine Science Symposia 219: 231-240.

Buck KR, Nielsen TG, Hansen BW, Gastrup-Hansen D, Thomsen HA (1998). Infiltration phyto- and protozooplankton assemblages in the annual sea ice of Disko Island, West Greenland, spring 1996. Polar Biology 20: 377-381.

Buckland ST, Bloch D, Cattanach KL, Gunnlaugsson T, Hoydal K, Lens S, Sigurjónsson J (1993). Distribution and abundance of long-finned pilot whales in the North Atlantic, estimated from NASS-1987 and NASS-89 data. Cambridge. Report of the International Whaling Commision Special Issue No. 14, p. 33-50.

Buckland ST, Anderson DR, Burnham KP, Laake JL, Borchers DL, Thomas L (2001). Introduction to Distance Sampling. Estimating abundance of biological populations. Oxford University Press, Oxford.

Burmeister A (2002). Preliminary notes on the reproductive condition of mature female snow crabs (*Chionoecetes opilio*) from Disko Bay and Sisimiut, west Greenland. In: Paul AJ, Dawe EG, Elner R, Jamieson GS, Kruse GH, Otto RS, SainteMarie B, Shirley TC, Woodby D (eds): Crabs in Cold Water Regions: Biology, Management, and Economics, Vol 19. Lowell Wakefield Fisheries Symposia Series, p. 255-267.

Burmeister A (2012). Assessment and advice of snow crab in West Greenland 2013 and 2014. Technical Report no. 88, Greenland Institute of Natural Resources.

Burns JJ (1981). Bearded seal *Erignatus barbatus*. In: Ridgway SH, Harrison FRS (eds): Handbook of Marine Mammals, Vol 2. Academic Press, San Diego.

Burns JJ, Montague JJ, Cleveland JC (1993). The Bowhead Whale. – The Society for Marine Mammalogy. Spec. Pub. No 2. Pp. 787.

CAFF (2010). Arctic Biodiversity Trends 2010 – Selected indicators of change. CAFF International Secretariat. Akureyri, Iceland.

Camilli R, Reddy CM, Yoerger DR, Van Mooy BAS, Jakuba MV, Kinsey JC, McIntyre CP, Sylva SP, Maloney JV (2010). Tracking hydrocarbon plume transport and biodegradation at Deepwater Horizon. Science 330: 201-204.

Campbell JS, Simms JM (2009). Status Report on Coral and Sponge Conservation in Canada. Fisheries and Oceans Canada. 87 pp.

Camus L, Dahle S (2007). Biological impact of oil on the sea-ice of the Arctic. Exploration & Production, Oil & Gas Review 11: 28-30.

Camus L, Olsen GH (2008). Embryo aberrations in sea-ice amphipod *Gammarus wilkitzkii* exposed to water soluble fraction of oil. Marine Environmental Research 66: 221-222.

Camus L, Jones MB, Børseth JF, Grosvik BE, Regoil F, Depledge MH (2002a). Total oxyradical scavenging capacity and cell membrane stability of haemocytes of the Arctic scallop, *Chlamys islandicus*, following benzo(a)pyrene exposure. Marine Environmental Research 54: 425-430.

Camus L, Jones MB, Børseth JF, Regoil F, Depledge MH (2002b). Heart rate, respiration and sum oxyradical scavenging capacity of the Arctic spider crab *Hyas araneus*, following exposure to polycyclic aromatic compounds via sediment injection. Aquatic Toxicology 62: 1-13.

Camus L, Birkely SR, Jones MB, Børseth JF, Grosvik BF, Gulliksen B, Lonne OJ, Regoli F, Depledge MH (2003). Biomarker responses and PAH uptake in *Mya truncata* following exposure to oil-contaminated sediment in an Arctic fjord (Svalbard). Science of the Total Environment 308: 221-234.

Castellote M, Clark CW, Lammers MO (2010). Acoustic compensation to shipping and airgun noise by Mediterranean fin whales (*Balaenoptera physalus*). Journal of the Acoustical Society of America 127: 1726.

Caulfield RA (1997). Greenlanders, whales and whaling: sustainability and self-determination in the Arctic. University Press of New England, Darthmouth, NH.

Cerchio S, Jacobsen JK, Norris TF (2001). Temporal and geographical variation in songs of humpback whales, *Megaptera novaeangliae*: synchronous change in Hawaiian and Mexican breeding assemblages. Animal Behaviour 62: 313-329.

Challenger G, Mauseth G (2011) Seafood safety and oil spills. In: Fingas M (ed): Oil spill science and technology. Elsevier, p. 1083-1100.

Cheung WWL, Lam VWY, Pauly D (eds.) 2008. Modeling present and climate- shifted distribution of marine fishes and invertebrates. Fisheries Centre Research Reports 16(3). 72pp.

Cheung W, Lam V, Sarmiento J, Kearney K, Watson R, Zeller D, Pauly D (2010). Large-scale redistribution of maximum fisheries catch potential in the global ocean under climate change. Global Change Biology 16: 24–35.

Christensen T (1975). Some marine algae from West Greenland. Botanisk Tidskrift 70: 143-146.

Christensen T (1981). Havbundens planter. In: Böcher TW, Nielsen CO, Schou A (eds): Danmarks Natur Grønland og Færøerne, Vol 10. Politikens Forlag, p. 184-192.

Christensen FT, Steensboe JS, Mosbech A (1993). Oil spill simulations as a contingency planning tool offshore West Greenland. Proceedings of POAC 93 Vol. 2, p. 693-707.

Christensen T, Falk K, Boye T, Ugarte F, Boertmann D, Mosbech A (2013). Identifikation af sårbare marine områder i den grønlandske del af arktis. Videnskabelig rapport fra DCE 43, 72 pp.

Christian JR, Mathieu A, Thomson DH, White D, Buchanan RA (2003). Effects of seismic energy on Snow crab (*Chionoecetes opilio*). LGL Ltd., Oceans Ltd. & National Energy Board. Calgary, Canada. Environmental Studies Research Funds Report No. 144, 56 pp.

Christiansen JS, Karamushko LI, Nahrgang J (2010). Sub-lethal levels of waterborne petroleum may depress routine metabolism in polar cod *Boreogadus saida* (Lepechin, 1774). Polar Biology 33: 1049-1055.

Clausen D, Johansen KL, Mosbech A, Boertmann D, Wegeberg S (2012). Environmental Oil Spill Sensitivity Atlas for the West Greenland (68°-72° N) Coastal Zone, 2nd revised edition. DCE – Danish Centre for Environment and Energy Scientific Report No. 44. http://www2.dmu.dk/Pub/SR44.pdf

Cohen DM, Inada T, Iwamoto T, Labignan I (1990). Gadiform fishes of the world (order: Gadiformes). An annotated and illustrated catalogue of cods, hakes, grenadiers and other gadiform fishes known to date. FAO Species Catalogue 10: 1-442.

Comiso JC, Parkinson CL, Gersten R, Stock L (2008). Accelerated decline in the Arctic Sea-ice cover. Geophysical Research Letters 35:6:

Compton R, Goodwin L, Handy R, Abbott V (2008). A critical examination of worldwide guidelines for minimising the disturbance to marine mammals during seismic surveys. Marine Policy 32: 255-262.

COSEWIC (2006). Assessment and update status report on the Atlantic walrus (*Odobenus rosmarus rosmarus*) in Canada. Committee on the status of endangered wildlife in Canada, Ottawa, ix, 65 pp. (www.sararegistry.gc.ca/status/status_e.cfm).

Cronin MA, Hills S, Born EW, Patton JC (1994). Mitochondrial-dna variation in Atlantic and Pacific walruses. Canadian Journal of Zoology 72: 1035-1043.

Cross WE, Wilce RT, Fabijan MF (1987). Effects of releases of oil and dispersed oil on Arctic nearshore macrobenthos. III. macroalgae. Arctic 40: 211-219.

Cummings WC, Thompson PO (1971). Underwater Sounds from the Blue Whales, *Balaenoptera musculus*. Journal of the Acoustical Society of America 4: 1193-1198.

Dahl TM, Lydersen C, Kovacs KM, Falk-Petersen S, Sargent J, Gjertz I, Gulliksen B (2000). Fatty acid composition of the blubber in white whales (*Delphinapterus leucas*). Polar Biology 23: 401-409.

Dalebout ML, Ruzzante DE, Whitehead H, Øien N (2006). Nuclear and mitochondrial markers reveal distinctiveness of a small population of bottlenose whales (*Hyperoodon ampullatus*) in the western North Atlantic. Molecular Ecology 15: 3115–3129.

Dalen J, Hovem JM, Karlsen HE, Kvadsheim PH, Løkkeborg S, Mjelde R, Pedersen A, Skiftesvik AB (2008). Kunnskabsstatus of forskningsbehov med hensyn til skremmeeffekter og skadevirkninger av seismiske lydbølger på fisk og sjøpattedyr. Oljedirektoratet, Fisjkeridirektoratet af Statens Forureningstilsyn. Bergen, Norway.

Daly KL, Wallace DWR, Smith WO, Skoog A, Lara R, Gosselin M, Falck E, Yager PL (1999). Non-Redfield carbon and nitrogen cycling in the Arctic: Effects of ecosystem structure and dynamics. Journal of Geophysical Research Oceans 104: 3185-3199.

Davies JM, Addy, JM, Blackman RA, Blanchard, JR, Ferbrache, JE, Moore, DC, Somerville HJ, Whitehead A, Wilkinson T (1984). Environmental Effects of the Use of Oil-based Drilling Muds in the North Sea. Marine Pollution Bulletin 15: 363-370.

Davis RA, Richardson J, Thiele L, Dietz R, Johansen P (1990). State of the Arctic Environment. Report of Underwater noise. Finnish Initiative on Protection of the Artic Environment.

Dean TA, Jewett SC (2001). Habitat-specific recovery of shallow subtidal communities following the *Exxon Valdez* oil spill. Ecological Applications 11: 1456-1471.

Derenbach JB, Gereck MV (1980). Interference of petroleum hydrocarbons with the sex pheromone reaction of *Fucus vesiculosus*. Journal of Experimental Biology and Ecology 44: 61-65.

Derocher AE, Lunn NJ, Sterling I (2004). Polar Bears in a Warming Climate. Integr Comp Biol 44: 163-176.

DFO (2004). Review of scientific information on impacts of seismic sound on fish, invertebrates, marine turtles and marine mammals. Habitat Status Report 2004/002.

Di Iorio L, Clark C (2010). Exposure to seismic survey alters blue whale acoustic communication. Biological Letters 6: 51-54.

Diercks AR, Asper VL, Highsmith RC, Woolsey M, Lohrenz SE, McLetchie K, Gossett A, Lowe M, III, Joung D, McKay L (2010). The discovery of deep oil plumes at the deepwater Horizon oil spill site. American Geophysical Union, Fall Meeting 2010.

Dietz R, Heide-Jørgensen MP (1995). Movements and swimming speed of narwhals, *Monodon monoceros*, equipped with satellite transmitters in Melville Bay, northwest Greenland. Canadian Journal of Zoology 73: 2106-2119.

Dietz R, Riget F, Johansen P (1996). Lead, cadmium, mercury and selenium in Greenland marine animals. The Science of the Total Environment 186: 67-93.

Dietz R, Heide-Jorgensen MP, Richard PR, Acquarone M (2001). Summer and fall movements of narwhals (*Monodon monoceros*) from northeastern Baffin Island towards northern Davis Strait. Arctic 54: 244-261.

Dietz R, Heide-Jorgensen MP, Richard P, Orr J, Laidre K, Schmidt HC (2008a). Movements of narwhals (*Monodon monoceros*) from Admiralty Inlet monitored by satellite telemetry. Polar Biology 31: 1295-1306.

Dietz R, Bossi R, Rigét FF, Sonne C, Born EW (2008b). Increasing perfluoroalkyl contaminants in East Greenland polar bears (*Ursus maritimus*): A new toxic threat to the Arctic bears. Environ. Sci. Technol.42: 2701-2707

Dietz R, Born EW, Stewart REA, Heide-Jørgensen MP, Stern H, Riget F, Toudal L, Lanthier C, Villum-Jensen M, Teilmann J (2010). Movements of walruses (*Odobenus rosmarus*) tracked with satellite transmitters between Central West Greenland and Southeast Baffin Island 2005-2008. In: Stewart REA, Born EW, Kovacs K, Acquarone M (eds): Studies of the Atlantic walrus (*Odobenus rosmarus rosmarus*) in the North Atlantic Arctic NAMMCO Special Publication: submitted.

Dommasnes A (2010). Changing distribution of marine fish. In: CAFF (ed): Arctic Biodiversity Trends 2010. – Selected indicators of change. CAFF International Secretariat, Akureyri, Iceland.

Donovan GP (1991). A review of IWC stock boundaries. Cambridge. Report of the International Whaling Commission Special Issue No. 13, p 39-68.

Drinkwater KF (2006). The regime shift of the 1920s and 1930s in the North Atlantic. Progress in Oceanography 68: 134-151.

Drinkwater KF (2009). Comparison of the response of Atlantic cod (*Gadus morhua*) in the high-latitude regions of the North Atlantic during the warm periods of the 1920s–1960s and the 1990s–2000s. Deep Sea Research II 56: 2087–2096.

Driskell WB, Ruesink JL, Lees DC, Houghton JP, Lindstrom SC (2001). Long-term signal of disturbance: *Fucus gardneri* after the *Exxon Valdez* oil spill. Ecological Applications 11: 815-827.

Dunn RA, Hernandez O (2009). Tracking blue whales in the eastern tropical Pacific with an ocean-bottom seismometer and hydrophone array. Journal of the Acoustical Society of America 126: 1084-1094.

Dunton KH, Schell DM (1987). Dependence of consumers on macroalgal (*Laminaria solidungula*) carbon in an arctic kelp community: $\delta^{13}C$ evidence. Marine Biology 93: 615-625.

Dünweber M, Swalethorp R, Kjellerup S, Nielsen TG, Arendt KE, Hjorth M, Tönnesson K, Møller EF (2010). Succession and fate of the spring diatom bloom in Disko Bay, western Greenland. Marine Ecology Progress Series 419: 11-29.

Düwel D, Wegeberg S (1990) Kalkinkrusterede rødalger på Disko: Artsbestemmelse, systematik og biologi. In: Andersen PF, Düwel L, Hansen OS (eds): Feltkursus i Arktisk Biologi, Godhavn 1990. Copenhagen University, p. 61-94.

D'Vincent CG, Nilson RM, Hanna RE (1985). Vocalization and coordinated feeding behaviour of the humpback whale in South-eastern Alaska. Sci. Rep. Cet. Res. Tokyo 36, 41-47.

Edinger E, Baker K, DeVillers R, Wareham V (2007). Coldwater corals off Newfoundland and Labrador: Distribution and fisheries impacts. World Wildlife Foundation. Toronto, Canada. WWF Report No. 899, 41 pp.

Egevang C, Boertmann D (2001). The Greenland Ramsar sites. A status report. National Environmental Research Institute (NERI). Copenhagen.

Egevang C, Boertmann D (2003). Havternen i Grønland. Danmarks Miljøundersøgelser (DMU). Faglig Rapport nr. 438, 69 pp.

Egevang C, Boertmann D (2008). Ross's gulls (*Rhodostethia rosea*) breeding, in Greenland: A review, with special emphasis on records from 1979 to 2007. Arctic 61: 322-328.

Egevang C, Boertmann D, Kristensen OS (2005). Monitering af havternebestanden på Kitsisunnguit (Grønne Ejland) og den sydlige del af Disko Bugt 2002-2004. Pinngortitaleriffik, Grønlands Naturinstitut (GNIR). Nuuk, Greenland. Teknisk Rapport No. 62.

Engås A, Løkkeborg S, Ona E, Soldal AV (1996). Effects of seismic shooting on local abundance and catch rates of cod (*Gadus morhua*) and haddock (*Melanogramma aeglefinus*). Canadian Journal of Fisheries and Aquatic Sciences 53: 2238-2249.

Erhvervsdirektoratet 2007. National Turismestrategi 2008-2010. – Grønlands Hjemmestyre. http://www.visitgreenland.dk/media(1925,1030)/National_Turismestrategi_2008-2010.pdf

Eskesen IG, Wahlberg M, Simon M, Larsen ON (2011). Comparison of echolocation clicks from geographically sympatric killer whales and long-finned pilot whales. Journal of the Acoustical Society of America 130: 9-12.

Fabry VJ, Seibel BA, Feely RA, Orr JC (2008). Impacts of ocean acidification on marine fauna and ecosystem processes. ICES Journal of Marine Science 65: 414-432.

Faksness L-G, Brandvik PJ (2005). Dissolution of water soluble components from oil spills encapsulated in ice. Proceedings 28th Arctic and Marine Oilspill Program Technical Seminar (AMOP), p. 59-73.

Falk, K, Durinck, J (1993). The winter diet of thick-billed murres, *Uria lomvia*, in western Greenland, 1988-1989. Can. J. Zoology 71: 264-272.

Falk K, Benvenuti S, Dall'antonia L, Kampp K, Ribolini A (2000). Time allocation and foraging behaviour of chick-rearing Brunnich's Guillemots *Uria lomvia* in high-arctic Greenland. Ibis 142: 82-92.

Falk-Petersen S, Pavlov V, Timofeev S, Sargent JR (2007) Climate variability and possible effects on Arctic food chains: The role of *Calanus*. In: Ørbæk JB, Tombre T, Kallenborn R, Hegseth E, Falk-Petersen S, A.H H (eds): Arctic Alpine Ecosystems and People in a Changing Environment. Springer Verlag, Berlin, p. 147-166.

Falk-Petersen S, Mayzaud P, Kattner G, Sargent J (2009). Lipids and life strategy of Arctic *Calanus*. Marine Biology Research 5: 18-39.

Fay FH (1982). Ecology and Biology of the Pacific walrus, *Odobenus rosmarus divergens* Illiger. U.S. Department of the Interior Fish and Wildlife Service. North American Fauna No. 74, 279 pp.

Fay FH (1985). *Odobenus rosmarus*. American Society of Mammalogists. Lawrence, Kansas. Mammalian Species No. 238, p 1-7.

Fay FH, Ray GC, Kibalćhich AA (1984) Time and location of mating and associated behaviour of the Pacific walrus *Odobenus rosmarus divergens* Illiger. In: Fay FH, Fedoseev GA (eds): Soviet-American Cooperative Research on Marine Mammals Vol 1- Pinnipeds NOAA Technical Reports NMFS 12, Washington D.C, p. 89-99.

Foote AD, Osborne RW, Hoelzel AR (2004). Whale-call response to masking boat noise. Nature 428: 910.

Ford JKB (1989). Acoustic behaviour of recident killer whales (*Orcinus orca*) off Vancouver Island, British Columbia. Canadian Journal of Zoology 67: 727-745.

Ford JKB, Ellis GM (2003). Reassessing the social organization of resident killer whales in British Columbia. Fourth international orca symposium and workshops, September 23-28 2002, CEBC-CNRS, France: 72-74.

Ford JKB, Fisher HD (1978). Underwater acoustic signals of the narwhal (*Monodon monoceros*). Canadian Journal of Zoology 56: 552-560.

Foyle T, O'Dor RK, Elner R (1989). Energetically defining the thermal limits of the snow crab. Journal of Experimental Biology 145: 371-393.

Fraser GS, Russell J, Zharen WMV (2006). Produced water from offshore oil and gas installations on the grand banks, Newfoundland and Labrador: are the potential effects to seabirds sufficiently known. Marine Ornithology 34: 147-156.

Fredriksen S (2003). Food web studies in a Norwegian kelp forest based on stable isotope ($\delta^{13}C$ and $\delta^{15}C$) analysis. Marine Ecology Progress Series 260: 71-81.

Frederiksen M, Vorkamp K, Bossi R, Riget FF, Dam M, Svensmark B (2007). Method development for simultaneous analysis of HBCD, TBBPA and dimethyl-TBBPA in marine biota from Greenland and the Faroe Islands. International Journal of Environmental Analytical Chemistry 87: 1095-1109.

Frederiksen M, Boertmann D, Cuykens AB, Hansen J, Jespersen M, Johansen KL, Mosbech A, Nielsen TG, Söderkvist J (2008). Life in the marginal ice zone: oceanographic and biological surveys in Disko Bay and south-eastern Baffin Bay April-May 2006. National Environmental Research Institute (NERI), University of Aarhus. Roskilde, Denmark. NERI Technical Report No. 694, 92 pp.

Freiwald A, Fosså JH, Grehan A, Koslow T, Roberts JM (2004). Cold-water coral reefs. UNEP-WCMC, Cambridge, UK.

Freuchen P (1921). Om Hvalrossens Forekomst og Vandringer ved Grønlands Vestkyst (Distribution and migration of walruses along the western coast of Greenland). Videnskabelige Meddelelser Dansk Naturhistorisk Forening København (In Danish) (Translated: Fisheries Research Board of Canada Translation Series 2383 14 pp) 72: 237-249.

Friis-Rødel E, Kanneworff P (2002). A review of capelin (*Mallotus villosus*) in Greenland waters. ICES Journal of Marine Science 59: 890-896.

Frimer O (1993). Occurrence and distribution of king eiders *Somateria spectabilis* and common eiders S. mollissima at Disko, West Greenland. Polar Research 12: 111-116.

Gaston AJ, Irons D (2010). Seabirds - murres (guillemots). In: CAFF (ed): Arctic Biodiversity Trends 2010 – Selected indicators of change. CAFF International Secretariat, Akureyri, Iceland, p. 35-37.

George JC, Bada J, Zeh J, Scott L, Brown SE, O'Hara T, Suydam R (1999). Age and growth estimates of bowhead whales (*Balaena mysticetus*) via aspartic acid racemization. Canadian Journal of Zoology 77: 571–580.

Geraci JR, St. Aubin DJ (1990). Sea Mammals and Oil. Confronting the risk. Academic Press, San Diego.

GESAMP (1993). Impact of oil and related chemicals on the marine environment. Joint group of experts on the scientific aspects of marine pollution (GESAMP). International Maritime Organization (IMO), London. GESAMP Reports and Studies No. 50, 180 pp.

Gilg O, Boertmann D, Merkel FR, Aebischer A, Sabard B (2009). Status of the endangered ivory gull, *Pagophila eburnea*, in Greenland. Polar Biology 32: 1275-1286.

Gilg O, Strøm H, A. A, Gavrilo MV, Volkov AE, Miljeteig C, Sabard B (2010). Post-breeding movements of northeast Atlantic ivory gull *Pagophila eburnea* populations. Journal of Avian Biology 41: 1-11.

Gjertz I, Kovacs KM, Lydersen C, Wiig O (2000). Movements and diving of bearded seal (*Erignathus barbatus*) mothers and pups during lactation and post-weaning. Polar Biology 23: 559-566.

Goodale DR (1981). The temporal and geographic distribution of Humpback, Finback and Right Whale Calves. University of Rhode Island, Kingson RI. M.S. Thesis.

Gordon J, Gillespie D, Potter J, Frantzis A, Simmonds MP, Swift R, Thompson D (2003). A Review of the Effects of Seismic Surveys on Marine Mammals. Marine Technology Society Journal 37: 16-34.

Gosselin M, Levasseur M, Wheeler PA, Horner RA, Booth BC (1997). New measurements of phytoplankton and ice algal production in the Arctic Ocean. Deep-Sea Research Part I – Oceanographic Research Papers 44: 1623-1644.

Gradinger R, Friedrich C, Spindler M (1999). Abundance, biomass and composition of the sea-ice biota of the Greenland Sea pack ice. Deep-Sea Research Part I-Oceanographic Research Papers 46: 1457-1472.

Graham B, Reilly WK, Beinecke F, Boesch DF, Garcia TD, Murrey CA, Ulmer F (2011). Deep Water. The Gulf oil disaster and the future of offshore drilling. Report to the President. National Commission on the BP Deepwater Horizon Oil Spill and Offshore Drilling.

Gray JS, Clarke KR, Warwick RM, Hobbs G (1990). Detection of initial effects of pollution on marine benthos: an example from the Ekofisk and Eldfisk oilfields. North Sea 66: 285-299.

Grebmeier JM, Overland JE, Moore SE, Farley EV, Carmack EC, Cooper LW, Frey KE, Helle JH, McLaughlin FA, McNutt SL (2006). A Major Ecosystem Shift in the Northern Bering Sea. Science 311: 1461-1464.

Greene CRJ, McLennan MW, Norman RG, McDonald TL, Jakubczak RS, Richardson WJ (2004). Directional frequency and recording (DIFAR) sensors in seafloor recorders to locate calling bowhead whales during their fall migration. Journal of the Acoustical Society of America 1116: 799-813.

Grenvald JC, Hjorth M, Nielsen TG (2012). Effects of pyrene exposure and temperature on early development of two co-existing Arctic copepods. Ecotoxicology, DOI 10.1007/s10646-012-1016-y.

Guinet C, Domenici P, de Stephanis R, Barrett-Lennard L, Ford JKB, Verborgh P (2007). Killer whale predation on bluefin tuna: Exploring the hypothesis of the endurance-exhaustion technique. Marine Ecology Progress Series 347: 111-119.

Gundersen AC, Stenberg C, Fossen I, Lyberth B, Boje J, Jorgensen OA (2010). Sexual maturity cycle and spawning of Greenland halibut *Reinhardtius hippoglossoides* in the Davis Strait. Journal of Fish Biology 77: 211-226.

Gutt J (1995). The occurrence of sub-ice algal aggregations off Northeast Greenland. Polar Biology 15: 247-252.

Hall JD, Gallagher M, Brewer K, Regos P, Isert P (1994). 1993 Kuvlum exploration area site specific monitoring program. Prepared for ARCO Alaska, Inc., Anchorage, AK, by Coastal and Offshore Pacific Corporation, Walnut Creek, CA.

Hammeken NA, Kingsley MCS (2010). The fishery for Northern shrimp (*Pandalus borealis*) off West Greenland, 1970-2010. Northwest Atlantic Fisheries Organization. Dartmouth, Canada. NAFO Scientific Council Research Document No. 10/53, Serial No. N5844.

Hammill MO, Lydersen C, Ryg M, Smith TG (1991). Lactation in the ringed seal (*Phoca hispida*). Canadian Journal of Fisheries and Aquatic Sciences 48: 2471-2476.

Hannam ML, Bamber SD, Moody JA, Galloway TS, Jones MB (2009). Immune function in the Arctic Scallop, *Chlamys islandica*, following dispersed oil exposure. Aquatic Toxicology 92: 187-194.

Hannam ML, Bamber SD, Moody AJ, Galloway TS, Jones MB (2010). Immunotoxicity and oxidative stress in the Arctic scallop *Chlamys islandica*: Effects of acute oil exposure. Ecotoxicology and Environmental Safety 73: 1440-1448.

Hansen BW (1999). Cohort growth of planktotrophic polychaete larvae: are they food limited? Marine Ecology Progress Series 178: 109-119.

Hansen RG (2010). Abundance and distribution of long-finned pilot whales, white-beaked dolphins and harbour porpoise in west Greenland. Master Thesis, Copenhagen University, Denmark and Greenland Institute of Natural Resources.

Hansen PM, Hermann F (1953). Fisken og havet ved Grønland. Skrifter fra Danmarks Fiskeri- og Havundersøgelser 15: 128 pp.

Hansen OS, Schlütter H (1992) Makroalgezonering i tidevandszonen på Disko. In: Andersen PF, Düwel L, OS H (eds): Feltkursus i Arktisk Biologi, Godhavn 1990, p. 95-136.

Hansen BW, Nielsen TG, Levinsen H (1999). Plankton community structure and carbon cycling on the western coast of Greenland during the stratified summer situation III. Mesozooplankton. Aquatic Microbial Ecology 16: 233-249.

Hansen BU, Elberling B, Humlum O, Nielsen N (2006). Metrological trends (1991-2004) at Arctic Station, Central West Greenland (69º15'N) in a 130 years perspective. Danish Journal of Geography 106: 45-55.

Harvey JT, Dalheim ME (1994). Cetaceans in oil. In: Marine Mammals and the *Exxon Valdez*. Academic Press, San Diego, p. 257-264.

Hassel A, Knutsen T, Dalen J, Skaar K, Løkkeborg S, Misund OA, Østensen Ø, Fonn M, Haugland EK (2004). Influence of seismic shooting on the lesser sandeel (*Ammodytes marinus*). ICES Journal of Marine Science 61: 1165-1173.

Hawkins SJ, Gibbs PE, Pope ND, Burt GR, Chesman BS, Bray S, Proud SV, Spence SK, Southward AJ, Langston WJ (2002). Recovery of polluted ecosystems: the case for long-term studies. Marine Environmental Research 54: 215-222.

Hazen TC et al (2010). Deep-sea oil plume enriches indigenous oil-degrading bacteria. Science 330: 204-208.

Heath MF, Evans MI (2000). Important bird areas in Europe. Priority sites for conservation. BirdLife International, Cambridge, UK.

Heath MF, Evans MI (2000). Important Bird Areas in Europe: Priority sites for conservation 1, Northern Europe. Cambridge, UK, Birdlife International (Bird Life International Conservation Series No. 8)

Hedeholm RB (2010). The importance of small pelagic fishes to the energy flow in marine ecosystems: the Greenlandic capelin. Ph.D. Thesis, Aarhus University, Denmark and Greenland Institute of Natural Resources, Greenland.

Hedeholm R, Gronkjaer P, Rosing-Asvid A, Rysgaard S (2010). Variation in size and growth of West Greenland capelin (*Mallotus villosus*) along latitudinal gradients. ICES Journal of Marine Science 67: 1128-1137.

Heide-Jørgensen MP (1988). Occurrence and hunting of killer whales in Greenland. Rit Fiskideildar 11: 115-135.

Heide-Jørgensen MP (2004). Aerial digital photographic surveys of narwhals, *Monodon monoceros*, in Northwest Greenland. Marine Mammal Science 20: 246-261.

Heide-Jørgensen MP (1994). Distribution, exploitation and population status of white whales (*Delphinapterus leucas*) and Narwhals (*Monodon monoceros*) in West Greenland. Meddelelser om Grønland, Bioscience 39: 135-151.

Heide-Jørgensen MP, Acquarone M (2002) Size and trends of the bowhead whale, white whale and narwhal stocks wintering off West Greenland. In: Heide-Jørgensen MPW, Wiig Ø (ed): White whales in the North Atlantic and the Russian Arctic. NAMMCO Scientific Publications 4, p. 191-210.

Heide-Jørgensen MP, Bunch C (1991). Occurrence and hunting of pilot whales in Greenland. Working paper, ICES Study group: 1-14.

Heide-Jørgensen MP, Dietz R (1995). Some characteristics of Narwhal, *Monodon monoceros*, diving behaviour in Baffin Bay. Canadian Journal of Zoology-Revue Canadienne De Zoologie 73: 2120-2132.

Heide-Jørgensen MP, Laidre KL (2007). Autumn space-use patterns of humpback whales (*Megaptera novaeangliae*) in West Greenland. Journal of Cetacean Research and Management 9: 121-126.

Heide-Jørgensen MP, Laidre KL (2008). Fluctuating abundance of minke whales in West Greenland. Cambridge. Report of the International Whaling Commission No. SC/60/AWMP5.

Heide-Jørgensen MP, Laidre KL (2010). Studies of bowhead whales in relation to the Disko West environmental assessment, 2009-2010. Greenland Institute of Natural Resources. Nuuk. GINR report to NERI for the Disko West Environmental Forum.

Heide-Jørgensen MP, Reeves RR (1996). Evidence of a decline in beluga, *Delphinapterus leucas*, abundance off West Greenland. ICES Journal of Marine Science 53: 61-72.

Heide-Jørgensen MP, Rosing-Asvid A (2002). Catch statistics for white whales in West Greenland 1862 to 1999. NAMMCO Scientific Publications 4: 127-142.

Heide-Jørgensen MP, Teilmann J (1994). Growth, reproduction, age structure and feeding habits of white whales (*Delphinapterus leucas*) in West Greenland waters. Meddelelser om Grønland, Bioscience 39: 195-212.

Heide-Jørgensen MP, Lassen H, Teilmann J, A. DR (1993). An index of the relative abundance of wintering belugas, *Delphinapterus leucas*, and narwhals, *Monodon monoceros*, of West Greenland. Canadian Journal of Fisheries and Aquatic Sciences 50: 2323-2335.

Heide-Jørgensen MP, Dietz R, Laidre KL, Richard P (2002). Autumn movements, home ranges, and winter density of narwhals (*Monodon monoceros*) tagged in Tremblay Sound, Baffin Island. Polar Biology 25: 331-341.

Heide-Jørgensen MP, Dietz R, Laidre KL, Richard P, Orr J, Schmidt HC (2003a). The migratory behaviour of narwhals (*Monodon monoceros*). Canadian Journal of Zoology 81: 1298-1305.

Heide-Jørgensen MP, Richard P, Dietz R, Laidre KL, Orr J, Schmidt HC (2003b). An estimate of the fraction of belugas (*Delphinapterus leucas*) in the Canadian high Arctic that winter in West Greenland. Polar Biology 26: 318-326.

Heide-Jørgensen MP, Witting L, Jensen MV (2003c). Inshore-offshore movements of two fin whales (*Balaenoptera physalus*) tracked by satellite off West Greenland. Journal of Cetacean Research and Management 5: 241-245.

Heide-Jørgensen MP, Laidre KL, Jensen MV, Dueck L, Postma LD (2006a). Dissolving stock discreteness with satellite tracking: Bowhead whales in Baffin Bay. Marine Mammal Science 22: 34-45.

Heide-Jørgensen MP, Laidre K, Borchers D, Samarra F, Stern H (2007a). Increasing abundance of bowhead whales in West Greenland. Biology letters 3: 577-580.

Heide-Jørgensen MP, Stern H, Laidre KL (2007b). Dynamics of the sea-ice edge in Davis Strait. Journal of Marine Systems 67: 170-178.

Heide-Jørgensen MP, Laidre KL, Borchers D, Marques TA, Stern H, Simon M (2009). The effect of sea-ice loss on beluga whales (*Delphinapterus leucas*) in West Greenland. Polar Research 29: 198-208.

Heide-Jørgensen MP, Born EW, Laidre KL, Fossette S, Hansen RG, Dietz R, Rasmussen M, Stern H (2010a). Abundance and trends in abundance of the Atlantic walrus (*Odobenus rosmarus rosmarus*) in Central West Greenland. In: Stewart REA, Born EW, Kovacs K, Acquarone M (eds): Studies of the Atlantic walrus (*Odobenus rosmarus rosmarus*) in the North Atlantic Arctic NAMMCO Special Publication: submitted.

Heide-Jørgensen MP, Laidre KL, Wiig Ø, Postma L, Dueck L, Bachmann L (2010b). Large-scale sexual segregation of bowhead whales. Endangered Species Research 13: 73-78.

Heide-Jørgensen MP, Laidre KL, Burt ML, Borchers DL, Marques TA, Hansen RG, Rasmussen M, Fossette S (2010c). Abundance of narwhals (*Monodon monoceros*) on the hunting grounds in Greenland. Journal of Mammalogy 91: 1135-1151.

Heide-Jørgensen MP, Witting L, Laidre KL, Hansen RG (2010d). Fully corrected estimates of minke whale abundance in West Greenland in 2007. Journal of Cetacean Research and Management 11: 75-82.

Heide-Jørgensen MP, Laidre KL, Simon M, Burt ML, Borchers DL, Rasmussen M (2010e). Abundance of fin whales in West Greenland in 2007. Journal of Cetacean Research and Management 11: 83-88.

Heide-Jørgensen MP, Laidre KL, Hansen RG, Simon M, Burt ML, Borchers DL, Hansen J, Harding K, Rasmussen M, Dietz R, Teilmann J (2012a). Rate of increase and current abundance of humpback whales in West Greenland. Journal of Cetacean Research and Management 12: 1-14.

Heide-Jørgensen MP, Garde E, Nielsen HN, Andersen ON (2012b). Biological data from the hunt of bowhead whales in West Greenland 2009-2011. Journal of Cetacean Research and Management 12: 329-333.

Herman DP, Burrows DG, Wade PR, Durban JW, Matkin CO, Leduc RG, Barrett-Lennard LG, Krahn MM (2005). Feeding ecology of eastern North Pacific killer whales *Orcinus orca* from fatty acid, stable isotope, and organochlorine analyses of blubber biopsies. Marine Ecology Progress Series 302: 275-291.

Heugens EHW, Hendriks AJ, Dekker T, Van Straalen NM, Admiraal W (2001). A review of the effects of multiple stressors on aquatic organisms and analysis of uncertainty factors for use in risk assessment. Critical Reviews in Toxicology 31: 247-284.

Hirche HJ, Kosobokova K (2007). Distribution of *Calanus finmarchicus* in the northern North Atlantic and Arctic Ocean - Expatriation and potential colonization Effects of Climate Variability on Sub-Arctic Marine Ecosystems - A GLOBEC Symposium, GLOBEC-ESSAS Symposium on 'Effects of climate variability on sub-arctic marine ecosystems' Victoria, Canada, p 2729-2747.

Hirst AG, Rodhouse PG (2000). Impacts of geophysical seismic surveying on fishing success. Reviews in Fish Biology and Fisheries 10: 113-118.

Hjermann DØ, Melson A, Dingsør GE, Durant JM, Eikeset AM, Røed LP, Ottersein G, Storvil G, Stenseth NC (2007). Fish and oil in the Lofoten-Barents Sea System: synoptic review of the effects of oil spill on fish populations. Marine Ecology Progress Series 339: 283-299.

Hjorth M, Dahllöf I (2008). A harpacticoid copepod *Microsetella* spp. from sub-Arctic coastal waters and its sensitivity towards the polyaromatic hydrocarbon pyrene. Polar Biology 31: 1437-1443.

Hjorth M, Nielsen TG (2011). Oil exposure in a warmer Arctic: potential impacts on key zooplankton species. Marine Biology: 1-9.

Hjorth M, Vester J, Henriksen P, Forbes V, Dahllöf I (2007). Functional and structural responses of marine plankton food web to pyrene contamination. Marine Ecology Progress Series 338: 21-31.

Hjorth M, Forbes VE, Dahllöf I (2008). Plankton stress responses from PAH exposure and nutrient enrichment. Marine Ecology Progress Series 363: 121-130.

Hoekstra PF, O'Hara TM, Pallant SJ, Solomon KR, Muir DCG (2002). Bioaccumulation of organochlorine contaminants in bowhead whales (*Balaena mysticetus*) from Barrow, Alaska. Archives of Environmental Contamination and Toxicology 42: 497-507.

Hoelzel AR, Hey J, Dahlheim ME, Nicholson C, Burkanov V, Black N (2007). Evolution of Population Structure in a Highly Social Top Predator, the Killer Whale. Mol Biol Evol 24: 1407-1415.

Hoffman MD, Garfield N, Bland R (2010). Frequency synchronization of blue whale calls near Pioneer Seamount. J Acoust Soc Am 128: 490-494.

Holland DM, Thomas RH, De Young B, Ribergaard MH, Lyberth B (2008). Acceleration of Jakobshavn Isbræ triggered by warm subsurface ocean waters. Nature Geoscience 1: 659-664.

Holth TF, Beylich BRA, Skarpheðinsdottir HÜ, Liewenborg B, Grung M, Hylland K (2009). Genotoxicity of environmentally relevant concentrations of water-soluble oil components in cod (*Gadus morhua*). Environmental Science and Technology 43: 3329-3334.

Hooker SK, Baird RW (1999). Deep-diving behaviour of the northern bottlenose whale, *Hyperoodon ampullatus* (Cetacea : Ziphiidae). Proceedings of the Royal Society of London Series B - Biological Sciences 266: 671-676.

Hooker SK, Whitehead H (2002). Click characteristics of northern bottlenose whales (*Hyperoodon ampullatus*). Marine Mammal Science 18: 69-80.

Hooker SK, Whitehead H, Gowans S, Baird RW (2002). Fluctuations in distribution and patterns of individual range use of northern bottlenose whales. Marine Ecology Progress Series 225: 287-297.

Hop H, Poltermann M, Lønne OJ, Falk-Petersen S, Korsnes R, Budgell WP (2000). Ice amphipod distribution relative to ice density and under-ice topography in the northern Barents Sea. Polar Biology 23: 357-367.

Hopcroft RR, Clarke C, Nelson RJ, Raskoff KA (2005). Zooplankton communities of the Arctic's Canada Basin: the contribution by smaller taxa. Polar Biology 28: 198-206.

Horner R, Schrader GC (1982). Relative contributions of ice algae, phytoplankton, and benthic microalgae to primary production in nearshore regions of the Beaufort Sea. Arctic 4: 485-503.

Horsted SA (1978). The life cycle of shrimp, *Pandalus borealis Krøjer*, in Greenland waters in relation to potential yield. ICNAF Selected Papers 4: 51-60.

Horsted SA (2000). A review of the cod fisheries at Greenland, 1910-1995. Journal of North-water Atlantic Fish Science 28: 1-112.

Horsted SA, Smidth E (1956). The deep sea prawn (*Pandalus borealis*) in Greenland waters. Meddelelser fra Danmarks Fiskeri- og Havundersøgelser 1: 1-118.

Hovgaard H, Christensen S (1990). Population Structure and Migration Patterns of Atlantic Cod *Gadus morhua* in West Greenland Waters Based on Tagging Experiments from 1946 to 1964. Northwest Atlantic Fisheries Organization Scientific Council Studies: 45-50.

Hovgaard H, Wieland K (2008) Fishery and Environmental Aspects Relevant for the Emergence and Decline of Atlantic Cod (*Gadus morhua*) in West Greenland Waters. In: Resiliency of Gadid Stocks to Fishing and Climate Change, Vol 24, p. 89-110.

Huse G (1998). Sex-specifik life history strategies in capelin (*Mallotus villosus*)? Canadian Journal of Fisheries and Aquatic Sciences 55: 631-638.

Hvidegaard SM, Forsberg R, Hanson S, Skourup H, Pedersen LT (2008). Sea Ice Conditions off NW and NE Greenland from Satellite Measurements, Airborne and In-situ data – Version 2. National Space Institute (DTU Space), Denmark and Danish Meteorological Institute (DMI), Denmark Unpublished report 61 pp.

Hylland K, Lang T, Vethaak AD (2006). Biological effects of contaminants in marine pelagic ecosystems. Society of Environmental Toxicology and Chemistry (SETAC), Pensacola, FL (USA).

Hylland K, Tollefsen KE, Ruus A, Jonsson G, Sundt RC, Sanni S, Røe Utvik TI, Johnsen S, Nilssen I, Pinturier L, Balk L, Barsiene J, Marigòmez I, Feist SW, Børseth JF (2008). Water column monitoring near oil installations in the North Sea 2001-2004. Marine Pollution Bulletin 56: 414-429.

ICES (2006). Report of the Working Group on ICES/NAFO Working Group on Harp and Hooded Seals (WGHARP), 12-16 June 2006. ICES Headquarters. Copenhagen. ICES Working Group Report CM 2006/ACFM:32, 28 pp.

ICES (2010). Report of the ICES/NAFO Joint Working Group on Deep-water Ecology (WGDEC), 22–26 March 2010, Copenhagen, Denmark. ICES CM 2010/ACOM: 26. 160 pp.

ICES (2011). Report of the Working Group on Harp and Hooded Seals (WGHARP), 15-19 August 2011. ICES. St. Andrews, Scotland, UK. CM 2011/ACOM, 68 pp.

IMO 2009. BMW Convention & Guidelines, 2009 Ed. – International Maritime Organization.

Irwin BD (1990). Primary Production of Ice Algae on a Seasonally-Ice-Covered, Continental Shelf. Polar Biology: 247-254.

IUCN 2012. IUCN Red List of Threatened Species. Version 2012.2. <www.iucnredlist.org>. Downloaded on 29 November 2012.

IWC (1991). Chairman's report of the forty-second annual meeting. Rep IWC 41: 31-32.

IWC (2008). The 2008 Scientific Committee report Cetacean Res. Manage. Online report, Vol 10. Homepage visited 2008.09.02. http://www.iwcoffice.org/_documents/sci_com/SCRepfiles2008/SCReportFINAL.pdf

Jacobsen JA, Asmund G (2000). TBT in marine sediments and blue mussels (*Mytilus edulis*) from central-west Greenland. Science of the Total Environment 245: 131-136.

Jefferson TA, Webber MA, Pitman RL (2008). Marine mammals of the world, a comprehensive guide to their identification. Academic Press, London.

Jensen AS (1926). Investigations of the 'Dana' in West Greenland waters, 1925. 39, 85-102.

Jensen AS (1935). The Greenland halibut, *Reinhardtius hippoglossoides* (Walbaum): its development and migrations. Det Kgl Danske Videnskabernes Selskab, Skr, Naturv Math Afd, Copenhagen 6: 1-31.

Jensen ADS (1939). Concerning a change of climate during recent decades in the Arctic and subarctic regions, from Greenland in the west to Eurasia in the east, and contemporary biological and geophysical changes. Det Kgl Danske Videnskabernes Selskab, Biologiske Meddelelser 14: 75 pp.

Jensen AS, Fristrup B (1950). Den arktiske klimaforandring og dens betydning, særlig for Grønland. Geografisk Tidsskrift 50: 20-44.

Jensen T, Palerud R, Olsgard F, Bakke SM (1999). Spredning og effekter av syntetiske borevæsker i miljøet. Norwegian Ministry of Petroleum and Industry. Rapport 99-3507, 49 pp.

Jensen LK, Carroll J, Pedersen G, Hylland K, Dahle S, Bakke T (2006). A multi-generation *Calanus finmarchicus* culturing system for use in long-term oil exposure experiments. Journal of Experimental Marine Biology and Ecology 333: 71-78.

Jensen AM, Sheehan GW, MacLean SA (2008a). Inuit and Marine Mammals. In: Perrin WF, Wursig B, Thewissen JGM (eds): Encyclopedia of Marine Mammals. Academic Press, p. 628-637.

Jensen MH, Nielsen TG, Dahllöf I (2008b). Effects of pyrene on grazing and reproduction of *Calanus finmarchicus* and *Calanus glacialis* from Disko Bay, West Greenland. Aquatic Toxicology 87: 99-107.

Jenssen BM (2006). Endocrine-discrupting chemicals and climate change: a worst-case combination for Arctic marine mammals and seabirds? Environmental Health Perspectives 114: 76-80.

Jernelöv A (2010). The threats from oil spills: now, then, and in the future. Ambio 39: 353-366.

JNCC 2010 JNCC guidelines for minimising the risk of injury and disturbance to marine mammals from seismic surveys. – Joint Nature Conservation Council, Aberdeen. http://jncc.defra.gov.uk/pdf/JNCC_Guidelines_Seismic%20Guidelines_Aug%202010.pdf

Jochens A, Biggs D, Benoit-Bird K, Engelhaupt D, Gordon J, Hu C, Jaquet N, Johnson M, Leben R, Mate B, Miller P, Ortega-Ortiz J, Thode A, Tyack P, Würsig B (2008). Sperm whale seismic study in the Gulf of Mexico. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA. OCS Study MMS 2008-006. Synthesis report 341 pp.

Johansen Ø (1999). Exploratory drillings at the Fylla Field south west of Greenland: Near Field spreading of oil and gas from potential deep water blowouts. SINTEF, Trondheim.

Johansen Ø, Rye H, Melbye AG, Jensen HV, Serigstad B, Knutsen T (2001). Deep Spill JIP – Experimental discharges of gas and oil at Helland Hansen, June 2000. SINTIF Technical Report.

Johansen Ø, Skognes K, Aspholm OØ, Østby C, Moe KA, Fossum P (2003). Utredning af helårs oljevirksomhet i området Lofoten-Barentshavet, Uhellsutslipp av olje – konsekvenser i vannsøylen (ULB 7-c). SINTEF rapport, Trondheim.

Johansen KL, Boertmann D, Mosbech A, Hansen TB. 2012. Manual for seabird and marine mammal survey on seismic vessels in Greenland. 3rd revised edition, May 2012. Scientific Report from DCE – Danish Centre for Environment and Energy No. 38. http://www.dmu.dk/Pub/SR38.pdf

Jones PH (1980). The effect on birds of a North Sea gas flare. British Birds 73: 547-555.

Jonsson H, Sundt RC, Aas E, Sanni S (2010). The Arctic is no longer put on ice: Evaluation of Polar cod (*Boreogadus saida*) as a monitoring species of oil pollution in cold waters. Marine Pollution Bulletin 60: 390-395.

Joye S, MacDonald (2010). Offshore oceanic impacts from the BP oil spill. Nature Geoscience 3: 446.

Juul-Pedersen T, Gissel Nielsen T, Michel C, Friis Møller E, Tiselius P, Thor P, Olesen M, Selander E, Gooding S (2006). Sedimentation following the spring bloom in Disko Bay, West Greenland, with special emphasis on the role of copepods. Marine Ecology-Progress Series 314: 239-255.

Jørgensen OA (1997a). Movement patterns of Greenland halibut, *Reinhardtius hippoglossoides*, at West Greenland, as inferred from trawl survey distribution and size data. Journal of Northwest Atlantic Fishery Science 21: 23-37.

Jørgensen OA (1997b). Pelagic occurence of greenland halibut, *Reinhardtius hippoglosoides*, at West Greenland waters. Journal of Northwater Atlantic Fishery Science 21: 39-50.

Jørgensen OA (2012). Assessment of the Greenland Halibut Stock Component in NAFO Subarea 0 + Division 1A Offshore + Divisions 1B-1F. NAFO SCR Doc.12/031, Serial No. N6057.

Jørgensen OA, Hammeken-Arboe N (2013). Distribution of the commercial fishery for Greenland halibut and Northern shrimp in Baffin Bay. Technical Report no. 91. Greenland Institute of Natural Resources.

Jørgensen OA, Hvingel C, Møller PR, Treble M (2005). Identification and mapping of bottom fish assemblages in Davis Strait and Southern Baffin Bay. Can J FishAquat Sci 62: 1833-1852.

Kahru M, Brotas AS, Manzano-Sarabiaz M, Mitchell BG (2011). Are phytoplankton blooms occurring earlier in the Arctic? Global Change Biology 17: 1733-1739.

Kaiser MJ, Pulsipher AG (2005). Rigs-to-Reef programs in the Gulf of Mexico. Ocean Development & International Law 36: 119-134.

Kapel FO (1979). Exploitation of large whales in West Greenland in the twentieth century. International Whaling Commision. Unpublished Report No. 29.

Kapel FO (1985). On the occurrence of sei whales (*Balaenoptera borealis*) in West Greenland Waters. Cambridge. Report of the International Whaling Commission No. 35, p. 349-352.

Kapel FO (1991). Grønlandssælernes fødevalg ved Vestgrønland. Grønlands Fiskeriundersøgelser. Copenhagen, Denmark. Unpublished Report, 63 pp.

Kapel FO, Petersen R (1982). Subsistence hunting - the Greenland case. Report of the International Whaling Commission, special issue 4: 51-74.

Karlsen HG, Bille-Hansen J, Hansen KQ, Andersen HS, Skourup H (2001). Distribution and variability of icebergs in the eastern Davis Strait 63° N to 68° N. Bureau of Minerals and Petroleum (BMP) and Danish Meterological Institute (DMI). Greenland Survey Report (ASIAQ) No. 2001-1, 36 pp.

Karnovsky NJ, Hunt GL (2002). Estimation of carbon flux to dovekies (Alle alle) in the North Water. Deep-Sea Research Part II-Topical Studies in Oceanography 49: 5117-5130.

Karnovsky NJ, Kwasniewski S, Weslawski JM, Walkusz W, Beszczynska-Möller A (2003). Foraging behavior of little auks in a heterogeneous environment. Marine Ecology Progress Series 253: 289-303.

Karnovsky NJ, Hobson KA, Iverson S, Hunt GL (2008). Seasonal changes in diets of seabirds in the North Water Polynya: a multiple-indicator approach. Marine Ecology Progress Series 357: 291-299.

Karpouzli E, Leaper R (2003). Opportunistic observations of interactions between sperm whales and deep-water trawlers based on sightings from fisheries observers in the northwest Atlantic. Aquatic Conservation: Marine and Freshwater Ecosystem 14: 95-103.

Karsten U (2007). Salinity tolerance of Arctic kelps from Spitsbergen. Phycological Research 55: 257-262.

Kattner G, Hagen W, Lee RF, Campbell R, Deibel D, Falk-Petersen S, Graeve M, Hansen BW, Hirche HJ, Jonasdottir SH, Madsen ML, Mayzaud P, Müller-Navarra D, Nichols PD, Paffenhofer GA, Pond D, Saito H, Stubing D, Virtue P (2007). Perspectives on marine zooplankton lipids. Canadian Journal of Fisheries and Aquatic Sciences 64: 1628-1639.

Kenchington E, Link H, Roy V, Archambault P, Siferd T, Treble M, Wareham V (2011). Identification of Mega- and Macrobenthic Ecologically and Biologically Significant Areas (EBSAs) in the Hudson Bay Complex, the Western and Eastern Canadian Arctic. Research Document 2011/071, ISSN 1919-5044 (Online).

Kerr RA (2010). A lot of oil on the loose. Not so much to be found. Science 329: 734-735.

Ketten DR (1995). Estimates of blast injury and acoustic trauma zones for marine mammals from underwater explosions. In: Kastelein RA, Thomas JA, Nachtigall PE (eds): Sensory systems of aquatic mammals. De Spil Publishers, Woerden, p. 391-407.

Ketten DR, Lien J, Todd S (1993). Blast injury in humpback whale ears: evidence and implications. Journal of the Acoustical Society of America 94: 1849-1850.

Kideys AE (2002). Fall and rise of the Black Sea ecosystem. Science 297: 1482-1483.

Kingsley MCS (1998) The Number of ringed seals (*Phoca hispida*) in Baffin Bay and associated waters. In: Heide-Jørgensen MP, Lydersen C (eds): Ringed Seals in the North Atlantic, Vol 1. NAMMCO Scientific Publications, p. 181-196.

Kingsley MC, Siegstad H, Wieland K 2012. The West Greenland trawl survey for *Pandalus borealis*, 2012, with reference to earlier results. NAFO SCR Doc 12/044.

Kinze CC (2002) White-beaked dolphin. In: Perrin WF, Würsig B, Thewissen JGM (eds): Encyclopaedia of marine mammals. Academic Press, San Diego, p. 1255-1258.

Kjellerup S, Dünweber M, Swalethorp R, Hansen BW, Nielsen TG, Møller EF (2011). Importance of timing vertical migration and reproduction to the Arctic spring bloom in a future warmer climate, with emphasis on the potential competition between co-existing *Calanus finmarchicus* and *C. glacialis*. Submitted to Marine Ecology-Progress Series.

Koeller P, Fuentes-Yaco C, Platt T, Sathyendranath S, Richards A, Ouellet P, Orr D, Skuladottir U, Wieland K, Savard L, Aschan M (2009). Basin-Scale Coherence in Phenology of Shrimps and Phytoplankton in the North Atlantic Ocean. Science 324: 791-793.

Koski WR, Davis RA (1994). Distribution and numbers of narwhals (*Monodon monoceros*) in Baffin Bay and Davis Strait. Meddelelser om Grønland, Bioscience 39: 15-40.

Krause-Jensen D, Kühl M, Christensen PB, Borum J (2007). Benthic primary production in Young Sound, Northeast Greenland. Meddelelser om Grønland, Bioscience 58: 160-173.

Krause-Jensen D, Marbà N, Olesen B, Christensen PB, Sejr MK, Rodrigues J, Rysgaard S (2011). Benthic marine vegetation in Greenland - response to climate forcing. Arctic Frontiers. The Arctic in the earth System perspective: the role of tipping points, Tromsø.

Kroeker KJ, Kordas RL, Crim RN, Singh GG (2010). Meta-analysis reveals negative yet variable effects of ocean acidification on marine organisms. Ecology Letters 13: 1419-1434.

Kvenvolden KA, Cooper CK (2003). Natural seepage of crude oil into the marine environment. Geographical Marine Letters 23: 140-146.

Kyhn LA, Tougaard J, Sveegaard S (2011). Underwater noise from the drillship Stena Forth in Disko West, Baffin Bay, Greenland. National Environmental Research Institute, Aarhus University, Denmark. 30 pp. NERI Technical Report No. 838

Kyhn, LA, Boertmann, D, Tougaard J, Johansen K, Mosbech A (2012). Guidelines to environmental impacts assessment of seismic activities in Greenland waters. 3rd revised edition, Dec. 2011. DCE - Danish Centre for Environment and Energy.

La Bella G, Cannata S, Froglia C, Ratti S, Rivas G (1996). First assessment of effects of air-gun seismic shooting on marine resources in the central Adriatic Sea. International conference on health, safety and environment in oil & gas exploration & production, New Orleans LA, 9-12 June 1996: 227-238.

Labansen A, Merkel FR, Boertmann D, Nyeland J (2010). Status of the black-legged kittiwake (*Rissa tridactyla*) breeding population in Greenland, 2008. Polar Research 29: 391-403.

Laidre KL, Heide-Jørgensen MP (2005). Winter feeding intensity of narwhals (*Monodon monoceros*). Marine Mammal Science 21: 45-57.

Laidre KL, Heide-Jorgensen MP, Jorgensen OA, Treble MA (2004). Deep-ocean predation by a high Arctic cetacean. ICES Journal of Marine Science 61: 430-440.

Laidre KL, Heide-Jørgensen MP (2011). Life in the lead: extreme densities of narwhals *Monodon monoceros* in the offshore pack ice. Marine Ecology Progress Series 423: 269-278.

Laidre KL, Heide-Jørgensen MP, Dietz R, Hobbs RC, Jørgensen OA (2003). Deep-diving by narwhals *Monodon monoceros*: differences in foraging behavior between wintering areas? Marine Ecology Progress Series 261: 269-281.

Laidre KL, Heide-Jorgensen MP, Nielsen TG (2007). Role of the bowhead whale as a predator in West Greenland. Marine Ecology Progress Series 346: 285-297.

Laidre KL, Stirling I, Lowry LF, Wiig O, Heide-Jorgensen MP, Ferguson SH (2008). Quantifying the sensitivity of arctic marine mammals to climate-induced habitat change. Ecological Applications 18: S97-S125.

Laidre KL, Heagerty PJ, Heide-Jorgensen MP, Witting L, Simon M (2009). Sexual segregation of common minke whales (*Balaenoptera acutorostrata*) in Greenland, and the influence of sea temperature on the sex ratio of catches. ICES Journal of Marine Science 66: 2253-2266.

Laidre KL, Heide-Jorgensen MP, Heagerty P, Cossio A, Bergstrom B, Simon M (2010). Spatial associations between large baleen whales and their prey in West Greenland. Marine Ecology Progress Series 402: 269-284.

Larsen F, Kapel FO (1981). Collection of Biological Material of Minke Whales in West Greenland, 1979. Rep int Whal Commn 31: 279-285.

Larsson AI, Purser A (2011). Sedimentation on the cold-water coral *Lophelia pertusa*: Cleaning efficiency from natural sediments and drill cuttings. Marine Pollution Bulletin 62: 1159-1168.

Lavoie D, Denman KL, MacDonald R (2010). Effects of future climate change on primary productivity and export fluxes in the Beaufort Sea. Journal of Geophysical Research-Oceans 115: C04018:

Law RJ, Moffat CF (2011). The Braer oil spill, 1993. In: Fingas M (ed.): Oil spill science and technology. Elsevier, p. 1119-1126.

Lawson JW (2005). Overviews: Beluga whale and noise. In J JCNB/NAMMCO 2005: Joint Scientific Meeting Nuuk, Greenland, October 13-16, 2005. Final report, 53 pp.

Lee K, Azetsu-Scott K, Cobanli SE, Dalziel J, Niven S, Wohlgeschaffen G, Yeats P (2005). Overview of potential impacts from produced water discharges in Atlantic Canada. In: Armsworthy SL, Cranford PJ, Lee K (eds): Offshore oil and gas environmental effects monitoring Approaches and technologies. Batelle Press, Columbus, Ohio, p. 319-342.

Lee RF, Hagen W, Kattner G (2006). Lipid storage in marine zooplankton. Marine Ecology Progress Series 307: 273-306.

Lefebvre L, Brêthes JC (1991). Orientation of movements of tagged, male, snow crabs (*Chionoecetes opilio*) in the southwestern Gulf of St. Lawrence. Canadian Journal of Fisheries and Aquatic Sciences 48: 1167-1175.

Lehtonen KK, Schiedek D, Koehler A, Lang T, Vuorinen PJ, Förlin L, Barsiene J, Pempkowiak J, Gercken J (2006). BEEP project in the Baltic Sea: overview of results and outlines for a regional biological effects monitoring strategy. Marine Pollution Bulletin 53: 523-537.

Letcher RJ, Bustnes JO, Dietz R, Jenssen BM, Jørgensen EH, Sonne C, Verreault J, Vijayan MM, Gabrielsen GW (2010). Exposure and effects assessment of persistent organohalogen contaminants in arctic wildlife and fish. Science of the Total Environment 408: 2995-3043.

Levinsen H, Nielsen TG, Hansen BW (1999). Plankton community structure and carbon cycling on the western coast of Greenland during the stratified summer situation. II. Heterotrophic dinoflagellates and ciliates. Aquatic Microbial Ecology 16: 217-232.

LGL (2005). Husky delineation/exploration drilling program for Jeanne d'Arc Basin area environmental assessment. LGL Limited, Canning and Pitt Associates, Inc., PAL Environmental Services. St. John's. LGL Report SA845.

Lie KK, Meier S, Olsvik PA (2009). Effects of environmental relevant doses of pollutants from offshore oil production on Atlantic cod (*Gadus morhua*). Comparative Biochemistry and Physiology Part C: Toxicology & Pharmacology 150: 141-149.

Lien J, Todd S, Stevick P, Marques F, Ketten D (1993). The Reaction of humpback whales to explosives: Orientation, movements and behaviour Journal of the Acoustical Society of America 94: 1849.

Lippert H, Iken K, Rachor E, Wiencke C (2001). Macrofauna associated with macroalgae in the Kongsfjord (Spitsbergen). Polar Biology 24: 512-522.

Ljungblad D, Thompson PO, Moore SE (1982). Underwater sounds recorded from migrating bowhead whales, *Balaena mysticetus*, in 1979. Journal of the Acoustical Society of America 71: 477-482.

Ljungblad DK, Wursig B, Swartz SL, Keene JM (1988). Observations on the behavioral responses of bowhead whales (*Balaena mysticetus*) to active geophysical vessels in the Alaskan Beaufort Sea. Arctic 41: 183-194.

Lopez JC, Lopez D (1985). Killer whales (*Orcinus orca*) of Patagonia, and their behavior of intentional stranding while hunting nearshore. Journal of Mammalogy 66: 181-183.

Lorentsen S-H, Sjøtun K, Grémillet D (2010). Multi-trophic consequences of kelp harvest. Biological Conservation 143: 2054-2062.

Lovell JM, Findlay MM, Moate RM, Yan HY (2005). The hearing abilities of the prawn *Palaemon serratus*. Comparative Biochemistry and Physiology B-Biochemistry & Molecular Biology, Part A 140: 89-100.

Lunn N, Vongraven D, Schliebe S, Belikov SE (2010). Polar bears. In: CAFF (ed.) Arctic Biodiversity Trends 2010 – Selected indicators of change. CAFF International Secretariat, Akureyri, Iceland.

Lyngs P (2003). Migration and winter ranges of birds in Greenland - an analysis of ringing recoveries. Dansk Ornitologisk Forenings Tidsskrift 97: 1-167.

Lyrholm T, Gyllensten U (1998). Global matrilineal population structure in sperm whales as indicated by mitochondrial DNA sequences. Proceedings of the Royal Society of London Series B - Biological Sciences 265: 1679-1684.

Løkkeborg S, Ona E, Vold A, Pena H, Salthaug A, Totland B, Øvredal JT, Dalen J, Handegard NO (2010). Effects of seismic surveys on fish fish distribution and catch rates of gillnets and longlines in Vesterålen in summer 2009. Havforskningsinstituttet, Bergen. Fisken og Havet 2/2010 (In Norwegian with summary in English).

Macdonald RW, Mackay D, Li YF, Hickie B (2003). How will global climate change affect risks from long-range transport of persistent organic pollutants? Human and Ecological Risk Assessment 9: 643-660.

Macdonald RW, Harne TJ, Fyfe (2005). Recent climate change in the Arctic and its impact on contaminant pathways and interpretation of temporal trend data. Science of the Total Environment 342: 5–86.

MacNeil MA, Graham NAJ, Cinner JE, Dulvy NK, Loring PA, Jennings S, Polunin NCV, Fisk AT, McClanahan TR (2010). Transitional states in marine fisheries: adapting to predicted global change. Philosophical Transactions of the Royal Society B 365: 3753-3763.

Madsen PT, Wahlberg M, Møhl B (2002). Male sperm whale (*Physeter macrocephalus*) acoustics in a high-latitude habitat: implications for echolocation and communication. Behavioural Ecology and Sociobiology 53: 31-41.

Madsen PT, Johnson M, Miller P, Aguilar de Soto N, P. T (2006). Quantitative measures of airgun pulses impinging on sperm whales using onboard tags and controlled exposures. Journal of the Acoustical Society of America 120: 2366-2379.

Madsen SD, Nielsen TG, Hansen BW (2008). Annual population development and production by small copepods in Disko Bay, western Greenland. Marine Biology 155: 63-77.

Malmquist HJ (2004). Life History Traits of Arctic Charr and Environmental Factors: Local Variability and Latitudinal Gradients. Poster A2: paper 8 presented at ACIA International Symposium on Climate Change in the Arctic. Reykjavik, Iceland. 9-12, November 2004. http://www.natkop.is/photos/ACIA_utdrattur.pdf

Martin AR, Clarke MR (1986). The diet of sperm whales (*Physeter macrocephalus*) captured between Iceland and Greenland. Journal of the Marine Biological Association of the United Kingdom 66: 779-790.

Matkin CO, Saulitis EL, Ellis GM, Olesiuk P, Rice SD (2008). Ongoing population-level impacts on killer whales *Orcinus orca* following the '*Exxon Valdez*' oil spill in Prince William Sound, Alaska. Marine Ecology Progress Series 356: 269-281.

McCauley RD, Fewtrell J, Duncan AJ, Jenner C, Jenner MN, Penrose JD, Prince RIT, Adhitya A, Murdoch J, McCabe K (2000). Marine Seismic Surveys – A Study of Environmental Implications. APPEA Journal 40: 692-708.

McCauley RD, Fewtrell J, Popper AN (2003). High intensity anthropogenic sound damages fish ears. Journal of the Acoustical Society of America 113: 638-642.

McCay DF (2003). Development and application of damage assessment modelling: example assessment for the North Cape oil spill. Marine Pollution Bulletin 47: 341-359.

McCay DPF, Gibson M, Cobb JS (2003a). Scaling restoration of American lobsters: combined demographic and discounting model for an exploited species. Marine Ecology Progress Series 264: 197-212.

McCay DPF, Peterson CH, DeAlteris JT, Catena J (2003b). Restoration that targets function as opposed to structure: replacing lost bivalve production and filtration. Marine Ecology Progress Series 264: 177-196.

McDonald MA, Hildebrand JA, Mesnick S (2009). Worldwide decline in tonal frequencies of blue whale songs. Endang Species Res 9: 13-21.

McKinney MA, Peacock E, Letcher R (2009). Sea ice-associated diet change increases the levels of chlorinated and brominated contaminants in polar bears. Environ. Sci. Technol. 43: 4334-4339.

Meier S, Klungsøyr J, Svardal A (2002). Alkylerte fenolers hormonelle innvirkning på torsk. Havforskningsinstituttet. Bergen. Unpublished Report, 33 pp.

Melle W, Serigstad B, Ellertsen B (2001). Environmental risk of deep water oil drilling – A preliminary analysis. Senter for marint miljø, Havforskningsinstituttet, Bergen. Rapport nr. 1/2001.

Mellinger DK, Carson CD, Clark CW (2000). Characteristics of minke whale (*Balaenoptera acutorostrata*) pulse trains recorded near Puerto Rico. Marine Mammal Science 16: 739-756.

Mellinger DK, Stafford KM, Moore SE, Dziak RP, Matsumoto H (2007). An overview of fixed passive acoustic observation methods for cetaceans. Oceanography 20: 36-45.

Mendes S, Newton J, Reid RJ, Zuur AF, Pierce GJ (2007). Stable carbon and nitrogen isotope ratio profiling of sperm whale teeth reveals ontogenetic movements and trophic ecology. Oecologia 151: 605-615.

Merkel FR (2008). Bestandsstatus for ederfuglen i Ilulissat, Uummannaq og Upernavik kommuner, 2001-2007. Resultater fra overvågning gennemført af lokale optællere i samarbejde med Grønlands Naturinstitut. Greenland Institute of Natural Resources. Nuuk. Technical Report No. 73, 36 pp.

Merkel FR (2010). Evidence of recent population recovery in common eiders breeding in western Greenland. Journal of Wildlife Management 74: 1869-1874.

Merkel FR, Gilchrist G (2010) Indicator 5 – Seabirds – common eiders. In: Kurvits Tea (ed): Arctic Biodiversity Trends 2010 Selected indicators of change. CAFF International Secretariat, Akureyri, Iceland.

Merkel FR, Johansen, KL (2011). Light-induced bird strikes on vessels in Southwest Greenland. Marine Pollution Bulletin 62: 2330-2336.

Merkel FR, Mosbech A, Boertmann D, Grøndahl L (2002). Winter seabird distribution and abundance off south-western Greenland, 1999. Polar Research 21: 17-36.

Merkel FR, Jamieson SE, Falk K, Mosbech A (2007). The diet of Common Eiders wintering in Nuuk, Southwest Greenland. Polar Biology 30: 227-234.

Michel C, Nielsen TG, Nozais C, Gosselin M (2002). Significance of sedimentation and grazing by ice micro- and meiofauna for carbon cycling in annual sea-ice (northern Baffin Bay). Aquatic Microbial Ecology 30: 57-68.

Mikkelsen B, Bloch D, Heide-Jørgensen MP (2007). A note on movements of two fin whales (*Balaenoptera physalus*) tracked by satellite telemetry from the Faroe Islands in 2001. J Cetacean Res Manage 9: 115-120.

Mikkelsen D, Rysgaard S, Glud R (2008). Microalgal composition and primary production in Arctic sea-ice: a seasonal study from Kobbefjord (Kangerluarsunnguaq), West Greenland. Marine Ecology Progress Series: 65-74.

Miller LA, Pristed J, Møhl B, Surlykke A (1995). The click-sounds of narwhals (*Monodon monoceros*) in Inglefield Bay, Northwest Greenland. Marine Mammal Science 11: 491-502.

Miller GW, Moulton VD, Davis RA, Holst M, Millman P, MacGillivray A, Hannay D (2005). Monitoring seismic effects on marine mammals – Southeastern Beaufort Sea 2001-2002. In: Armsworthy SL, Cranford PJ, Lee K (eds): Offshore oil and gas environmental effects monitoring Approaches and technologies. Batelle Press, Columbus, Ohio, p. 511-542.

Miller PJO, Johnson MP, Madsen PT, Biassoni, N, Quero M, Tyack PL (2009). Using at-sea experiments to study the effects of airguns on the foraging behavior of sperm whales in the Gulf of Mexico. Deep-Sea Res. I 56: 1168-1181.

Molnar J, Gamboa R, Revenga C, Spalding M (2008). Assessing the global threat of invasive species to marine biodiversity. Frontiers in Ecology and the Environment 6: 485–492.

Moore SE, Huntington HP (2008). Arctic marine mammals and climate change: impacts and resilience. Applications 18: Supplement, 2008: S157-S165.

Mortensen P, Buhl-Mortensen L (2004). Distribution of deep-water gorgonian corals in relation to benthic habitat features in the Northeast Channel (Atlantic Canada). Marine Biology 144: 1223-1238.

Mosbech A (ed.) (2002). Potential environmental impacts of oil spills in Greenland. An assessment of information status and research needs. National Environmental Research Institute (NERI), Roskilde, Denmark. NERI Technical report No.415. 106 pp.

Mosbech A, Boertmann D (1999). Distribution, abundance and reaction to aerial surveys of post-breeding king eiders (*Somateria spectabilis*) in western Greenland. Arctic 52: 188-203.

Mosbech A, Johnson SR (1999). Late winter distribution and abundance of sea-associated birds in south-western Greenland, the Davis Strait and southern Baffin Bay. Polar Research 18: 1-17.

Mosbech A, Dietz R, Boertmann D, Johansen P (1996). Oil exploration in the Fylla area. An initial assessment of the potential environmental impacts. NERI Technical Report No. 156, 92 pp.

Mosbech A, Boertmann D, Nymand J, Riget F, Acquarone M (1998). The Marine Environment in Southwest Greenland. Biological resources, resource use and sensitivity to oil spill. National Environmental Research Institute (NERI). Roskilde, Denmark. NERI Technical Report No. 236, 205 pp.

Mosbech A, Boertmann D, Olsen BØ, Olsvig S, Platen FV, Buch E, Hansen KQ, Rasch M, Nielsen N, Møller HS, Potter S, Andreasen C, Berglund J, Myrup M (2004a). Environmental oil spill sensitivity atlas for the South Greenland coastal zone. National Environmental Research Institute (NERI). Roskilde, Denmark. NERI Technical Report No. 493, 341 pp.

Mosbech A, Boertmann D, Olsen BØ, Olsvig S, Platen FV, Buch E, Hansen KQ, Rasch M, Nielsen N, Møller HS, Potter S, Andreasen C, Berglund J, Myrup M (2004b). Environmental oil spill sensitivity atlas for the West Greenland (68°-72° N) coastal zone. National Environmental Research Institute (NERI). Roskilde, Denmark. NERI Technical Report No. 494, 442 pp.

Mosbech A, Hansen CS, Flagstad A, Nyegaard H, Danø R (2004c). Satellite tracking of eiders (*Somateria* spp.). Pp 39-47 in Boertmann D (ed.) Background studies in Nuussuaq and Disko, West Greenland. NERI Technical Report No. 482. http://www2.dmu.dk/1_viden/2_Publikationer/3_fagrapporter/rapporter/FR482.PDF

Mosbech A, Danø R, Merkel FR, Sonne C, Gilchrist HG, Flagstad A (2006a). Use of satellite telemetry to locate key habitats for King Eiders *Somateria spectabilis* in West Greenland. In: Boere CG, Galbraith C, Stroud DA (eds): Waterbirds around the world. The Stationery Office, Edinburgh, p 769-776.

Mosbech A, Gilchrist HG, Merkel FR, Sonne C, Flagstad A, Nyegaard H (2006b). Year-round movements of Northerns Common Eiders *Somateria mollissima borealis* breeding in Arctic Canada and West Greenland followed by satellite telemetry. Ardea 94: 651-665.

Mosbech A, Boertmann D, Jespersen M (2007a). Strategic environmental impact assessment of hydrocarbon activities in the Disko West area. National Environmental Research Institute. Roskilde. NERI Technical Report No. 618, 187 pp.

Mosbech A, Hansen AB, Asmund G, Dahllöf I, Petersen DG, Strand J (2007b). A chemical and biological study of the impact of a suspected oil seep at the coast of Marraat, Nuussuaq, Greenland. With a summary of other environmental studies of hydrocarbons in Greenland. National Environmental Research Institute, University of Aarhus. NERI Technical Report 629: 56 pp. http://www2.dmu.dk/Pub/FR629.pdf

Mosbech A, Merkel F, Boertmann D, Falk K, Frederiksen M, Johansen K, Sonne C (2009). Thick-billed Murre studies in Disko Bay (Ritenbenk), West Greenland. NERI Technical Report No. 749. http://www.dmu.dk/udgivelser/faglige-rapporter/700-749/abstracts/fr749-dk/

Muir DCG, de Wit CA (2010). Trends of legacy and new persistent organic pollutants in the circumpolar arctic: Overview, conclusions, and recommendations. Science of the Total Environment 408: 2851-3051.

Munk P (2002). Larval sand lance (*Ammodytes* sp.) in the diet of small juvenile wolffish (*Anarhichas* spp.): predatory interactions in frontal water masses off western Greenland. Canadian Journal of Fisheries and Aquatic Sciences 59: 1759-1767.

Munk P, Nielsen TG, Hansen BW (2000). Spatial patterns in growth rate variability of Arctic cod in Disko Bay, West Greenland. ICES annual meeting 2000. ICES Report CM2000/N:22.

Munk P, Hansen BW, Nielsen TG, Thomsen HA (2003). Changes in plankton and fish larvae communities across hydrographic fronts off West Greenland. Journal of Plankton Research 25: 815-830.

Muus B (1990). Fisk In: Muus B, Salomonsen F, Vibe C (eds): Grønlands Fauna. Gyldendal, Copenhagen, p. 23-153.

Muus B, Nielsen JG (1998). Havfisk og fiskeri i Nordvesteuropa. Gads forlag, Copenhagen.

Müller R, Laepple T, Barsch I, Wiencke C (2009). Impact of oceanic warming on the distribution of seaweeds in polar and cold-temperate waters. Botanica Marina 52: 617-638.

Møhl B, Wahlberg M, Madsen PT, Heerfordt A, Lund A (2003). The monopulsed nature of sperm whale clicks. J Acoust Soc Am 114: 1143-1154.

Møller PR, Jørgensen OA (2000). Distribution and abundance of eelpouts (pisces, Zoarcidae) off West Greenland. Sarsia 85: 23-48.

Møller EF, Nielsen TG (2000). Plankton community structure and carbon cycling off the western coast of Greenland, with emphasis on sources of DOM for the bacterial community. Aquatic Microbial Ecology 22: 13-25.

Møller EF, Thor P, Nielsen TG (2003). Production of DOC by *Calanus finmarchicus*, *C. glacialis* and *C. hyperboreus* through sloppy feeding and leakage from fecal pellets. Marine Ecology Progress Series 262: 185-191.

Møller PR, Nielsen JG, Knudsen SW, Poulsen JY, Sunksen K, Jorgensen OA (2010). A checklist of the fish fauna of Greenland waters. Zootaxa: 1-84.

NAFO 2011. Scientific Council Reports 2010. Northwest Atlantic Fisheries Organazation. Dartymouth, Canada.

Nahrgang J, Camus L, Gonzalez P, Goksoyr A, Christiansen JS, Hop H (2009). PAH biomarker responses in polar cod (*Boreogadus saida*) exposed to benzo(a)pyrene. Aquatic Toxicology 94: 309-319.

Nahrgang J, Camus L, Broms F, Christiansen JS, Hop H (2010a). Seasonal baseline levels of physiological and biochemical parameters in polar cod (*Boreogadus saida*): Implications for environmental monitoring. Marine Pollution Bulletin 60: 1336-1345.

Nahrgang J, Camus L, Carls MG, Gonzalez P, Jonsson M, Taban IC, Bechmann RK, Christiansen JS, Hop H (2010b). Biomarker responses in polar cod (*Boreogadus saida*) exposed to the water soluble fraction of crude oil. Aquatic Toxicology 97: 234-242.

Nahrgang J, Camus L, Gonzalez P, Jonsson M, Christiansen JS, Hop H (2010c). Biomarker responses in polar cod (*Boreogadus saida*) exposed to dietary crude oil. Aquatic Toxicology 96: 77-83.

Nahrgang J, Jonsson M, Camus L (2010d). EROD activity in liver and gills of polar cod (*Boreogadus saida*) exposed to waterborne and dietary crude oil. Marine Environmental Research 70: 120-123.

Nakken O (1922). Scientific Basis for Management of Fish Resources with Regard to Seismic Exploration. Fisheries and Offshore Petroleum Exploitation, Proceedings of Petropiscis, Second International Conference, Bergen, Norway.

NAMMCO-IWC 2006. Report of the Joint NAMMCO/IWC Scientifi c Workshop on the Catch History, Stock Structure and Abundance of North Atlantic Fin Whales. Reykjavík, Iceland, 23-26 March 2006. http://www.iwcoffi ce.org/conservation/estimate.html. Web site visited 20080918.

NAMMCO (2008). Status of marine mammals in the North Atlantic. The beluga whale. http://www.nammco.no/webcronize/images/Nammco/667.pdf.

NAMMCO (2009). Meeting Report of the NAMMCO Scientific Committee on Atlantic Walrus, 23-26 November 2009, Copenhagen. 23 pp.

NAMMCO (2010). NAMMCO Annual Report 2009. North Atlantic Marine Mammal Commission. Tromsø, Norway. 529 pp.

National-Research-Council (2003). Cumulative Environmental Effects of Oil and Gas Activities on Alaska's North Slope. The National Academy Press Washington DC. Web page visited 09042008: http://books.nap.edu/openbook.php?record_id=10639&page=R1

Nazareth J, Steensboe J (1998). Physical environment of eastern Davis Strait and northeastern Labrador Sea. An overview. Mineral Resources Administration for Greenland (MRA) and Danish Meteorological Institute (DMI). Technical Report No. 97-9, 35 pp.

Neff JM (1987. Biological effects of drilling fluids, drill cuttings and produced water. In: Boesch DF, Rabalais NN (eds): Long-term Environmental Effects of Offshore Oil and Gas Development. Elsevier Applied Science, London and New York, p. 469-538.

Nelson GA, Ross MR (1991). Biology and Population Changes of Northern Sand Lance (*Ammodytes dubius*) from the Gulf of Maine to the Middle Atlantic Bright. Journal of Northwest Atlantic Fishery Science 11: 11-28.

Nielsen JG, Bertelsen E (1992). Fisk i grønlandske farvande. Atuakkiorfik, Nuuk

Nielsen JG, Fosså S (1993). Lycodes adolfi, a new species of eelpout (Zoarcidae) from Greenland. Cybium 17: 39-44.

Nielsen TG, Hansen B (1995). Plankton community structure and carbon cycling on the western coast of Greenland during and after the sedimentation of a diatom bloom. Marine Ecology Progress Series 125: 239-257.

Nielsen JW, Kliem N, Jespersen M, Christiansen BM (2006). Oil drift and fate modelling at Disko Bay. Danish Meteorological Institute, Denmark. Technical Report No. 06-06.

Nielsen JW, Murawski J, Kliem N (2008). Oil drift and fate modelling off NE and NW Greenland. Danish Meteorological Institute, Denmark. Technical Report No. 08-12.

Nielsen OK, Lyck E, Mikkelsen MH, Hoffmann L, Gyldenkærne S, Winther M, Nielsen M, Fauser P, Thomsen M, Plejdrup MS, Albrektsen R, Hjelgaard K, Johannsen VK, Vesterdal L, Rasmussen E, Arfaoui K, Baunbæk L (2010). Denmark's National Inventory Report 2010. Emission Inventories 1990-2008 - Submitted under the United Nations Framework Convention on Climate Change and the Kyoto Protocol. National Environmental Research Institute, Aarhus University. NERI Technical Report No 784. http://www.dmu.dk/Pub/FR784.pdf

NMFS (2002). Biological opinion. Endangered Species Act-Section 7. Consultation and Operation of the Liberty Oil Production Island. National Marine Fisheries Service. Anchorage. Consultation No. F/AKR/2001/00889, 51 pp.

NMFS (2003). Taking marine mammals incidental to conducting oil and gas exploration activities in the Gulf of Mexico. National Marine Fisheries Service Federal Register 68: 9991-9996.

NMFS (2005). Small takes of marine mammals incidental to specified activities: Marine seismic survey of the Aleutian Islands in the North Pacific Ocean. Notice of issuance of an incidental take authorization. National Marine Fisheries Service Federal Register 70: 901-913.

NOAA (2010). A draft supplemental environmental impact statement for the *Exxon Valdez* oil spill restoration plan. US National Oceanic and Atmosphaeric Administration. 66 pp.

NOAA (2011). Deepwater Horizon/BP Oil Spill Information. http://sero.nmfs.noaa.gov/deepwater_horizon_oil_spill.htm

Norderhaug KM, Christie H, Fosså JH, Fredriksen S (2005). Fish-macrofauna interactions in a kelp (*Laminaria hyperborea*) forest. Journal of the Marine Biological Association of the United Kingdom 85: 1279-1286.

Nowacek DP, Thorne LH, Johnston DW, Tyack PL (2007). Responses of cetaceans to anthropogenic noise. Mammal Review 37: 81-115.

Noyes PD, McElwee MK, Miller HD, Clark BW, Van Tiem LA, Walcott KC, Erwin KN, Levin ED (2009). The toxicology of climate change: Environmental contaminants in a warming world. Environment International 35: 971-986.

Nyegaard R, Boje J (2012). An Assessment of the Greenland Halibut Stock Component in NAFO Division 1A Inshore. NAFO SCR Doc. 12/036, Serial No. N6063.

Obbard ME, Thiemann GW, E. P, DeBruyn T (2010). Proceedings of 15th Working Meeting of the Polar Bear Specialist Group, Copenhagen, Denmark. IUCN. Gland, Switzerland and Cambridge, UK. IUCN Occassional Papers of the IUCN Species Survival Commission No. 43, 225 pp.

OED (2006). Sameksistens mellom fiskerinæringen og oljevirksomheten i området Lofoten-Barentshavet innenfor rammen af en bærekraftig utvikling. Olje- og enenergidepartementet, Oslo.

OLF (2005). Environmental Report 2004. The Norwegian Oil industry Association. Stavanger. Unpublished Report.

Olsen GH, Sva E, Carroll J, Camus L, De Coen W, Smolders R, Øveraas H, Hylland K (2007). Alterations in the energy budget of Arctic benthic species exposed to oil-related compounds. Aquatic Toxicology 83: 85-92.

Olsen GH, Carroll J, Sva E, Camus L (2008). Cellular energy allocation in the Arctic sea-ice amphipod *Gammarus wilkitzkii* exposed to the water soluble fractions of oil. Marine Environmental Research 66: 213-214.

Olsgaard F, Gray J (1995). A comprehensive analysis of the effects of offshore oil and gas exploration and production on the benthic communities of the Norwegian continental shelf. Marine Ecology Progress Series 122: 277-306.

Olsvig S, Mosbech A (2003). Fiskeriressourcer på det lave vand i det nordlige Vestgrønland. En interviewundersøgelse om forekomsten og udnyttelsen af lodde, stenbidder og ørred. Arbejdsrapport fra DMU 74 pp.

Orr JC, Fabry VJ, Aumont O, Bopp L, Doney SC, Feely RA, Gnanadesikan A, Gruber N, Ishida A, Joos F, Key RM, Lindsay K, Maier-Reimer E, Matear R, Monfray P, Mouchet A, Najjar RG, Plattner GK, Rodgers KB, Sabine CL, Sarmiento JL, Schlitzer R, Slater RD, Totterdell IJ, Weirig MF, Yamanaka Y, Yool A (2005). Anthropogenic ocean acidification over the twenty-first century and its impact on calcifying organisms. Nature 437: 681-686.

Outridge PMRW, Macdonald RW, Wang F, Stern GA, Dastoor AP (2008). A mass balance inventory of mercury in the Arctic Ocean. Environmental Chemistry 5: 89-111.

Overrein Ø (2002). Virkninger av motorferdsel på fauna og vegetasjon. Norsk Polarinstitutt, Tromsø. Rapportserie nr. 119.

Paetkau D, Amstrup SC, Born EW, Calvert W, Derocher AE, Garner GW, Messier F, Stirling I, Taylor MK, Wiig Ø, Strobeck C (1999). Genetic structure of the world's polar bear populations. Molecular Ecology 8: 1571-1584.

PAME (2009). Arctic offshore oil and gas guidelines. Protection of the Arctic Marine Environment (PAME), Arctic Council. Akureyri.

PAME in prep. Identification of Arctic marine areas of heightened ecological and cultural significance – 'AMSA IIc draft repport'.

Palsbøll P, Bérubé M, Larsen AH, Jørgensen H (1997). Primers for the amplification of tri- and tetramer microsatellite loci in baleen whales. Molecular Ecology 6: 893-895.

Pampoulie C, Danielsdóttir AK, Bérubé M, Palsbøll PJ, Árnason A, Gunnlaugsson TH, Ólafsdóttur D, Øien N, Witting L, Víkingsson GA (2008). Lack of genetic divergence among samples of the North Atlantic Fin Whale collected at feeding grounds: congruence among microsatellite loci and mtDNA in the new Icelandic dataset. International Whaling commission/scientific commitee/60/PFI11.

Panasenko LD, Sobolova MS (1980). Food interrelations between the Barents Sea capelin and polar cod. ICES Council Meeting 1980 G:23: 15 pp.

Parkinson CL (2000). Variability of Arctic sea-ice: The view from space, an 18-year record. Arctic 53: 341-358.

Parry GD, Gason A (2006). The effect of seismic surveys on catch rates of rock lobsters in western Victoria, Australia. Fisheries Research 79: 272-284.

Parsons DG (2005). Predators of northern shrimp, *Pandalus borealis* (Pandalidae), throughout the North Atlantic. Mar. Biol. Res. 1:59-67.

Parsons ECM, A.J. W, Gore MA (2008). The nature of Humpback Whale (*Megaptera novaeangliae*) song. Journal of Marine Animals and Their Ecology 1: 22-31.

Patenaude NJ, Richardson WJ, Smultea MA, Koski WR, Miller GW, Wuersig B, Greene CRJ (2002). Aircraft sound and disturbance to bowhead and beluga whales during spring migration in the Alaskan Beaufort Sea. Marine Mammal Science 18: 309-355.

Payne K, Payne RS (1985). Large scale changes over 19 years in songs of humpback whales in Bermuda. Zeitschrift für Tierpsychologie 68: 89-114.

Pedersen PM (1976). Marine, benthic algae from southernmost Greenland. Meddelelser om Grønland 199: 1-80.

Pedersen PM (2011). Grønlands havalger. Forlaget Epsilon.dk, Denmark.

Pedersen SA, Kanneworff P (1995). Fish on the West Greenland shrimp grounds, 1988-1992. ICES Journal of Marine Science 52: 165-182.

Pedersen SA, Smidt ELB (2000). Zooplankton distribution and abundance in West Greenland waters 1950-1984. Journal of Northwest Atlantic Fishery Science 26: 45-102.

Pedersen SA, Storm L (2002). *Pandalus borealis* recruitment in West Greenland waters. Part II. Lipid classes and fatty acids in *Pandalus borealis* shrimp larvae: Implication for survival expectations and trophic relationships. Journal of Northwater Atlantic Fishery Science 30: 47-60.

Pedersen SA, Storm L, Simonsen CS (2002). Northern shrimp (*Pandalus borealis*) recruitment in West Greenland waters part I. Distribution of *Pandalus* shrimp larvae in relation to hydrography and plankton Journal of Northwest Atlantic Fishery Science 30: 19-46.

Pedersen SA, Ribergaard MH, Simonsen CS (2005). Micro- and mesozooplankton in Southwest Greenland waters in relation to environmental factors. Journal of Marine Systems 56: 85-112.

Perez C, Velando A, Munilla I, Lopez-Alonso M, Oro D (2008). Monitoring polycyclic aromatic hydrocarbon pollution in the marine environment after the Prestige oil spill by means of seabird blood analysis. Environmental Science and Technology 2008: 707-713.

Petersen DG, Dahllöf I (2007). Combined effects of pyrene and UV-light on algae and bacteria in an arctic sediment. Ecotoxicology 16: 371-377.

Petersen DG, Reichenberg F, Dahllöf I (2008). Phototoxicity of pyrene affects benthic algae and bacteria from the Arctic. Environmental Science and Technology 42: 1371-1376.

Peterson C, H., Rice SD, Short JW, Esler D, Bodkin JL, Ballachey BE, B. ID (2003). Long-term ecosystem response to the *Exxon Valdez* oil spill. Science 302: 2082-2086.

Picado A, Bebianno MJ, Costa MH, Ferreira A, Vale A (2007). Biomarkers: a strategic tool in the assessment of environmental quality of coastal waters. Hydrobiologica 587: 79-87.

Piepenburg D, Archambault P, Ambrose Jr WG, Blanchard A, Bluhm BA, Carroll ML, Conlan KE, Cusson M, Feder HM, Grebmeier JM, Jewett SC, Lévesque M, Petryashov VV, Sejr MK, Sirenko BI, Wlodarska-Kowalczuk M (2010). Towards a pan-Arctic inventory of the species diveristy of the macro- and megabenthic fauna of the Arctic shelf areas. Marine Biodiversity 41: 51-70

Pitman RL, Ensor P (2003). Three different forms of killer whales in Antarctic waters. Journal of Cetacean Research and Management 5: 131-139.

Pomerleau C, Ferguson SH, Walkusz W (2011). Stomach contents of bowhead whales (*Balaena mysticetus*) from four locations in the Canadian Arctic. Polar Biology 34: 616-624.

Poot H, Ens BJ, de Vries H, Donners MAH, Wernand MR, Marquenie JM (2008). Green light for nocturnally migrating birds. Ecology and Society 13: 47.

Popper AN, Fewtrell J, Smith ME, McCauley RD (2004). Anthropogenic sound: Effects on the behavior and physiology of fishes. Marine Technology Society Journal 37: 35-40.

Prieto R, Janiger D, Silva MA, Waring GT, Gonçalves JM (2011), The forgotten whale: a bibliometric analysis and literature review of the North Atlantic sei whale *Balaenoptera borealis*. Mammal Review 42: 235–272.

Pritchard P, Karlson U. 2002. Fate and degradation of oil. Pp 31-48 in Mosbech, A (ed.): Potential Environmental impacts of oil spills in Greenland. An assessment of informations status and research needs. NERI Technical Report No. 415.

Pörtner HO, Peck M (2010). Climate change impacts on fish and fisheries: towards a cause and effect understanding. Journal of Fish Biology 77: 1745-1779.

Quillfeldt CHv, Hegseth EN, Johnsen G, Sakshaug E, Syvertsen EE (2009). Ice algae. In: Sakshaug E, Johnsen G, Kovacs K (eds): Ecosystem Barents Sea. Tapir Academic Press, Trondheim.

Ramsay MA, Stirling I (1990). Fidelity of female polar bears to winter-den sites. J Mammal 71: 233-236.

Rankin S, Barlow J (2007). Vocalizations of the sei whale *Balaenoptera borealis* off the Hawaiian islands. Bioacoustics 16:

Rasmussen MH (1999). Hvidnæsens lydproduktion, adfærd samt udbredelse. Master Thesis, University of Odense.

Rasmussen RO (2005). Analyse af fangererhvervet i Grønland. Department of Fisheries and Hunting, Greenland Home Rule. Nuuk. Unpublished Report, 158 pp.

Rasmussen MH, Miller LA (2002). Whistles and clicks from white-beaked dolphins, *Lagenorhynchus albirostris*, recorded in Flaxaflói Bay, Iceland. Aquatic Mammals 28: 78-89.

Ray JP, Engelhardt FR (1992). Produced water. Technological/Environmental Isues and Solutions. Plenum Press, New York and London.

Reese CS, Calvin JA, George JC, Tarpley RJ (2001). Estimation of fetal growth and gestation in bowhead whales. Journal of the American Statistical Association 96: 915-923.

Reeves RR, Ljungblad DK, Clarke JT (1984). Bowhead whales and acoustic seismic surveys in the Beaufort Sea. Polar Record 22: 271-280.

Reeves RR, Smeenk C, Kinze CC, Brownell RL, Lien J (1999). White-beaked dolphin – *Lagenorhynchus albirostris* (Gray, 1846). In: Ridgway SH, Harrison SR (eds): Handbook of marine mammals Vol 6. Academic Press, London, p. 1-30.

Renaud PE, Jensen T, Wassbotten I, Mannvik HP, Botnen H (2007). Offshore sediment monitoring on the Norwegian shelf. A regional approach 1996-2006. Akvaplan-niva report No. 3487-003.

Rendell LE, Gordon J (1999). Vocal response of long-finned pilot whales (*Globicephala melas*) to military sonar in the Ligurian Sea. Marine Mammal Science 15: 198-204.

Research Council of Norway (2012). Long-term effects of discharges to sea from petroleum-related activities. The results of ten years' research. http://www.npd.no/Global/Engelsk/3-Publications/Reports/PROOFNY_Resultatrapport_Allegro_Douglas_Ferguson_20120509_en.pdf

Ribergaard MH (2011). Ensemble oil drift modelling for bottom spill off Southwest Greenland. Danish Meteorological Institute, Scientific Report 11-02.

Ribergaard MH, Pedersen SA, Adlandsvik B, Kliem N (2004). Modelling the ocean circulation on the West Greenland shelf with special emphasis on northern shrimp recruitment. Continental Shelf Research 24: 1505-1519.

Ribergaard MH, Kliem N, Jespersen M (2006). HYCOM for the North Atlantic Ocean with special emphasis on West Greenland Waters. Danish Meteorological Institute (DMI), National Environmental Research Institute (NERI). Copenhagen, Denmark. Technical Report No. 06-07.

Rice DW (1989) Sperm whale. *Physeter macrocephalus* Linnaeus, 1758. In: Ridgway SH, Harrison SR (eds): Handbook of Marine Mammals, Vol 4. Academic Press, London, p. 177-233.

Rice SD, Spies RB, Wolfe DA, Wright BA (1996). Proceedings of the *Exxon Valdez* Oil Spill Symposium. American Fisheries Society, Maryland.

Richard PR, Laake JL, Hobbs RC, Heide-Jorgensen MP, Asselin NC, Cleator H (2010). Baffin Bay Narwhal population distribution and numbers: Aerial surveys in the Canadian High Arctic, 2002-04. Arctic 63: 85-99.

Richardson WJ, Wursig B, Greene CRJ (1986). Reactions of bowhead whales, *Balaena mysticetus*, to seismic exploration in the Canadian Beaufort Sea. Journal of the Acoustical Society of America 79: 1117-1128.

Richardson WJ, Hickie JP, Davis RA, Thomson DH (1989). Effects of offshore petroleum operations on cold water marine mammals: A literature review American Petroleum Institute (API). Health and Environmental Sciences Department King City, Ontario, Canada. Report prepared by LGL Ltd. Publication No. 4485, 385 pp.

Richardson WJ, Greene CRJ, Malme CI, Thomson DH (1995). Marine mammals and noise. Academic Press, San Diego, US.

Richardson K, Markager S, Buch E, Lassen MF, Kristensen AS (2005). Seasonal distribution of primary production, phytoplankton biomass and size distribution in the Greenland Sea. Deep-Sea Research Part I-Oceanographic Research Papers 52: 979-999.

Rigét F, Böcher J (1998) The fresh water environment. In: Born E, Böcher J (eds): The ecology of Greenland. Ilinniusiorfik, Nuuk, p. 221-236.

Rigét, F, Bignert, A, Braune, B, Stow, J, Wilson, S (2010). Temporal trends of legacy POPs in Arctic biota, an update. Sci. Total Environ. 408: 2874-2884.

Ringuette M, Fortier L, Fortier M, Runge JA, Belanger S, Larouche P, Weslawski JM, Kwasniewski S (2002). Advanced recruitment and accelerated population development in Arctic calanoid copepods of the North Water. Deep-Sea Research Part II: Topical Studies in Oceanography 49: 5081-5099.

Rivkin RB, Tian R, Anderson MR, Payne JF (2000). Ecosystem level effects of offshore platform discharges: Identification, assessment and modelling. Proceedings of the 27th Annual Aquatic Toxicity Workshop, St. John's, Newfoundland, Canada, October 01-04, 2000. Canadian Technical Report of Fisheries and Aquatic Sciences 2331: 3-12.

Roche C, Guinet C (2007). Marine mammals and demersal longline fishery interactions in Crozet and Kerguelen exclusive economic zones: an assessment of depredation levels. CCAMLR Science 14: 67-82.

Roe HSJ (1969). The food and feeding habits of sperm whales (*Physeter catodon* L.) taken off the west coast of Iceland. J Cons Int Explor Mer 33: 93-102.

Rosenvinge LKR (1893). Grønlands havalger. Meddelelser om Grønland 3: 765-981.

Rosenvinge LKR (1898). Deuxiéme mémoire sur les algues du Groenland. Meddelelser om Grønland 20: 1-125.

Rosing-Asvid A (2010a). Catch history and status of the harbour seal (*Phoca vitulina*) in Greenland. In: Desportes G, Bjørge A, Rosing-Asvid A, Waring G (eds): Harbour seals in the North Atlantic and the Baltic. NAMMCO Scientific Publications 8, p. 159-172.

Rosing-Asvid A (2010b). Seals of Greenland. Ilinniusiorfik Undervisningsmiddelforlag, Nuuk.

Rosing-Asvid A (2011). Status of harbor seals and grey seals in Greenland. NAMMCO. NAMMCO Working Group Paper on Coastal Seals, 12 pp.

Ross SL (1992). Evaluation of the behaviour and cleanup of offshore oil-well blowout spills in west Greenland. S.L. Ross Ltd. 87 pp.

Ross WG (1993). Commercial whaling in the North Atlantic sector. In: Burns JJ, Montague JJ, Cowles CJ (eds): The bowhead whale. Society for Marine Mammalogy. Special Publications No. 2. Allan Press.

Rothrock DA, Yu Y, Maykut GA (1999). Thinning of the Arctic sea-ice cover. Geophysical Research Letters 26: 3469-3472.

Ryals BM, Rubel EW (1988). Hair cell regeneration after acoustic trauma in adult Cortunix quail. Science 240: 1774-1776.

Rye H, Nordtug T, Skognes K (2003). Spredning og deponering av kaks og slam. Spredning av producert vann med doser på organismer. Spredning av radioaktivitet. OED studie 5a og 5b – udredning Lofoten-Barentshavet. Sintef. Unpublished Report.

Rysgaard S, Glud RN (2007). Carbon cycling and climate change: Predeictions for a High Arctic marine ecosystem. Meddelelser om Grønland, Bioscience 58: 206-214.

Rysgaard S, Kuhl M, Glud R, Hansen J (2001). Biomass, production and horizontal patchiness of sea-ice algae in a high-Arctic fjord (Young Sound, NE Greenland). Marine Ecology Progress Series: 15-26.

Rysgaard S, Glud RN, Sejr MK, Bendtsen J, Christensen PB (2007). Inorganic carbon transport during sea ice growth and decay: A carbon pump in polar seas. Journal of Geophysical Research Oceans 112: 8 pp.

Rysgaard S, Arendt K, Frederiksen MS, Egevang C, Labansen A, Mortensen J, Simon M, Pedersen LF, Witting L, Bergstrøm B, Mikkelsen D (2008). Nuuk Basic: The MarineBasic Programme 2005–2006. In: Jensen LM, Rasch M (eds): Nuuk Ecological Research Operations, 1st Annual Report, 2007. Danish Polar Centre, Danish Agency for Science, Technology and Innovation, Ministry of Science, Copenhagen, p. 38-73.

Rätz H-J (1999). Structures and changes of the demersal fish assemblage off Greenland, 1982-1996. NAFO Sci Council Stud 32: 1-15.

Røe TI, Johnsen S (1999). Bioavailability of polycyclic aromatic hydrocarbons in the North Sea. Environmental Science Technology 33: 1963-1969.

Savard L, Parsons DG, Carlsson DM (1994). Estimation of age and growth of northern shrimp (*Pandalus borealis*) in Davis Strait (NAFO Subareas 0+1) using cluster and modal analyses. J. Northw. Atl. Fish. Sci. 16: 63-74

Sainte-Marie B, Sevigny JM, Gauthier Y (1997). Laboratory behavior of adolescent and adult males of the snow crab (*Chionoecetes opilio*) (Brachyura: Majidae) mated noncompetitively and competitively with primiparous females. Canadian Journal of Fisheries and Aquatic Sciences 54: 239-248.

Santos MB, Pierce GJ, Boyle PR, Reid RJ, Ross HM, Patterson IAP, Kinze CC, Tougaard S, Lick R, Piatkowski U, Hernández-García V (1999). Stomach contents of sperm whales *Physeter macrocephalus* stranded in the North Sea 1990-1996. Marine Ecology Progress Series 183: 218-294.

Schaaning MT, Trannum HC, Øxnevad S, Carroll JL, Bakke T (2008). Effects of drilling cuttings on biogeochemical fluxes and macrobenthos of marine sediments. Journal of Experimental Marine Biology and Ecology 361: 49-57.

Scheifele PM, Andrew S, Cooper RA, Darre M, Musiek FE, Max L (2005). Indication of a Lombard vocal response in the St. Lawrence River beluga. Journal of the Acoustical Society of America 117: 1486-1492.

Schick RS, Urban DL (2000). Spatial components of bowhead whale (*Balaena mysticetus*) distribution in the Alaskan Beaufort Sea686. Canadian Journal of Fisheries and Aquatic Sciences 57: 2193-2200.

Schiedek D, Sundelin B, Readman JW, Macdonald RW (2007). Interactions between climate change and contaminants (review). Marine Pollution Bulletin 54: 1845-1856.

Schmidt-Etkin D (2011) Spill occurrences: A world overview In: Fingas M (ed): Oil spill science and technology. Elsevier, p. 7-47.

Schreiber EA, Burger J (2002). Biology of marine Birds. CRC Press.

Schrope M (2011). Deep wounds. Nature 472: 152-154.

Shumway SE, Perkins HC, Schick DF, Stickney AP (1985). Synopsis of biological data on the pink shrimp, *Pandalus borealis* Kroyer, 1838. NOAA/National Marine Fisheries Service, (NOAA Technical Report NMFS, 30).

Scott CL, Kwasniewski S, Falk-Petersen S, Sargent JR (2000). Lipids and life strategies of *Calanus finmarchicus*, *Calanus glacialis* and *Calanus hyperboreus* in late autumn, Kongsfjorden, Svalbard. Polar Biology 23: 510-516.

Sejr MK, Christensen PB (2007). Growth, production and carbon demand of macrofauna in Young Sound, with special emphasis on the bivalves Hiatella arctica and *Mya truncata* In: Rysgaard S, Glud RN (eds): Carbon cycling in Arctic Marine ecosystems: Case study Young Sound Vol 58. Meddelelser om Grønland, Bioscience, Copenhagen, p. 214.

Sejr MK, Blicher ME, Rysgaard S (2009). Sea ice cover affects inter-annual and geographic variation in growth of the Arctic cockle *Clinocardium ciliatum* (Bivalvia) in Greenland. Marine Ecology Progress Series 389: 149-158.

Sergy GA, Blackall PJ (1987). Design and conclusion of the Baffin Island oil spill project. Arctic 40 (Suppl. 1): 1–9.

Serrano A, Sánchez F, Preciado I, Parra S, Frutos I (2006). Spatial and temporal changes in benthic communities of the Galician continental shelf after the Prestige oil spill. Marine Pollution Bulletin 53: 315-331.

SFT (2008). Kostnader og nytte for miljø og samfunn ved å stille krav om injeksjon/reinjeksjon av produsert vann, nullutslipp av borekaks og borevæske og inkludere radioaktivitet i nullutslippmålet. Statens Strålevern, Oljedirektoratet, Statens forureningstilsyn. www.klif.no/publikasjoner/2468/ta2468.pdf.

Short JW, Harris PM (1996). Chemical sampling and analysis of petroleum hydrocarbons in near-surface seawater of Prince William Sound after the *Exxon Valdez* oil spill. In: Rice DS (ed): Proceedings of the *Exxon Valdez* oil spill symposium. American Fisheries Society, Bethesda, Maryland, p. 17-28.

Short JW, Lindeberg MR, Harris PM, Maselko JM, Pella JJ, Rice SD (2004). Estimate of oil persisting on the beaches of Prince William Sound 12 years after the *Exxon Valdez* oil spill. Environmental Science and Technology 38: 19-25.

Shumway SE, Perkins HC, Schick DF, Stickney, AP (1985). Synopsis of biological data on the pink shrimp, *Pandalus borealis* Krøyer, 1838. FAO Fisheries Synopsis, 144; NOAA Technical Report NMFS, 30: 57 p.

Siegstad H, Neve PB, Heide-Jørgensen MP, Härkönen T (1998) Diet of the Ringed Seal (*Phoca hispida*) in Greenland. In: Heide-Jørgensen MP, Lydersen C (eds): Ringed Seals in the North Atlantic, Vol 1. NAMMCO scientific publications, p. 229-241.

Similä T, Ugarte F (1997). Social organisation of north Norwegian killer whales. NFH, University of Tromsø.

Simon M (2010). The sounds of whales and their food: Baleen whales, their foraging behaviour, ecology and habitat use in an arctic habitat. Ph.D. Thesis, Aarhus University, Denmark.

Simon MJ, Kristensen TK, Tendal OS, Kinze CC, Tougaard S (2003). *Gonatus fabricii* (Mollusca, Theuthida) as an important food source for sperm whales (*Physeter macrocephalus*) in the northeast Atlantic. Sarsia 88: 244-246.

Simon M, Kingsley M, Witting L (2007a). Seasonal and spatial distribution and sex ratio of fin whale catches off West Greenland, 1987-2006. International Whaling commission/scientific commitee/59/AWMP2:

Simon M, Wahlberg M, Miller LA (2007b). Echolocation clicks from killer whales (*Orcinus orca*) feeding on herring (*Clupea harengus*) (L). Journal of the Acoustical Society of America 121: 749-752.

Simon M, McGregor PK, Ugarte F (2007c). The acoustic behaviour of herring-eating killer whales (*Orcinus orca*). Acta Ethologica 10: 47-53.

Simon M, Johnson M, Tyack P, Madsen PT (2009). Behaviour and kinematics of continuous ram filtration in bowhead whales (*Balaena mysticetus*). Proceedings of the Royal Society B-Biological Sciences 276: 3819-3828.

Simon M, Stafford KM, Beedholm K, Lee CM, Madsen PT (2010). Singing behavior of fin whales in the Davis Strait with implications for mating, migration and foraging. Journal of the Acoustical Society of America 128: 3200-3210.

Simonsen CS, Munk P, Folkvord A, Pedersen SA (2006). Feeding ecology of Greenland halibut and sandeel larvae off West Greenland. Marine Biology 149: 937-952.

Simpson AC, Howell BR, Warren PJ (1970). Synopsis of avilable data on the shrimp *Pandalus montagui*. FAO. FAO Fisheries Synopsis No. 92, p 1225-1249.

Širovic A, Hildebrand JA, Wiggins SM (2007). Blue and fin whale call source levels and propagation range in the Southern Ocean. J. Acoust. Soc. Am. 122 (2): 1208-1215.

Sjare B, Stirling I (1996). The breeding behavior of Atlantic walruses, *Odobenus rosmarus rosmarus*, in the Canadian High Arctic. Canadian Journal of Zoology 74: 897-911.

Sjare B, Stirling I, Spencer C (2003). Structural variation in the songs of Atlantic walruses breeding in the Canadian High Arctic. Aquatic Mammals 29: 297-318.

Skadsheim A, Sanni S, Pinturier L, Moltu UE, Buffagni M, Bracco L (2009). Assessing and monitoring local and long-range-transported hydrocarbons as potential stressors to fish stocks. Deep Sea Research Part II: Topical Studies in Oceanography 56: 2037-2043.

Slotte A, Hansen K, Dalen J, Ona E (2004). Acoustic mapping of pelagic fish distribution and abundance in relation to a seismic shooting area off the Norwegian west coast. Fisheries Research 67: 143-150.

Smidt E (1969). The greenland halibut, *Reinhardtius hippoglossoides* (Walb.), biology and exploitation in greenland waters. Meddelelser fra Danmarks Fiskeri- og Havundersøgelser 6: 79-148.

Smith SL, Schnack-Schiel SB (1990). Polar Zooplankton, Part B: Chemistry, Biology, and Geology. Academic Press, London.

Smultea MA, Würsig B (1995). Behavioral reactions of bottlenose dolphins to the Mega Borg oil spill, Gulf of Mexico 1990. Aquatic Mammals 21: 171-181.

Sonne C (2010). Health effects from long-range transported contaminants in Arctic top predators: An integrated review based on studies of polar bears and relevant model species. Environment International 36: 461-491.

Sonne C, Dietz R, Leifsson PS, Asmund G, Born EW, Kirkegaard M (2007). Are liver and renal lesions in East Greenland polar bears (*Ursus maritimus*) associated with high mercury levels? Environmental Health 6: 11.

Sousa A, Laranjeiro F, Takahashi S, Tanabe S, Barroso CM (2009). Imposex and organotin prevalence in a European post-legislative scenario: Temporal trends from 2003 to 2008. Chemosphere 77: 566-573.

Southall BL, Bowles AE, Ellison WT, Finneran J, Gentry R, Green CR, Kastak CR, Ketten DR, Miller JH, Nachtigall PE, Richardson WJ, Thomas JA, Tyack PL (2007). Marine Mammal Noise Exposure Criteria. Aquat Mamm 33: 411-521.

Spraker TR, Lowry LF, Frost KJ (1994). Gross necropsy and histopathological lesions found in harbor seals. In: Loughlin TR (ed): Marine mammals and the '*Exxon Valdez*'. Academic Press, San Diego, CA, p. 281-312.

Statistics of Greenland. http://www.stat.gl/default.asp?lang=en

Stafford KM, Moore SE, Laidre KL, Heide-Jørgensen MP (2008). Bowhead whale springtime song off West Greenland. J Acoust Soc Am 125: 3315-3323.

St. Aubin DJ (1990). Phyisiologic and toxic effects on pinnipeds. In: Geraci JR, D.J. SA (eds): Sea mammals and oil Confronting the risks. Academic Press, p. 24.

Stein M (2007). Warming periods off Greenland during 1800–2005: their potential influence on the abundance of cod (*Gadus morhua*) and Haddock (*Melanogrammus aeglefinus*) in Greenlandic waters. Journal Northwest Atlantic Fisheries Science 39: 1-20.

Stendel M, Christensen NH, Petersen D (2008). Arctic Climate and Climate Change with a Focus on Greenland. Advances in Ecological Research 40: 13-43.

Stenberg C (2007). Recruitment processes in West Greenland waters. With special focus on Greenland halibut (*Reinhardtius hippoglossoides*, W.). Ph.D Thesis, University of Bergen, Norway.

Stenson GB, Myers RA, Ni HI, Warren WG (1996). Pup production of hooded seals (*Cystophora cristata*) in the Northwest Atlantic. NAFO Sci.Coun. Studies 26:105-114.

Stevick PT, Allen J, Clapham PJ, Katona SK, Larsen F, Lien J, Mattila DK, Palsbøll PJ, Sears R, Sigurjonsson J, Smith TD, Vikingsson G, Øien N, Hammond PS (2006). Population spatial structuring on the feeding grounds in North Atlantic humpback whales (*Megaptera novae-angliae*). Journal of Zoology 270: 244–255.

Stewart REA (2008). Redefining walrus stocks in Canada. Arctic 61: 292-398.

Stimpert AK, Wiley DN, Whitlow WLA, Johnson MP, Arsenault R (2007). 'Megapclicks': acoustic click trains and buzzes produced during night-time foraging of humpback whales (*Megaptera novaeangliae*). Biol. Lett. 3, 467-470.

Stirling I, Parkinson CL (2006). Possible effects of climate warming on selected populations of polar bears (*Ursus maritimus*) in the Canadian Arctic. Arctic 59: 261-275.

Stjernholm M, Boertmann D, Mosbech A, Nymand J, Jeremiassen SR, Myrup M, Merkel F (2011). Environmental oil spill sensitivity atlas for the Northwest Greenland (72°-75° N) coastal zone. National Environmental Research Institute (NERI), University of Aarhus. Roskilde, Denmark. No. 828, 210 pp.

Stone CJ, Tasker ML (2006). The effects of seismic airguns on cetaceans in UK waters. Journal of Cetacean Research and Management 8: 255-263.

Storm L, Pedersen SA (2003). Development and drift of northern shrimp larvae (*Pandalus borealis*) at West Greenland. Marine Biology 143: 1083-1093.

Strand J, Asmund G (2003). Tributyl accumulation and effects in marine molluscs from West Greenland. Environmental Pollution 123: 31-37.

Strand J, Larsen MM, Lockyer C (2005). Accumulation of organotin compounds and mercury in harbour porpoises (*Phocoena phocoena*) from the Danish waters and West Greenland. Science of the Total Environment 350: 59-71.

Sunnanå K (2005). Rognkjeks. In: Bakketeig I, Dommasnes A, Føyn L, Haug T, Iversen S, Røttingen I, Svendsen E, Torstensen E (eds): Havets Ressurser. Institute of Marine Research, Bergen, p. 128-130.

Swalethorp R, Kjellerup S, Dünweber M, Nielsen TG, Møller EF, Rysgaard S, Hansen BW (2011). Grazing, production and biochemical evidence for differences in the life strategies of *Calanus finmarchicus*, *C. glacialis* and *C. hyperboreus* in Disko Bay, Western Greenland. Submitted to Marine Ecology-Progress Series.

Söderkvist J, Nielsen TG, Jespersen M (2006). Physical and biological oceanography in West Greenland waters with emphasis on shrimp and fish larvae distribution. National Environmental Research Institute (NERI), University of Aarhus. Roskilde, Denmark. NERI Technical Report No. 581, 60 pp.

Søndergaard J, Asmund G, Johansen P, Rigét F (2011a). Long-term response of an arctic fiord system to lead-zinc mining and submarine disposal of mine waste (Maarmorilik, West Greenland). Marine Environmental Research 71: 331-341.

Søndergaard J, Johansen P, Asmund G, Rigét F (2011b). Trends of lead and zinc in resident and transplanted *Flavocetraria nivalis* lichens near a former lead-zinc mine in West Greenland. Science of the Total Environment 409: 4063-4071.

Sørensen EF, Simonsen V (1988). Genetic differentiation among populations of capelin *Mallotus villosus* from the West coast of Greenland. Journal of Applied Ichthyology-Zeitschrift Fur Angewandte Ichthyologie 4: 23-28.

Tang CCL, Ross CK, Yao T, Petrie B, DeTracey BM, Dunlap E (2004). The circulation, water masses and sea-ice of Baffin Bay. Progress in Oceanography 63: 183-228.

Taylor MK, Akeeagok S, Andriashek D, Barbour W, Born EW, Calvert W, Cluff HD, Laake J, Rosing-Asvid A, Stirling I, Messier F (2001). Delineating Canadian and Greenland polar bear (*Ursus maritimus*) populations by cluster analysis of movements. Canadian Journal of Zoology 79: 690-709.

Teloni V, Mark JP, Patrick MJO, Peter MT (2008). Shallow food for deep divers: Dynamic foraging behavior of male sperm whales in a high latitude habitat. Journal of Experimental Marine Biology and Ecology 354: 119-131.

Tervo OM, Parks SE, Miller LA (2009). Seasonal changes in the vocal behavior of bowhead whales (*Balaena mysticetus*) in Disko Bay, Western-Greenland. Journal of the Acoustical Society of America 126: 1570-1580.

Thibodeaux LJ, Valsaraj KT, John VT, Papadopoulos KD, Pratt LR, Pesika NS (2011). Marine Oil Fate: Knowledge Gaps, Basic Research, and Development Needs; A Perspective Based on the Deepwater Horizon Spill. Environmental Engineering Science 28: 87-93.

Thomsen F, Franck D, Ford JKB (2001). Characteristics of whistles from the acoustic repertoire of resident killer whales (*Orcinus orca*) off Vancouver Island, British Columbia. Journal of the Acoustical Society of America 109: 1240-1246.

Thompson PO, Cummings WC, Ha SJ (1986). Sounds, source levels, and associated behaviour of humpback whales, Southeast Alaska. J. Acoust. Soc. Am. 80: 735-740. (doi:10.1121/1.393947).

Thormar J (2006). The rhodoliths of Disko Fjord, greenland: first visual record of the *Lithothmanion glaciale/ tophiforme* (Corallinales, Rhodophyta) aggregation in Disko Fjord, 69 N, Greenland. In: Halberg KA (ed): Arctic Biology Field Course, Qeqartarsuaq 2006. Copenhagen University, p. 87-112.

Tilseth S, Solberg TS, Westrheim K (1984). Sublethal effects of the water-soluble fraction of ekofisk crude-oil on the early larval stages of cod (*Gadus morhua* L). Marine Environmental Research 11: 1-16.

Trannum, HC, Bakke T (2012). The environmental effects of the Deepwater Horizon oil spill - focus on effects on fish and effects of dispersants. NIVA report SNO 6283-2012.

Turner JT (2002). Zooplankton fecal pellets, marine snow and sinking phytoplankton blooms. Aquatic Microbial Ecology 27: 57-102.

Ugarte F, Heide-Jørgensen MP (2008). Standing Non-Detriment findings for exports from Greenland of products derived from beluga (*Delphinapterus leucas*). Report from the CITES scientific authority for Greenland.

Urick RJ (1983). Principles of underwater sound. Peninsula publishing, Los Altos.

Valentine (2010). Propane respiration jump-starts microbial response to a deep oil spill. Science 330: 208-211.

Valeur HH, Hansen C, Hansen KQ, Rasmussen L, Thingvad L (1996). Weather, sea and ice conditions in eastern Baffin Bay, offshore Northwest Greenland. A review. Danish Meteorological Institute. Copenhagen. Technical Report No. 96-12.

Van der Oost R, Beyer J, Vermeulen NPE (2003). Fish bioaccumulation and biomarkers in environmental risk assessment: A review. Environmental Toxicology and Pharmacology 13: 57-149.

Vibe C (1950). The marine mammals and the marine fauna in the Thule District (Northwest Greenland) with observations on the ice conditions in 1939-41. Meddelelser om Grønland, Bioscience 150: 1-115.

Vilhjálmsson H (1994). The Icelandic Capelin Stock. Journal of the Marine Research Institute: 279 pp.

Vilhjalmsson H (2002). Capelin (*Mallotus villosus*) in the Iceland-East Greenland-Jan Mayen ecosystem. ICES Journal of Marine Science 59: 870-883.

Villadsgaard A, Wahlberg M, Tougaard J (2007). Echolocation signals of wild harbour porpoises, *Phocoena phocoena*. The Journal of Experimental Biology 210: 56-64.

Villumsen A, Ottosen LM (2006). Heavy metal and TBT contamination in the sediment around Sisimiut, Greenland. Department of Civil Engineering, Technical University of Denmark, Lyngby. In: The Greenlandic Environment, Pollution and Solutions, p. 103.

Visser IN (2005). First observations of feeding on Thresher (*Alopias vulpinus*) and Hammerhead (*Sphyrna zygaena*) Sharks by Killer Whales (*Orcinus orca*) specialising on elasmobranch prey. Aquatic Mammal 31: 83-88.

Vold A, Løkkeborg S, Tenningen M, Saltskår J (2009). Analysis of commercial catch data to study the effects of seismic surveys on the fisheries in Lofoten and Vesterålen summer of 2008. Fisken og Havet 5/2009, Havforskningsinstituttet, Bergen (In Norwegian with summary in English).

Vorkamp K, Dam M, Riget F, Fauser P, Bossi R, Hansen AB (2007). Screening of 'new' contaminants in the marine environment of Greenland and the Faroe Islands. National Environmental Reseach Institute (NERI), University of Aarhus Roskilde, Denmark. NERI Technical Report No. 525, 97 pp.

Walsh JE (2008). Climate of the Arctic marine environment. Ecological Applications 18: Supplement, 2008, S3-S22:

Wardle CS, Carter TJ, Urquhart GG, Johnstone ADF, Ziolkowski AM, Hampson G, Mackie D (2001). Effects of seismic air guns on marine fish. Continental Shelf Research 21: 1005-1027.

Wassmann P, Ratkova TN, Andreassen I, Vernet M, Pedersen G, Rey F (1999). Spring bloom development in the marginal ice zone and the central Barents Sea. Marine Ecology 20: 321-346.

Wassmann P, Duarte CM, AgustÍ S, Sejr MK (2011). Footprints of climate change in the Arctic marine ecosystem. Global Change Biology 17: 1235-1249.

Watkins WA, Tyack P, Moore KE (1987). The 20-Hz signals of finback whales (*Balaenoptera physalus*). Journal of the Acoustical Society of America 82: 1901-1912.

Webb A, Durinck J (1992) Counting birds from ship. In: J. Komdeur JBGC (ed): Manual for aeroplane and ship surveys of waterfowl and seabirds, Vol 19. IWRB Spec, p. 24-37.

Wegeberg S (2007). Er tang en ny marin resource i Grønland. Vand & Jord 14: 117-120

Wegeberg S, Bangsholt J, Dolmer P, Hertz O, Mortensen AM, Pedersen PM (2005). Nordic Seaweed Project. Grønland. Resultatstatus for 2004. Københavns Universitet. 22 pp.

Wenzel FW, Allen J, Berrow S, Hazevoet CJ, Jann B, Seton RE, Steiner L, Stevik P, López Suárez P, Whooley P (2009). Current Knowledge on the Distribution and Relative Abundance of Humpback Whales (*Megaptera novaeangliae*) off the Cape Verde Islands, Eastern North Atlantic. Aquatic Mammals 35: 502-510.

Werth AJ (2001). How do mysticetes remove prey trapped in baleen? Bulletin Museum of Comparative Zoology 156(1): 189-203.

Węsławski JM, Kendall MA, Włodarska-Kowalczuk M, Iken K, Kędra M, Legezynska J, Sejr MK (2011). Climate change effects on Arctic fjord and coastal macrobenthic diversity - observations and predictions. Marine Biodiversity 41: 71-85.

Whitehead H (2003). Sperm whales social evolution in the ocean. The University of Chicago Press. 431 pp.

Whitehead H, Weilgart L (2000). The sperm whale: social females and roving males. Pp. 154–172 in: Mann, J, Connor RC, Tyack PL, Whitehead H (eds): Cetacean societies: field studies of whales and dolphins. University of Chicago Press, Chicago, IL.

Whitehead H, Wimmer T (2005). Heterogeneity and the mark–recapture assessment of the Scotian Shelf population of northern bottlenose whales (*Hyperoodon ampullatus*). Canadian Journal of Fisheries and Aquatic Sciences 62: 2573 - 2585.

Wieland K (2004) Length at sex transition in northern shrimp (*Pandalus borealis*) off West Greenland in relation to temperature and stock size. Fish. Res. 69:49-56.

Wieland K (2005). Changes in recruitment, growth and stock size of northern shrimp (*Pandalus borealis*) at West Greenland: temperature and density-dependent effects at released predation pressures. ICES Jour. Mar. Sci. 62:1454-1462.

Wieland K, Hovgaard H (2002). Distribution of Atlantic cod (*Gadus morhua*) eggs and larvae in Greenland offshore waters. Journal of Northwater Atlantic Fishery Science 30: 60-76.

Wieland K, Hovgaard H (2009). Cod versus shrimp dominance in West Greenland waters: Can climate change reverse the regime shift from a cod to a shrimp dominated ecosystem off West Greenland? ICES Council Meeting, ICES C.M. C:03: 1-24.

Wiese FK, Montevecchi WA, Davoren GK, Huettmann F, Diamond AW, Linke J (2001). Seabirds at risk around offshore oil platforms in the North-west Atlantic. Marine Pollution Bulletin 42: 1285-1290.

Wiese FK, Robertson GJ, Gaston AJ (2004). Impacts of chronic marine oil pollution and the murre hunt in Newfoundland on thick-billed murre *Uria lomvia* populations in the eastern Canadian Arctic. Biological Conservation 116: 205-216.

Wiig Ø, Belikov SE, Boltunov AN, Garner GW (1996). Selection of Marine Mammal Valued Ecosystem Components and description of impact hypotheses in the Northern Sea Route Area. INSROP Working Paper No. 40, 86 pp.

Williams R, Gero S, Bejder L, Calambokidis J, Kraus SD, Lusseau D, Read AJ, Robbins J (2011). Underestimating the damage: interpreting cetacean carcass recoveries in the context of the Deepwater Horizon/BP incident. Conservation Letters 4: 228-233.

Wimmer T, Whitehead H (2004). Movements and distribution of northern bottlenose whales, *Hyperoodon ampullatus*, on the Scotian Slope and in adjacent waters. Canadian Journal of Zoology 82: 1782–1794.

Witting L (2008). Assessment update for West Greenland fin whales. International Whaling Commission/Scientifi c/60/AWMP4. http://www.iwcoffi ce.org/Web site visited 20080918

Witting L, Born EW (2005). An assessment of Greenland walrus populations. ICES Journal of Marine Science 62: 266-284.

Zachary TS, Andrew JW, Heather NK, Rosalind MR, Scott DK (2009). Metabolism of ingested lipids by North Atlantic right whales. Marine Ecology Progress Series 6: 259-271.

Ziemer N, Kingsley MCS, Siegstad H (2010). Results of the Greeland bottom trawl survey for Northern shrimp (*Pandalus borealis*) off West Greenland (NAFO Sub area 1 and Division OA), 1988-2010. Northwest Atlantic Fisheries Organization. Dartmouth, Canada. NAFO Scientific Council Research Document No. 10/57, Serial No. N5848.

Øritsland NA, Engelhardt FR, Juck FA, Hurst RJ, Watts PD (1981). Effect of crude oil on polar bears. Env. Stud. 24: 268 pp.

Østby C, Nordstrøm L, Moe KA (2003). Konsekvenser av seismisk aktivitet. Alpha Miljørådgivning. Oslo, Norway. ULB delutredning 18.

Appendix 1. Oil spill scenarios in the Disko West area

The following oil spill scenarios are based on the spills modelled by Danish Meteorological Institute (DMI) in the report ‘Oil drift and fate modelling at Disko Bay’ (Nielsen et al. 2006). However, these models are based on spill periods in summer and winter, why some of the spill situations therefore are transposed to other seasons to get a more covering picture of the annual variation of the biology of the region.

The spill locations are shown in Figure 1. These are selected based on potential development areas as suggested by Geological Survey of Denmark and Greenland (GEUS). A medium crude oil of type ‘Statfjord’ with a density of 886.3 kg/m^3 was chosen to represent the spilled oil (Nielsen et al. 2006).

Two different spill situations were modelled at each site by the DMI report: A continuous (3000 t released each day over 10 days, in total 30,000 t) and an instantaneous spill where 15,000 t are released. However, a feasibility study indicates that the shuttle tankers which will be used in a future production situation may carry as much as 100,000 t of oil (APA 2003) why instantaneous spills may have the potential to be much larger.

Only surface spills are considered here, but the DMI-report states that the behaviour of subsurface spill is almost identical, as oil will surface quickly from a subsurface blow-out. However, the *Macondo*-spill in the Mexican Gulf in 2010, showed that at least in deep waters significant parts of the oil remained in the water column (cf. Section 11.1.2 in main report).

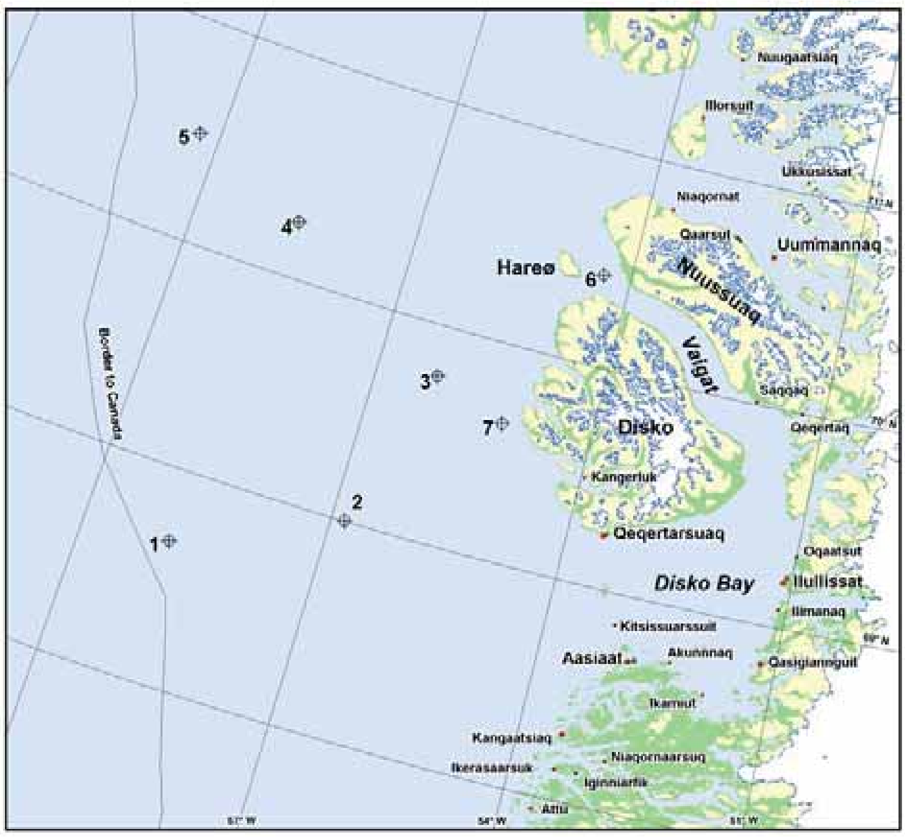


Figure 1. The seven spill locations and towns and settlements in the region.

Table 1. The impacts from the seven scenarios and alternative scenarios summarised. R = reversible, r = slowly reversible, No = no significant impacts expected. No* = No immediate impacts expected, but impacts possible following spring during ice melt. L = low impacts expected, M = moderate impacts expected, H = high impacts expected, ? = possible.

Scenario		Extent sq. km	Duration years	Season	Marine mammals	Birds	Fish	Benthic fauna	Primary prod. plankton	Shorelines	Local use	Commercial use	Long term effects likely
1		9000	>10	summer	L R	H r	M r	H r	L R	H r	H R	H R	yes
1	alt. drift	13000	>10	summer	L R	H r	L r	H r	L R	H r	H R	H R	yes
1	March alt.	9000	>10	spring	M R	H r	H r	H r	M R	H r	H R	H R	yes
2		1500	>10	autumn	L R	M R	L R	H r	L R	H r	L R	H R	yes
3		22000	1	winter	L R	L R	H? R	No	L R	No	No	L R	
3	Sept. alt.	22000	1	autumn	L R	H R	No	No	L R	No	No	H R	
4		8000	1	winter	M R	L R	H? R	No	No*	No	L R	L R	
4	alt. drift	10000	>5	winter	M R	H R	L R	No	L R	No	L R	L R	yes
5		10000	>10	summer	L R	H r	M R	H r	L R	H r	H R	H R	yes
6		30000	1	winter	M R	L R	H? R	No	No*	No	L R	L R	
6	Aug. alt.	30000	1	autumn	M R	H r	L R	No	L R	No	L R	H R	
7		unknown	1	spring	L R	L-M R	H? R	No	M R	No	L R	L R	

The spilled oil will evaporate one third during the first 24 hours of the spill and it will quickly disperse on the surface to a very thin layer and drift mainly governed by the wind. It will be fragmented in isolated patches where regions with an oil layer or sheen are interspersed with regions with no oil at a given time. In ten days the maximum displacement of the oil is 375 km and in 30 days 580 km from the spill site. A varying amount will settle on the shores, from 0 % to almost the total amount depending on spill type, distance to the shore and wind direction. Only during seabed releases, oil may settle on the sea bed, and up to 1 % of the released oil then settles (Nielsen et al. 2006).

Oil concentrations (total oil) in the subsurface layers will be high in the top meter below a spill, and will gradually decrease downwards. At the spill site maximum values in the upper 20 meters has been estimated to be 24,000 ppb (total oil) where oil layer thickness is 2 mm (Nielsen et al. 2006). However the concentration of oil in the water column depends strongly on how much is physically washed down in the water by wave action. In calm waters very little will be washed down and only water soluble fractions will contribute to the oil concentrations in the water below a spill. Due to drift and weathering processes concentrations in the water below a spill decreases quickly, when the oil moves away from the spill site. In Norwegian modelling work effects on plankton, fish egg and larvae are confined to the upper 10 m below an oil spill and high impact on fish egg and larvae will only occur if there is a match between spawning sites and time and the spill site and time (Johansen & Skognes 2003). As the temporal window for such matching situations is short e.g. 4 week for herring larvae and 6 weeks for cod, and due to the drift of the oil effective exposure for fish eggs and larvae in the upper water column will usually be short (2-3 days).

If oil is released below an ice cover, it will accumulate on the underside of the ice. Due to the roughness of the ice, the spread will be much hampered, and for example if the average oil layer thickness is 1 cm a 15,000 t spill will cover 1.5 km^2.

The drift-modelling maps from the DMI modelling are used to estimate the drift, coverage and extension of oil spills. These maps show the maximum area which can be affected by of the oil spills modelled for 30 days,.

The described scenarios do not include oil spill recovery. The results of such actions was in 1992 estimated for Southwest Greenland with the best available technology, and it was found that max. 17-25% of the oil on the sea surface could be recovered (S.L. Ross 1992), mainly due to harsh weather conditions, presence of ice, darkness and reduced visibility.

Impacts are classified as none, low, moderate, and high, or in a few cases – mainly fishery – they have been quantified.

In Table 1 the scenarios are summarised.

Spill scenario 1

15,000 t oil is released instantaneously at spill location 3, 48 km west of Disko Island. Release date is July 7th, and the oil drifts towards east and southeast and hit the coasts of southwest Disko and coasts between Aasiaat and Kangaatsiaq (Figure 2). The geographic extend of the affected sea will be app. 9,000 km^2, and more than 1500 km coastline is exposed for oil settlement.

Resources at risk
Marine mammals: Seals (mainly harp seals) and whales: Minke, fin, humpback whales and harbour porpoise.

Seabirds: Breeding colonial species such as gulls, fulmars and alcids (black guillemot, razorbill, Atlantic puffin, little auk), moulting seaducks as common eiders, king eiders and harlequin ducks. See Figures 13 and 14 in the main report. Fish: Arctic char occur in coastal waters and capelin roe and newly hatched larvae are present in the subtidal zone.

Benthic fauna: The benthic fauna is very rich and diverse on the bank areas (see Box 3 in main report).

Primary production and plankton (incl. fish and shrimp egg and larvae): In July the spring bloom is over and high production and plankton concentrations may be found at hydrodynamic discontinuities (Söderkvist et al. 2006). The most conspicuous and predictable hydrodynamic discontinuity in the area affected by the oil spill is the upwelling area at the northeast corner of Store Hellefiskebanke (Figure 3 in main report).

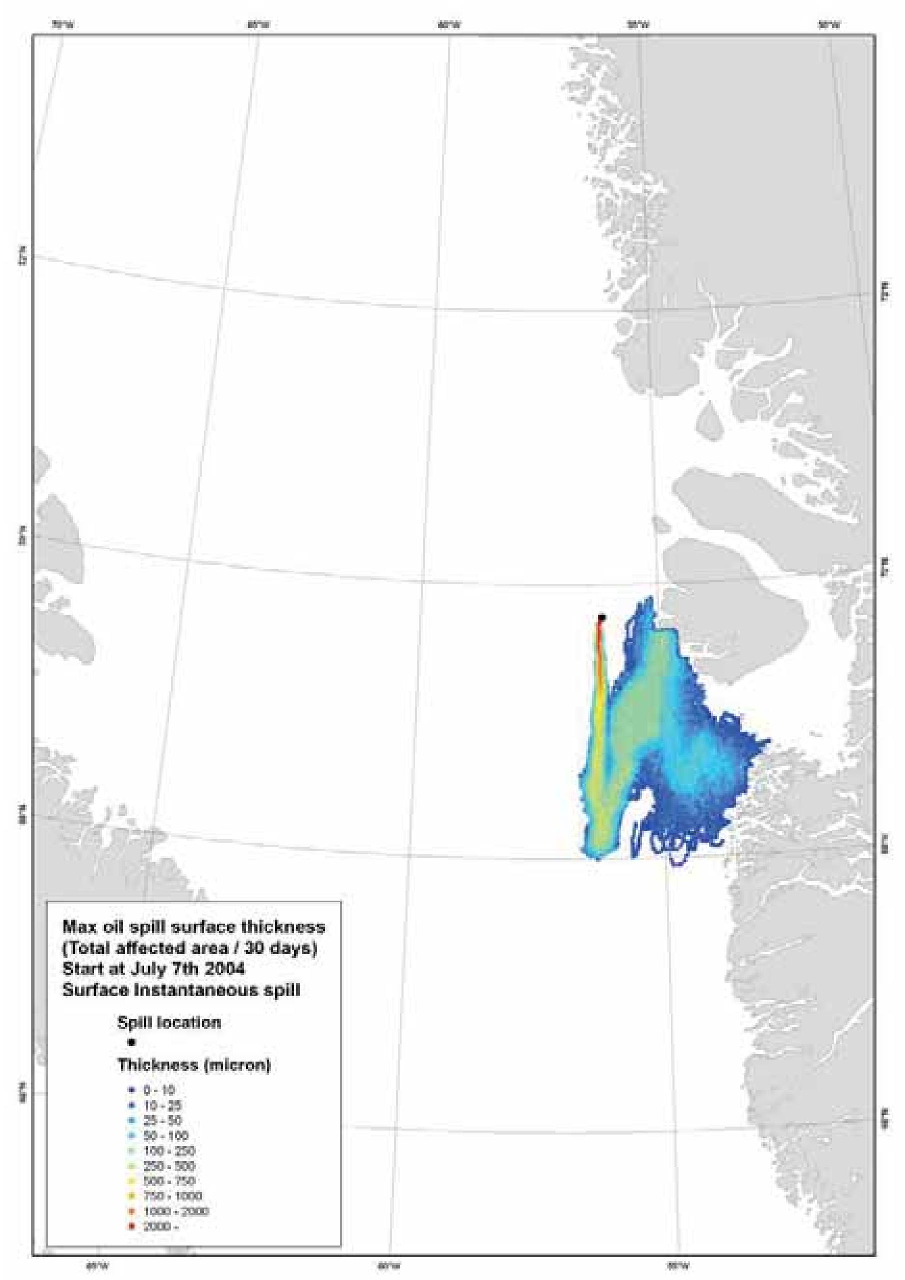
Shoreline sensitivity: The affected shorelines include all sensitivity classes, with shorelines with moderate sensitivity as the most frequent (Figure 57 in main report).

Offshore sensitivity: The affected offshore areas are classified as having extreme sensitivity to oil spills in the summer period (Figure 58 in main report).

Local use: Citizens from the towns of Qeqertarsuaq, Aasiaat and Kangaatsiaq and from the settlements of Kangerluk, Kitsissuarssuit, Niaqornaarsuk, Ikerasaarsuk, Iginniarfik and Attu all use the near shore parts of the affected region for fishing and hunting.

Commercial fisheries: Important fisheries for deep sea shrimp (annual average catch 1995-2004 was 3000 t) and snow crab (annual average catch 2002-2005 was 750 t) takes place almost throughout the region swept by the oil spill.

Figure 2. Spill scenario 1. This is part of Figure 39 in the DMI report (Nielsen at al. 2006), showing maximum surface layer thickness and entire area swept by an instantaneous oil spill at location 3 for wind period 1 (starting on July 7th 2004).



Impacts

Marine mammals: Low and reversible. The oil spill will not have any serious effects on the marine mammal populations, but the occurrence within the affected areas will be probably be reduced for some time.

Seabirds: High and for some species very slowly reversible. The important breeding colonies of Atlantic puffin and for some time razorbill in the outer Disko Bay (Brændevinsskær, Rotten) and along the coast south of Aasiaat will be impacted and a high proportion of the breeding adult birds will be exposed. There is a risk of complete extermination of these colonies. Other breeding birds in the affected area include fulmar, Iceland gull, kittiwake, great cormorant and arctic tern. These populations will also be impacted, but probably to a lower degree than the alcids. A high mortality among the great cormorants is expected, but this population has a high recovery potential. The moulting common eiders along the west coast of Disko will be impacted, but it is difficult to asses the numbers hit and killed by the oil. Particularly sensitive are the moulting harlequin ducks, which occur in dense flocks at some specific off-shore islands (e.g. Brændevinsskær). These flocks may be exterminated, and they probably represent all the males from the breeding population of a large region of northwest Greenland.

Fish: Medium and probably reversible. Capelin eggs and larvae may be affected in coastal waters and likewise will arctic chars that occur in the affected coastal waters will be exposed.

Benthic fauna: Potentially high. Impacts on coastal benthos communities will probably be an immediate reduction in diversity and a subsequent increase in abundance in opportunistic species. A recovery will depend on the degree of fouling, oil type and local conditions. There is a risk for fouling of the mussel beds, on which wintering and staging eider concentrations depend on.

Primary production and plankton (incl. fish and shrimp egg and larvae): Low and reversible. In general will the extensive vertical and horizontal distribution of plankton preclude high impacts. The most significant upwelling area in the region affected by the oil spill is more than 150 km away from the spill site. Here the layer of the oil on the surface will be less than 10 µm thick (Figure 2), which if all is mixed down into the water column below (to 10 meters depth) results in a concentration below the 90 ppb which is the Predicted No Effect Concentration (PNEC) applied in the Barents Sea (Johansen & Skognes 2003). In localised high concentration areas close to the spill site effects on the primary production and the plankton may occur, but on the broad scale these impacts will be low because of their small geographic extend and the movements of the oil. Therefore impacts on primary production and plankton in general must be assessed as low.

Shorelines: High. Extensive shore lines (estimated to more than 1500 km) risk contamination with oil from this spill, and it is estimated that 30 % of the oil will have settled on the coast after 30 days (Nielsen et al. 2006). Some of the coasts of southwest Disko are boulder coasts, where stranded oil may be caught for extensive periods.

Local use: High and reversible. The coastal fishery for Arctic char, blue mussel collection and hunting will be temporarily closed in order to avoid contamination of catches and consumption of contaminated products. See also Section 11.5.8 in main report.

Commercial fisheries: High and reversible. Although the populations of deep sea shrimp and snow crab will not be impacted, the fisheries for these species are at risk. If the fishing grounds swept by the spill are closed for two months (July and August) the in catches will be reduced with 16 % for shrimps and 19 % for snow crabs based on average annual catches (shrimps: 1995-2005 and crabs 2002-2005).

Long term effects

Oil trapped in boulder coasts may be preserved in a relatively fresh state for decades and will slowly be released to the environment causing a local chronic pollution (cf. Prince Williams Sound after the *Exxon Valdez* incident in 1989).

The recovery potential of the breeding populations of Atlantic puffin and razorbill is low in the affected region, due to decreasing numbers. Affected colonies will probably recover very slowly, if ever.

Summary for scenario 1

The impacts of an oil spill in the summer period from spill location 3 will be high if the oil moves as indicated by the DMI spill drift model (Figure 2). Most of the effects will be reversible, but for some specific coast types and some breeding colonies of seabirds effects probably will be apparent for decades.

Alternative drift pattern

If the oil spill in July is continuous instead of instantaneous, oil will also drift northwards and hit the coasts of northwest Disko and western Nuussuaq peninsula (Figure 3). The region northeast of the spill location is a very important moulting area for king eiders, and large concentrations will be exposed. There is a risk for substantial die-off, with long term effects on the population as the result. Long coast lines of western Disko and Nuussuaq will be contaminated with oil. The northwards drift of oil will also sweep the important deep sea shrimp fishing grounds at Hareø (cf. scenario 2). The effects of an oil spill with these characteristics will probably be more severe than for the instantaneous spill described in scenario 1.

Scenario 1 transposed to March

A much more sensitive period in this region is late winter and early spring. If the drift pattern for spilled oil at location 3 is transposed to March the risk of high impacts is much higher than in summer. This is due to the presence of large concentrations of wintering and migrating seabirds, mainly common and king eiders and thick-billed murres, to the presence of wintering marine mammals as bowhead whales, narwhals, white whales and walrus, to the longer coast lines (>1800 km) hit by the oil and because the oil may be trapped in bays and coasts where lumpsucker

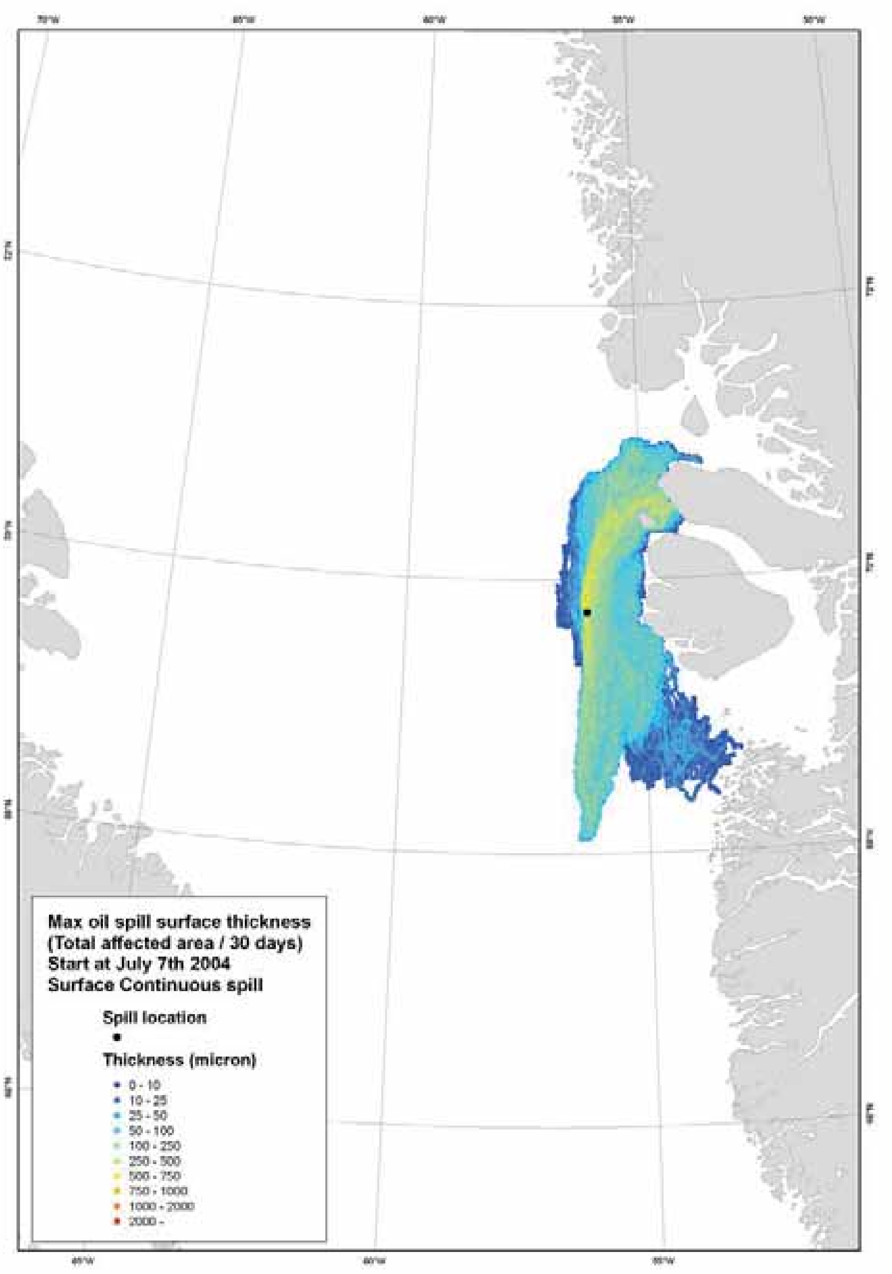


Figure 3. Spill scenario 1, alternative with a continuous spill. This is part of Figure 39 in the DMI report (Nielsen at al. 2006), showing maximum surface layer thickness and entire area swept by a continuous oil spill at location 3 for wind period 1.

and capelin spawn (and are fished) in the spring. However, ice will also limit the spreading of oil both by ice floes offshore and by land fast ice at the coast. Finally, the primary production spring bloom start in this period and the marginal ice zone is particularly sensitive in this respect. There is a risk for oil accumulation in this zone over long distances (particularly if the oil spill move as in Figure 3), with risk for impacts on both primary production and plankton. If the oil is spread over large areas as predicted (Figure 3), the amount per square unit will be low (a sheen or dispersed pieces of mousse) and therefore also the subsurface concentration will be low reducing the risk for impacts on both primary production and plankton.

Spill scenario 2

15,000 t oil is released instantaneously at spill site 6 in the mouth of Vaigat 11 km east of Hareø. Release date is August 13th and almost all oil settle quickly on the coasts of outer Vaigat and Hareø (Figure 4). The DMI model indicates that 67 % of the oil is settled on the coast after 10 days and 100 % after 30 days. The spill will affect app. 1500 km^2 sea surface and app. 150 km coastlines will probably be fouled with oil.

Figure 4. Spill scenario 2. This is part of Figure 48 in the DMI report (Nielsen at al. 2006), showing maximum surface layer thickness for an instantaneous and entire area swept by an oil spill at location 6 for wind period 2 (starting on August 13th 2004).

Resources at risk

Marine mammals: Harp seals and different whales occur in the area.

Seabirds: Several small seabird breeding colonies are found on the coast of Vaigat and Hareø. The most important is a kittiwake colony on the north coast of Disko Island where app. 100 pairs nested in 1994. At the time of the spill most of the breeding seabirds have fledged chicks and have left the area, and only small numbers will be exposed to the oil. Thick-billed murres on swimming migration pass rapidly through the Vaigat from late July and the major part is assessed to have passed through the spill site by early August (Box 6). However, in late breeding seasons the major part of the swimming migration may pass through the spill affected region simultaneously with the spill.

Fish: Arctic char occur along the coast.

Benthic fauna: The benthic communities have not been studied in the affected areas.

Primary production and plankton (incl. fish and shrimp egg and larvae): There are some significant upwelling areas at Hareø, and these will be impacted by the oil spill.

Shoreline sensitivity: Most of the affected shore lines of Vaigat are classified as having high sensitivity to oil spills. The shore lines of Hareø are classified as having low sensitivity (Figure 57 in main report).

Off-shore sensitivity: The outer Vaigat is classified as having high sensitivity to oil spills in August and September (Figure 58 in main report).

Local use: Citizens from the town of Qeqertarsuaq and from the settlements of Kangerluk, Qeqertaq and Saqqaq probably use the affected area for fishing and hunting, but to a limited degree, as the affected area is far from the settlements.

Commercial fisheries: Deep sea shrimp and snow crab are fished in the affected area, and particularly the shrimp fishery is important with annual average catches (1995-2004) of 11,000 t, while the crab fishery landed 30 t a year in 2002-2005.

Impacts

Marine mammals: Low, due to the limited spatial distribution of the spill and the probably low numbers of individuals present in the area.

Seabirds: Moderate to high. If the migration of thick-billed murres from the colony at Ritenbenk is timed as in 2005 and 2006 (Box 6) most of the birds have passed the affected area when the oil is spilled. However in late breeding season the migration may be delayed and may coincide with the spill.

Fish: Low, due to the small spatial distribution of the spill.

Benthic fauna: Potentially high. Impacts on coastal benthos communities will probably be an immediate reduction in diversity and a subsequent increase in abundance in opportunistic species. A recovery will depend on the degree of fouling, oil type and local conditions.

Primary production and plankton (incl. fish and shrimp egg and larvae): Probably low. Upwelling areas at Hareø will be affected by the spill, but due to their restricted spatial extend effects will probably be local and not significant on larger scale.

Shorelines: High, as the shorelines adjacent to the spill location will be heavily contaminated, and cleaning operations are probably extremely difficult.

Local use: Low, due to the long distance from towns and settlements.

Commercial use: High. If the fishery for deep sea shrimp and snow crab will be closed for two months, due to the contamination risk of catches, the catches of shrimp will be reduced with 17% and the catches of snow crab with 43% (based on annual average catches in respectively 1995-2004 and 2002-2005).

Long term effects

Oil caught in boulder beaches may be preserved and slowly released to the environment.

Summary for scenario 2

The impacts of an oil spill in the early autumn period from spill location 6 will be low to moderate and the spatial extend will restricted, if the oil moves as predicted by the DMI oil spill drift model (Figure 4). This is due to the limited extend of the spill and because most of the oil settle on the shores within a short period. The most sensitive seabird occurrences have left the area (unless the breeding season is delayed) and the most significant effects will be the closure of the shrimp fisheries in the waters around Hareø and heavy contamination of the shoreline habitats. There will be a risk for long term effects from stranded and preserved oil in boulder beaches.

Spill scenario 3

30,000 t oil is released continuously from a production site at site 5, 194 km west of Hareø and 36 km east of the Canadian border. Release date is Nov. 16th, and the oil drift towards north, east and south (Figure 5). The oil will enter Canadian waters and will not hit the coasts. The spill occurs when sea ice in Baffin Bay starts to form and there is a risk of entrapment of large amounts in the ice for later release during melt in spring. The affected area covers app. 22,000 km^2 if ice does not prevent the spreading of oil.

Resources at risk

Marine mammals: The affected area is an important winter habitat for narwhals, which arrive from October; most other marine mammals have left the affected area for the winter. Polar bears also occur, when ice is present and usually in late winter.

Seabirds: Substantial numbers of thick-billed murres migrate through the affected area during the autumn; however, most birds probably have passed through by mid-November. Fulmars also occur, but due to the late season probably in low numbers.

Fish: The most likely fish at risk in this region is polar cods living in the ice habitats. It is an ecological key species, being very numerous and constituting an important prey for whales, seals and seabirds (Box 1). The spawning period is winter and the eggs float under the ice.

Benthic fauna: The waters of the affected area are too deep for oil spill impacts on the benthos.

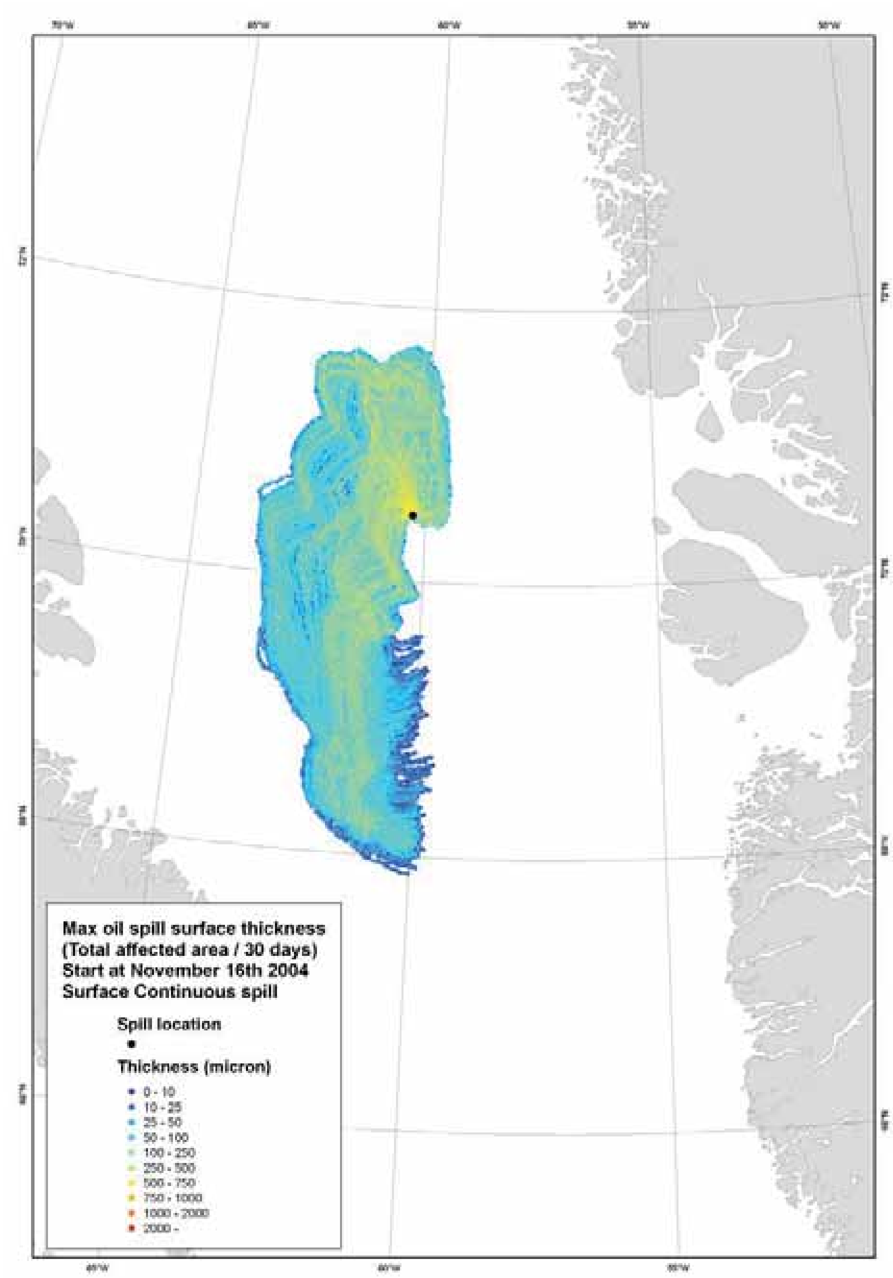


Figure 5. Spill scenario 3. This is part of Figure 46 in the DMI report (Nielsen at al. 2006), showing maximum surface layer thickness and entire area swept by a continuous oil spill at location 5 for wind period 3 (starting at November 16th 2004).

Primary production and plankton (incl. fish and shrimp egg and larvae): In winter there are low concentrations of plankton in the upper water columns and there is no primary production.

Shoreline sensitivity: The spill never reaches coasts.

Offshore sensitivity: In November and December the Greenland part of the affected area is classified as having high and moderate oil spill sensitivity (Figure 58 in main report).

Local use: There are no local use activities in the affected area due to the long distances from the coasts.

Commercial use: Greenland halibut is fished in the affected area, but this fishery have until now been carried out in the period July-October.

Impacts

Marine mammals: Probably low and reversible, but there is a concern for particularly narwhals. They are dependent on open waters for breathing. Discrete narwhal populations apparently winter in restricted areas where the number of breathing sites in cracks and lead in the dense drift ice can be few. If all these are covered with oil, whales are forced to inhale oil vapours when surfacing. Polar bear occurs in low densities, and some may be fouled with oil and subsequently die, but most likely in such small numbers that the population will not be affected.

Seabirds: Low impacts as most birds have left the affected area.

Fish: High impacts are possible, if the oil spread under the ice and if there are large stocks of spawning polar cod in the area. These may be impacted, particularly if the oil spill coincides with the spawning (occur in winter) and egg period, as both eggs and oil tend to accumulate under the ice. However, if the oil is released under ice, the affected area will be much more restricted than in Figure 5, because the roughness of the ice prevents spreading.

Benthic fauna: No impacts likely, due to the deep waters and as long as the oil stays on the surface.

Primary production and plankton (incl. fish and shrimp egg and larvae): Low and reversible, due to the season. However oil may become entrapped in the winter ice, and later released during spring e.g. at much more sensitive areas far from the spill location.

Shorelines: No impacts.

Local use: No impacts.

Commercial use: Low. The spill sweeps the offshore fishing grounds for Greenland halibut, and the fishery will be closed for November and perhaps again in May (oil released from the melting sea ice), in order to avoid contamination of catches. However, fishery is not possible in periods with ice cover, and the fishery has until now taken place in the period July-October, why effects of a closure period will most likely be negligible.

Long term effects

Probably none. But an increased mortality on discrete narwhal populations may have a long term effect as Greenland narwhal populations have suffered from unsustainable harvest.

Summary for scenario 3

The impacts of an oil spill in the early winter period from spill location 6 will be low if the oil moves as predicted by the DMI oil spill drift model (Figure 5). They will be so, mainly due to the far distances to coasts and to the season. However there is a risk of preservation, transportation and spring release of oil in much more sensitive areas such as the ice edge zone, and there is also a risk of long term impacts on narwhal populations.

Scenario 3 transposed to September

Other seasons in the affected area are much more sensitive than the early winter. In the autumn period, September and October, huge numbers of seabirds – mainly thick-billed murres and little auks move from breeding sites in North Greenland and Canada through Baffin Bay. As many as 100 million birds may perform this migration. The background studies (Box 1, Box 6) indicate that especially high numbers of thick-billed murres move through the assessment area, while the little auks move further west. Ivory gulls from the Arctic Canadian and northwest Greenland breeding populations may also perform an autumn migration through this region. Ivory gulls are not as sensitive to oil spills as alcids, but the concerned populations are severely decreasing and extra mortality on particularly adult birds may enhance this trend.

The Greenland halibut fishery takes place in the period July-October, and a two month closure of the fishery in this period will have a strong effect on the amount of landed catches. It is however not possible to estimate the reduction as the catch data are reported for 3 months periods.

Spill scenario 4

15,000 t oil is released instantaneously at spill site 2, 103 km southwest of Disko Island. Release date is January 3rd, and the oil drift towards north and south, and will not hit the coast (Figure 6). However, the model does not account for the presence of sea ice, which is abundant at this time of the year. If the oil is released under ice, the oil may be trapped and transported for long distances and released far from

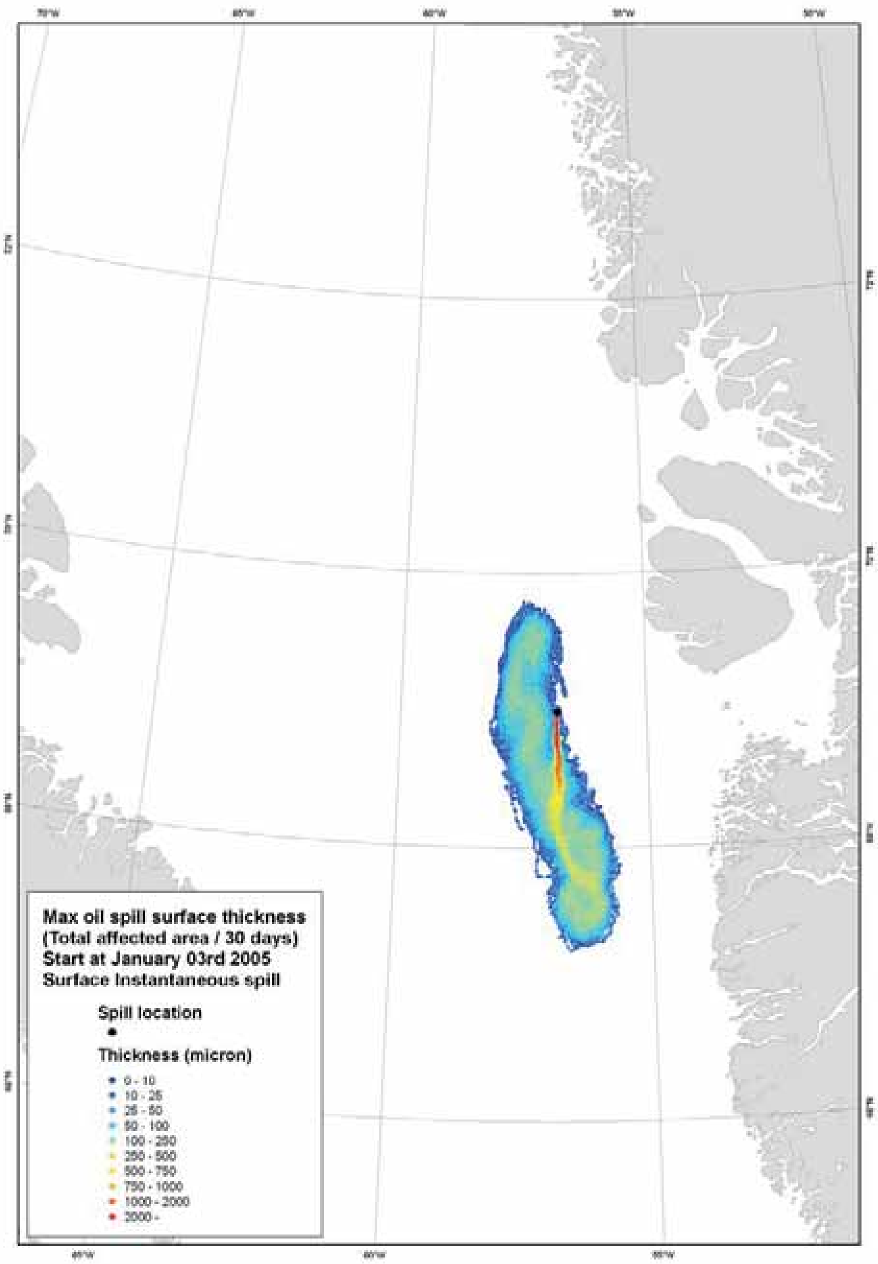


Figure 6. Spill scenario 4. This is part of Figure 37 in the DMI report (Nielsen at al. 2006), showing maximum surface layer thickness and entire area swept by an instantaneous oil spill at location 2 for wind period 4 (starting at January 3rd 2005).

the spill location when the ice melts in spring. Ice edges close to the spill location will also prevent spreading and will accumulate oil. The spill will affect app. 8,000 km^2 if ice does not prevent the spreading.

Resources at risk

Marine mammals: The spill area is habitat for wintering narwhals. The southern part of the affected area is also a very important winter habitat for walrus and bearded seal. When ice is present polar bears also occur.

Seabirds: Very few birds are present in the affected area during the winter, even if ice is absent. But the spill will approach a very important winter habitat for king eiders, where more than 400,000 birds representing almost the total flyway population may be present.

Fish: Possible polar cod in the ice habitats cf. scenario 3.

Benthic fauna: The waters of the affected area are too deep for oil spill impacts on the benthos.

Primary production and plankton (incl. fish and shrimp egg and larvae): None, at this time of the year.

Shoreline sensitivity: None, the oil will never settle on the coasts.

Offshore sensitivity: The affected areas are classified as having a high (northern part) and moderate (southern part) sensitivity to oil spills in winter, mainly due to the wintering narwhals (Figure 58 in main report).

Local use: Hunters primarily from Sisimiut, Attu, Aasiaat and Qeqertarsuaq hunt walrus in late winter in the affected area.

Commercial use: Important deep sea shrimp fisheries takes place in the affected area. The annual average catch in the area was in 1995-2004 app. 5000 t. However, in winter the fishery effort is relatively low due to the presence of sea ice.

Impacts

Marine mammals: Probably moderate. Oil spill impacts on narwhal populations are unknown, cf. scenario 3. Polar bears will also be exposed, but only few bears occur in the area and increased mortality among these will not affect the population as a whole. A very important winter habitat for walrus will be affected by the oil. In spring 2006, app. 400 walruses were estimated to stay on the ice in the region here (correcting for individuals in the water will perhaps double this figure). How these will respond to an oil spill is unknown. This population is subject to unsustainable hunting and their numbers are decreasing, why an oil spill may enhance this trend.

Seabirds: Low, due to the absence of seabirds. But if the oil moves along a slightly more south-easterly course a very important king eider habitat will be threatened, where high impacts are likely. A significant proportion of the population will be exposed to the oil and the recovery of a substantial die-off will probably take many years.

Fish: If the oil is released under ice with large numbers of spawning polar cod, high impacts are possible cf. scenario 3.

Benthic fauna: No impacts.

Primary production and plankton (incl. fish and shrimp egg and larvae): No impacts in winter, but there is a risk of impacts in spring if oil is transported and released during melt at the ice edge zone.

Shorelines: No impacts, as the spill will not settle on the coast.

Local use: Low impacts, which mainly will be a closure of the walrus hunting to avoid catches of contaminated animals.

Commercial fisheries: Low impacts, due to the low fishery effort when ice is present. A closure of the fishery in January and February means an average reduction in landings of 0.5 %. However if May also is closed due to release of oil from melting ice, the reduction in catches will increase to 13 % in the area swept by the oil spill (based on annual average catches 1995-2004).

Long term effects

Probably none, but narwhal populations may suffer from long term impacts cf. scenario 3. Effects on the walrus population cannot be excluded.

Summary for scenario 4

The impacts of an oil spill in mid-winter from spill location 6 will probably be low to moderate if the oil moves as predicted by the DMI oil spill model (Figure 6). They will be so, due to the season and the distance to the coasts. However, as impacts on marine mammals wintering in the affected area is not known there is a risk for more severe impacts. A slightly different trajectory of the spill will also increase the impact level to high, as this will affect the most important winter habitat for king eiders in Greenland, where almost the entire winter population often occur in the limited open water areas.

Spill scenario 5

15,000 t oil is released instantaneously at spill site 7, 10 km off the west coast of Disko Island. Release date is June 10th, and the oil drift towards south and east into the Disko Bay all the way to Ilulissat (Figure 7). App. 10,000 km^2 will be affected by the spill. Oil settles on the south and east coast of the bay and on the southwest coast of Disko and more than 1200 km coastline is exposed to the spill.

Resources at risk

Marine mammals: Minke, fin and humpback whales, harbour porpoises and seals, mainly harp seals.

Seabirds: Colonial breeding seabirds on the coast of Disko Island and on the many islands in Disko Bay. Particularly species at risk are great cormorants, Arctic terns, Atlantic puffins, little auks, razorbills, fulmars and Iceland gulls. The oil spill will not reach the breeding colony for thick-billed murres at Ritenbenk in inner Disko Bay, but will probably affect feeding areas for birds from this colony.

Fish: Capelin spawning along the coasts peak in mid June and lumpsucker spawning still occur in late June.

Benthic fauna: Generally have the West Greenland coast rich and diverse benthos communities (Box 3).

Primary production and plankton (incl. fish and shrimp egg and larvae): In July the spring bloom is over and high production and plankton concentrations may be found at hydrodynamic discontinuities (Söderkvist et al. 2006). The most con-

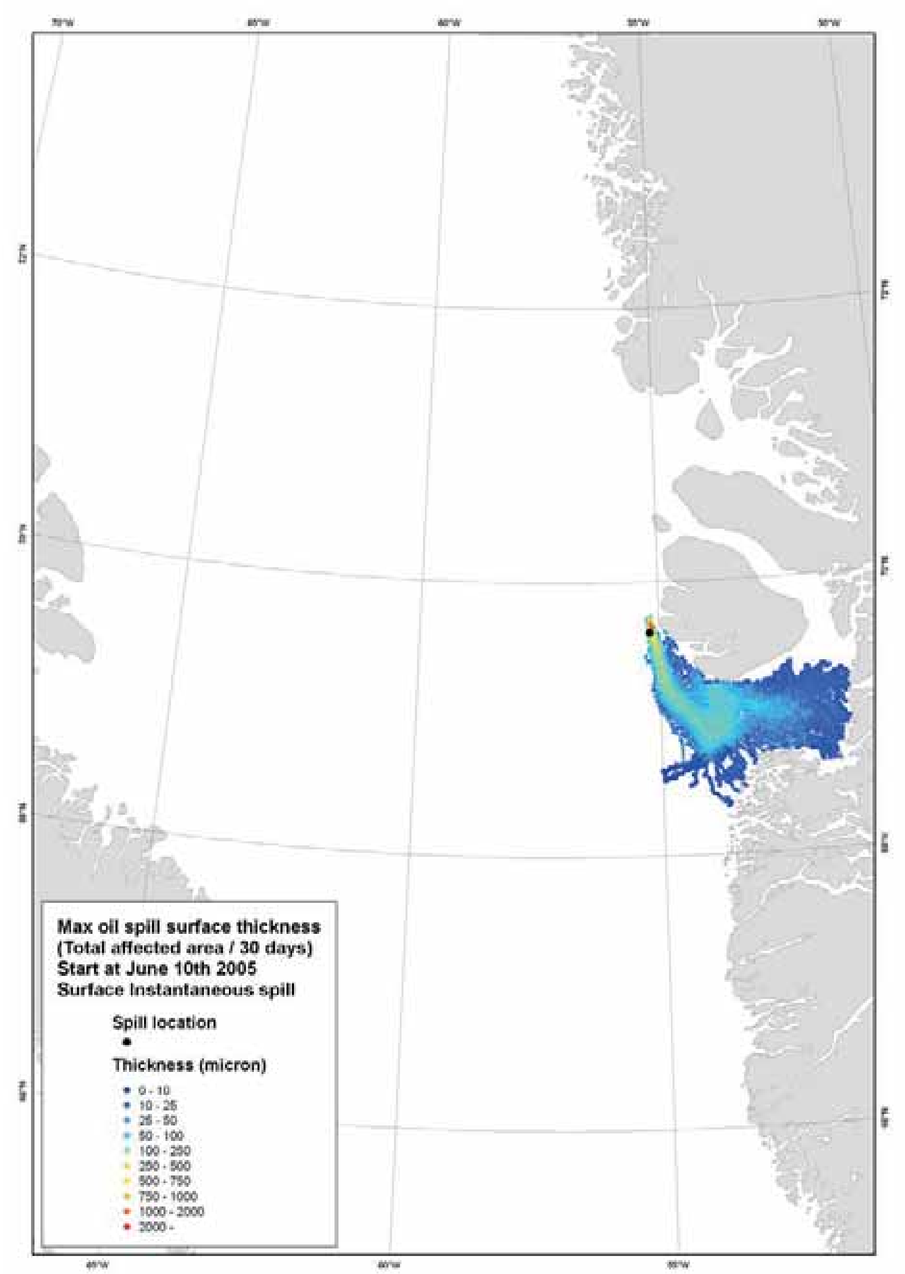


Figure 7. Spill scenario 5. This is part of Figure 53 in the DMI report (Nielsen at al. 2006), showing maximum surface layer thickness and entire area swept by an instantaneous oil spill at location 7 for wind period 5 (starting at June 10th 2005).

spicuous and predictable hydrodynamic discontinuity in the area affected by the oil spill are the upwelling area at the northeast corner of Store Hellefiskebanke some smaller upwelling areas in outer Disko Bay and off the mouth of the glacier fjord at Ilulissat.

Shoreline sensitivity: Most of the coastlines of the affected area are classified as having an extreme and high sensitivity to oil spills (Figure 57 in main report).

Offshore sensitivity: The affected offshore areas are classified as having an extreme sensitivity to oil spills in summer (Figure 58 in main report).

Local use: Citizens from the towns of Qeqertarsuaq, Aasiaat, Kangaatsiaq, Qasigiannguit and Ilulissat and from the settlements of Kangerluk, Kitsissuarsuit, Niaqornaarsuk, Ikerasaarsuk, Iginniarfik, Akunnaq, Ikamiut and Ilimanaq use the affected area for hunting and fishing.

Commercial use: Important fisheries for Greenland halibut off Ilulissat (annual catch in 2001 5500 t) and for deep sea shrimp (average annual catch 1995-2004 were app. 6000 t) and snow crab (annual average catches 2002-2005 were 550 t) in the Disko Bay.

Impacts

Marine mammals: Low, as no important concentrations areas are known and because seals and whales generally show low vulnerablity to oil spills.

Seabirds: High, as many breeding colonies will be affected and particularly the breeding sites for Atlantic puffin, razorbill and little auk are sensitive (cf. scenario 1). The breeding population of thick-billed murres will also be affected if the feeding areas are contaminated.

Fish: Moderate, as Arctic char may be contaminated by moving through oiled coastal waters.

Benthic fauna: Potentially high. Impacts on coastal benthos communities will probably be an immediate reduction in diversity and a subsequent increase in abundance in opportunistic species. A recovery will depend on the degree of fouling, oil type and local conditions. There is a risk for fouling of mussel beds.

Primary production and plankton (incl. fish and shrimp egg and larvae): Low and reversible. The spill occurs after the spring bloom, and generally is plankton widely dispersed both horizontally and vertically. The most significant primary production areas in the region affected by the oil spill are more than 130 km away from the spill site. This means that the oil is old and more or less weathered (less toxic), dispersed and very thin (less than 10 µm) resulting in very low concentrations (less than 90 ppb) in the upper water column when it hit the high-production areas (cf. scenario 1). Therefore impacts on primary production and plankton must be assessed as low. Higher impact on local upwelling phenomena and other discontinuities may occur, but these will be short lived due to their dynamic nature and the movements of the oil, and in the overall picture such impact will be low.

Shorelines: High impact as extensive shorelines will be contaminated.

Local use: High, as capelin, lumpsucker and Arctic char fisheries will be closed at contaminated coastlines and likewise blue mussel collection will be closed. Seal hunting probably also will be affected if seal abundance decrease at contaminated sites.

Commercial use: High. The shrimp fishery and snow crab fishery will be closed for at least two months and the same apply to the very important Greenland halibut fishery off Ilulissat. If the fishery is closed in June and July the reduction of shrimp catches will be 30% and the snow crab catches 31%. It is not possible to evaluate the reduction in the Greenland halibut fishery because the data are based on whole year landings, but it will be substantial.

Long term effects

Oil caught in boulder beaches may be preserved and slowly released to the environment.

Breeding colonies of Atlantic puffin and razorbill in the affected region have shown decreasing numbers in recent years, why increased mortality due to an oil spill may hamper recovery.

Summary for scenario 5

The impacts of an oil spill in mid-summer from spill location 7 will be high if the oil moves as predicted by the DMI oil spill model (Figure 7). This is because oil will contaminate long coastlines with local fishery, will hit important seabird breeding colonies in the most sensitive time of the year and because very important commercial fishery will be temporarily closed.

Spill scenario 6

30,000 t oil is released continuously at spill location 2, 103 km southwest of Disko Island. Initial release date is January 28th, and the oil drift towards north and north-west, and will not hit the coast (Figure 8). It will affect 25,000-30,000 km^2. However, the oil spill drift model does not take account for the presence of sea ice, which is abundant at this time of the year. If the oil is released under ice, the oil may be trapped and transported for long distances and released far from the spill location when the ice melts in spring. Dense ice usually occurs north and northwest of the spill site in winter, and this will prevent the spreading as shown in the model. The oil will therefore probably accumulate along the ice edge, in the lead systems, or spread to the adjacent coastal waters and coasts.

Resources at risk

Marine mammals: White whales, narwhals, walrus and polar bears occur in the affected area in winter.

Seabirds: Many wintering seabirds in the coastal leads west of Disko, but in the offshore areas very few birds occur.

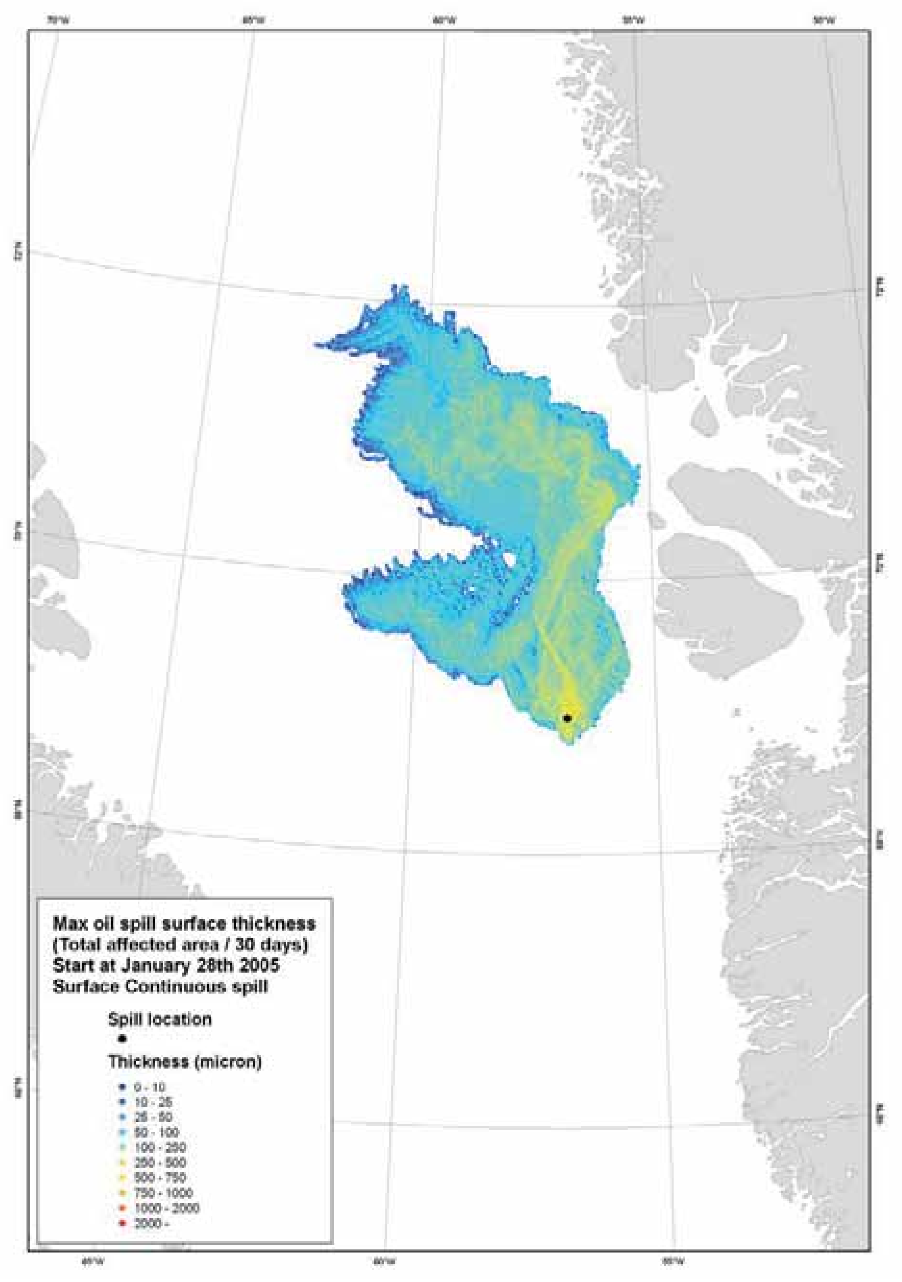


Figure 8. Spill scenario 6. This is part of Figure 38 in the DMI report (Nielsen at al. 2006), showing maximum surface layer thickness and entire area swept by a continuous oil spill at location 2 in wind period 6 (starting on January 28th 2005).

Fish: Polar cod living in the icy habitats cf. scenario 3.

Benthic fauna: Only if the oil moves towards the coast will benthic communities be at risk.

Primary production and plankton (incl. fish and shrimp egg and larvae): No production and very low plankton concentrations in winter.

Shoreline sensitivity: According to the oil spill model no oil will settle on the coast, but if the oil moves towards the coast of Disko, shorelines classified as having a moderate and extreme sensitivity to oil spill will be at risk (Figure 57 in main report).

Offshore sensitivity: In winter the affected waters close to the Greenland coast are classified as having extreme sensitivity to oil spills, while those further west are classified as having moderate sensitivity (Figure 58 in main report).

Local use: Citizens at least from Qeqertarsuaq, Uummannaq, Illorsuit, Niaqornat and Kangerluk may hunt narwhals, white whales and walrus in or close to the affected region.

Commercial use: Although the Greenland halibut fishing grounds will be hit, no fishery takes place in the winter months. If the oil spreads as the model indicates deep sea shrimp fishing grounds will only be hit marginally, and at a time of the year when no fishery takes place. However, if the oil is caught by an ice edge north of Disko, the important fishing grounds at Hareø may be affected if the oil moves more easterly, and here fishery takes place when ice conditions allows (cf. scenario 2).

Impacts
Marine mammals: Probably low to moderate, cf. scenario 3.

Seabirds: Low, as there are very few seabirds in the affected areas indicated by the model. However, if the oil drift is prevented by the ice and accumulates along ice edges and subsequently moves more easterly to the coastal leads along the Disko coast, high numbers of particularly common eiders may be exposed.

Fish: Impacts on polar cod living in the icy habitats are unknown, but may be locally high (cf. scenario 3).

Benthic fauna: No impacts if the oil spreads as in Figure 8, but if the oil moves to the shores of Disko high impacts must be expected.

Primary production and plankton (incl. fish and shrimp egg and larvae): Low impacts due to the season, but oil released in the marginal ice zone later during spring melt may impact primary production.

Shorelines: No impacts if the oil moves as shown in Figure 8, but high if it settles on the Disko coasts.

Local use: Low impacts, and mainly by a temporal closure of the hunt in order to avoid contaminated catches.

Commercial use: Low impacts due to the season.

Long term effects
Probably none as long as the oil stays offshore, but long term effects must be expected if the oils drift towards the west coast of Disko.

Summary for scenario 6

The impacts of an oil spill in mid-winter from spill location 2 will be low to moderate if the oil moves as predicted by DMI oil spill model (Figure 8), because of the season and the drift away from the coasts. However, ice may change the drift pattern considerably and oil may therefore be forced towards the coast or may be entrapped and later released at much more sensitive areas in the spring resulting in high impacts.

Scenario 6 transposed to August and September

Other seasons in the affected area are much more sensitive than the winter. In August and September thick-billed murres performing swimming migration accumulates in the waters west of Disko. These birds comprise the entire successful breeding population from the single breeding colony of the species in the Disko Bay region. The breeding population is app. 1300 indvs, and it has been decreasing during the recent decades. The proportion of pairs fledging chicks is unknown but is estimated at app. 75 %, resulting in a chick population of app. 1100. These are followed by one of the parent birds. The other parent bird stays at the nesting site for some time after the departure of the chick. This means that a substantial part of the breeding population and the breeding result of a season may be exposed to an oil spill with a drift pattern like the one in scenario 6. The studies presented in Box 6 indicate however, that the murres from the colony at Ritenbenk are spread over very large areas, reducing the risk of massive mortality. But extra mortality particularly on the adult birds is problematic for this colony because it will contribute to a further decrease in the breeding population. The commercial fisheries for Greenland halibut and deep sea shrimp will be much more impacted than in winter. The main part of the halibut fishery takes place in summer and autumn, and fisheries may be closed for months in order to avid contamination of catches.

Spill scenario 7

This scenario is based on the sea ice movements tracked by satellite in spring 2006. Two satellite transmitters were placed on the ice near spill site 4 (Figure 9). If 15,000 t of oil is released at spill site 4 (135 km west of Hareø and 98 km east of the Canadian border) in late April the oil will most likely accumulate below a dense ice cover with only small leads and cracks. How far it will spread below the ice is unknown and a.o. dependent on the roughness of the underside of the ice. The oil will move with the ice until release when the ice melts during May and June.

Resources at risk

Marine mammals: During April and May walrus, polar bear, bowhead whale, narwhal and white whale occur in the area and will initiate their spring migration towards the summer habitats in Canada. In June these species have left the area and in summer only few marine mammals are present in the area.

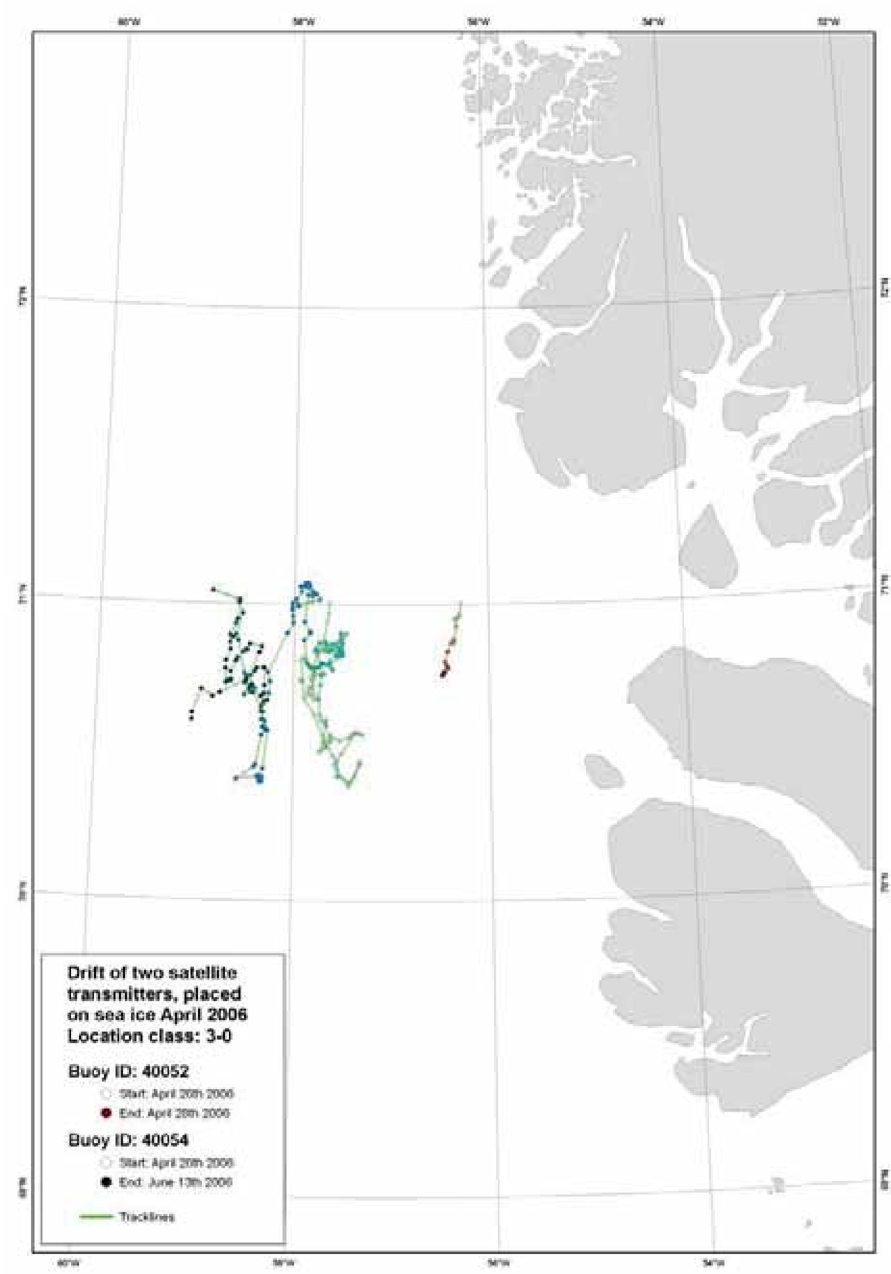
Seabirds: Very few in April and May. Migrating thick-billed murres will be present in leads throughout the area with increasing numbers through May. In June only fulmars and probably kittiwakes will be present in fair numbers.

Fish: The most likely fish at risk in this region is polar cods living in the ice habitats (cf. scenario 3).

Benthic fauna: None, if the oil stays offshore.

Primary production and plankton (incl. fish and shrimp egg and larvae): In spring primary production initiates under the ice and in the marginal ice zone.

Figure 9. Spill scenario 7. Drift pattern of two satellite transmitters placed on sea ice on April 27th 2006. One (ID 40052) stopped transmitting after 2 days when it had moved 21 km southwards. The other transmitter ID 40054)) was tracked until June 13th. The drift track is app. 500 km, but over all it moved 66 km towards southwest (Study carried out by DMI at the request of BMP).



Shoreline sensitivity: No shores will be affected.

Offshore sensitivity: The affected waters are classified as having moderate and high sensitivity in winter and spring.

Local use: Citizens at least from the town of Uummannaq and the settlements Niaqornat and Illorsuit may hunt marine mammals in the area although it is very far from the settlements, and ice – at least in April – prevents sailing.

Commercial use: The oil spill will sweep the offshore fishing grounds for Greenland halibut.

Impacts

Marine mammals: Probably low. Oil spill impacts on narwhals and white whales populations are unknown (cf. scenario 3). The same apply to walrus. Bowhead whales often feed in the surface and may get their baleen fouled with oil. The effect of such fouling is probably temporary and low.

Seabirds: Probably low to moderate, due to the scarcity of birds present in the affected region. During spring melt more seabirds may be present in the ice edge zone and may be exposed to the oil.

Fish: Impacts on polar cod living in the icy habitats are unknown, but may be high (cf. scenario 3).

Benthic fauna: No effects as long as the oil stay offshore.

Primary production and plankton (incl. fish and shrimp egg and larvae): Probably low. Spring bloom in and under the ice and in the marginal ice zone will be affected during spring, but to an unknown extend.

Shorelines: No effects as long as the oil stay offshore.

Local use: Low, but quarry species may be less abundant, and hunting may also be closed for a period to avoid intake of contaminated hunting products.

Commercial fisheries: Fishery for Greenland halibut will be closed for a period during the presence of oil. But a two months closure in May-June will have no effect, as the fishery usually starts in July.

Long term effects
Probably none as long as the oil stay offshore, but ice entrapped oil may be transported over long distances and released in coastal waters where the risk of long term effects is high.

Summary for scenario 7
The impacts of an oil spill in spring from spill location 4 will be most likely be low to moderate if the oil moves as indicated by the DMI oil spill model. They will be low because the oil never reaches coasts and only few individuals of birds and mammals will be exposed to the oil. However, effects on narwhals, white whales and walrus are possible and effects under the ice and in the marginal ice zone may also have the potential to cause effects on the primary production, polar cod stocks and other ice fauna.

References

APA 2003. Greenland offshore (West Disko) oil development feasibility assessment. – APA Petroleum Engineering Inc.

Johansen, Ø & Skognes, K. 2003. Utredning av helårs oljevirksomhet i området Lofoten – Barentshavet, uhellsutslipp av olje – konsekvenser i vannsøylen (ULB 7-c). – SINTEF, Trondheim.

Nielsen, J.W., Kliem, N. Jespersen, M. & Christensen B.M. 2006. Oil drift and fate modelling at Disko Bay. – Technical report 06-06, Danish Meteorological Institute, Copenhagen.

Ross, S.L. 1992: Evaluation of the behaviour and cleanup of offshore oil-well blowout spills in west Greenland. – S.L. Ross Ltd. 87 pp. + app.

Söderkvist, J., Nielsen, T.G. & Jespersen, M. 2006. Physical and biological oceanography in West Greenland waters with emphasis on shrimp and fish larvae distribution. – National Environmental Research Institute, Technical report 581.

DISKO WEST

A strategic environmental impact assessment of hydrocarbon activities

This report is a preliminary strategic environmental impact assessment of activities related to exploration, development and exploitation of oil in the waters of central West Greenland (67°-71° N), the Disko West area.

ISBN: 978-87-7156-029-9
ISSN: 2245-0203