DISKO WEST

– an updated strategic environmental impact assessment of oil and gas activities

Scientific Report from DCE – Danish Centre for Environment and Energy No. 438 2021

AARHUS UNIVERSITY
DCE – DANISH CENTRE FOR ENVIRONMENT AND ENERGY

DISKO WEST

– an updated strategic environmental impact assessment of oil and gas activities

Scientific Report from DCE – Danish Centre for Environment and Energy No. 438 2021

David Boertmann
Anders Mosbech

Dep. Bioscience, Aarhus University

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. 438
Title: Disko West – an updated strategic environmental impact assessment of oil and gas activities

Category.: Scientific advisory report

Editors and main authors: David Boertmann[1] & Anders Mosbech[1]

Contributing authors: Nanette Hammeken Arboe[2], Paul Batty[2], Martin E. Blicher[2], David Blockley[2], Erik W. Born[2], Tenna Boye[2], AnnDorte Burmeister[2], Helle T. Christensen[2], Daniel S. Clausen[1], Rune Dietz[1], Michael Dünweber[1], Janne Fritt-Rasmussen[1], Jørgen L.S. Hansen[1], Morten Hjorth[1], Teunis Jansen[2], Kasper L. Johansen[1], Alf B. Josefson[1], Thomas Juul-Pedersen[2], Mads Peter Heide-Jørgensen[2], Sanne Kjellerup[1], Diana Krawczyk[2], Kristin L. Laidre[2], Jannie Fries Linnebjerg[1], Flemming Merkel[2], Christian Mohn[1], Eva Friis Møller[1], Nynne H. Nielsen[2], Adriana Nogueira[2], Rasmus Nygaard[2], Josephine Nymand[2], Søren Post[2], Lars M. Rasmussen[2], Anja Retzel[2], Frank Rigét[1], Aqqalu Rosing-Asvid[2], Søren Rysgaard[1], Malene Simon[2], Dorte Søegaard Schrøder[2], Doris Schiedek[1], Mikael Sejr[1], Christian Sonne[1], Fernando Ugarte[2], Susse Wegeberg[1], Øystein Wiig (NHMO)

Institutions: [1]Dep. Bioscience, Aarhus University, [2]Greenland Institute of Natural Resources

Publisher: Aarhus University, DCE – Danish Centre for Environment and Energy ©
URL: http://dce.au.dk/en

Year of publication: 2021
Editing completed: 10 August 2021

Referees: Tom Christensen[1] (4 Protected areas and threatened species), Morten Frederiksen[1] (3.7 Seabirds), Kim Gustavson[1] (6 Review of petroleum activities and their environmental impacts, 7 Assessment, 8 Oil spill preparedness and response), Dorte Krause-Jensen[1] (3.3 Benthic flora), Lars Lund-Hansen AU (3.5 Sea ice ecology), John Mortensen[2] (2 Physical environment), Anders Mosbech[1] (5.1. Background levels of contaminants), Helle Buur Pedersen[1] (3.4 Benthic fauna), Helle Siegstad[2] (3.6 Fish and shellfish, 5.3.1 Commercial fisheries), Jakob Strand[1] (5.2 Plastic contamination), Outi Tervo[2] (3.8 Marine mammals, 5.3.4 Hunting of marine mammals), Mie Winding[2] (3.1 Primary productivity, 3.2 Zooplankton)

Quality assurance, DCE: Kirsten Bang
Greenlandic summary: Kelly Berthelsen
Reference list: Jonathan Stounberg
GIS: Georgina E. Scholes, Daniel S. Clausen, Kasper L. Johansen

Financial support: Greenland Government (Ministry for Industry, Energy, Research and Labour - MIERL and the Environmental Agency for Mineral Resource Activities – EAMRA)

Please cite as: Boertmann, D. & Mosbech, A. 2020. Disko West – an updated strategic environmental impact assessment of oil and gas activities. Scientific Report from DCE – Danish Centre for Environment and Energy No. 438, 384 pp. http://dce2.au.dk/pub/SR438.pdf

Abstract: This report is an updated strategic environmental impact assessment of activities related to exploration, development and exploitation of oil and gas in the sea west of central Greenland, between 67° and 72° N – the Disko West licencing round area. The previous version from 2013 needed an update before the area was openend for ‘open door’ applications in 2021. The report includes new research results from the area. The first part of the report gives an overview of the biology and ecology in the assessment area, followed by an evaluation of potential impacts from activities related to exploration and exploitation of oil and gas. Based on the presence of especially valuable (in an ecological sense), sensitive (to oil spills) coast lines and presence of sea ice in winter, the report recommends to consider not to open the Disko West assessment area for oil and gas activities within the present strategy period (2020-2024).

Keywords: Strategic environmental impact assessment, oil and gas exploration and exploitation, Davis Strait, Baffin Bay, Greenland
Layout: Tinna Christensen, Aarhus University, Silkeborg
Front page photo: Drift ice with some newly formed ice in Baffin Bay April 26, 2006; photo David Boertmann

ISBN: 978-87-7156-587-4
ISSN: 2245-0203

Number of pages: 384
Internet version: The report is available in electronic format (pdf) at http://dce2.au.dk/pub/SR438.pdf

Content

Preface

This report prepared by Danish Centre for Environment and Energy – DCE and Greenland Institute of Natural Resources was delivered in final draft to the Environmental Agency for Mineral Resources Activities by October 2020. The report conclude that if the high environmental Norwegian standards are applied in the assessment area, oil licensing should be avoided due to the environmental risk related to oil spills in sea ice. In June 2021, the new Greenland Government decided to abandon the current oil and gas strategy and a press release on July 15, 2021 announced to stop for issuing new oil licenses in Greenland.

The report is the second update of the strategic environmental impact assessment (SEIA) of oil and gas exploration and exploitation activities in the Disko West licence round area. The first edition was issued in 2006 in relation to the opening of the area for exploration and it was updated in 2013 in relation to a new licencing round. All exploration and exploitation licences in the Disko West licence round area have in recent years been handed back..

Summary and conclusions

This report is an update of a previous strategic environmental impact assessment of oil and gas activities in the waters off Disko Island in West Greenland (Boertmann et al. 2013). The covered area is termed as the Disko West assessment area and is situated between 67° N in the south and 72° N in the north and extends to the border of the *Exclusive Economic Zone* (EEZ) (Figure 1). The update is justified by the opening of the area for 'open door' applications in September 2020, however postponed to November 2020 due to the Corona situation.

The update is based on new research in the area and on all the new information from international literature on oil spill response, effects etc., which have been published since the previous edition, and of which much is from the *Exxon Valdez* and *Deepwater Horizon* incidents in the US in 1989 and 2010 respectively.

The report is prepared by DCE – Danish Center for Environment and Energy and Greenland Institute of Natural Resources (GINR), and funded by the Government of Greenland: The former Ministry of Industry, Energy, Science and Labour (today Ministry of Foreign Affairs and Energy) and the Environmental Agency for Mineral Resource Activities (EAMRA).

The purpose of an SEIA is to provide updated information to the political decision processes including the authority evaluation of applications and regulation of activities related to exploration and exploitation of oil and gas. However, the assessment do not assess the global climate impact of gasses released when potential oil and gas from Greenland fields is burned by consumers. The presented information is moreover available to the companies operating in Greenland, for example for the preparation of Environmental Impact Assessments of their activities.

This SEIA is part of a series of five SEIA's covering the waters off entire West Greenland and Northeast Greenland, and the SEIA covering the adjacent waters to the south – the Davis Strait area – is also under updating.

The SEIA describes the environment – the physical rather briefly – and the biological in more detail. It describes nature conservation, threatened species and the human use of the living resources. It also gives a summary of contaminant levels as far as they are known. Based on that information, the potential environmental impacts of oil and gas activities (incl. oil spills) in the region is assessed. Finally the report identify research needs to be addressed to improve the data base for environmental impact assessments, authority regulation oil spill response etc.

The different activities in a full life cycle of an oil field are briefly described and the environmental impacts of activities are as far as possible evaluated. However, as no oil have been exploited yet in Greenland and location of possible oil fields are unknown, it is difficult to evaluate effects and impacts from such activities, and the descriptions rely on experience from areas as similar as possible to the Greenland environment. These include the two large oil spills in the US (*Exxon Valdez* and *Deepwater Horizon*). The Norwegian SEIA of oil and gas activities in the Barents Sea (Anonymous 2003) and the Oil and Gas Assessment by Arctic Council (AMAP 2010).

Due to the sea ice and weather conditions, exploration activities generally will take place in summer and autumn (June to November), while production will be a year round activity.

The Environment

The assessment area is situated in the Arctic zone and has the typical arctic biological traits. That is a relatively low biodiversity, a food web with few levels and some areas with very high densities of organisms. The benthos communities are an exception, having a very high biodiversity. The in general low biodiversity is counteracted by some species being extremely abundant, some of these are key species in the ecology of the area, which means that the entire system is dependent of their presence. A characteristic trait is the high lipid content in many organisms. This may act as isolation towards the cold surroundings and also as energy reserve for periods when feeding is not possible. This high lipid content is significant in relation to contaminants in the environment, because many of these are lipophilic and can accumulate in the adipose tissues.

Overall, the assessment area is very rich in an Arctic biological/ecological context; the primary production in spring is high, the benthos communities are well developed and there are many seabirds and marine mammals.

Physical conditions

The physical conditions are briefly described with focus on oceanography and and ice condition. The assessment area is usually almost ice covered in winter and spring, and icebergs are numerous especially in Disko Bay.

There are open water areas along the coast in winter south of Disko Bay caused by strong tidal currents and offshore the drift ice is dynamic and open waters are found in cracks and leads. The open water areas in winter have high biological significance (seabirds and marine mammals) and are sensitive to oil spills and disturbing activities.

The shelf is wide, up to 120 km in the southern part of the assessment area. There is deep ocean to the west of the shelf and it is also traversed by deep troughs. Upwelling is strong along edges of the shelf, facilitating a high primary production, which supports the rich ecology.

Biology

The primary production in the assessment area is high in the spring especially along the marginal ice zone (MIZ), in the early ice free areas and along the shelf break, where it also continue into the summer facilitated by upwelling. Next level in the food web is the zooplankton, and among these, the large species of *Calanus* are very abundant. They are perennial and have a fixed annual cycle, where they in summer are in the surface waters and in winter in deep waters near the seabed. These *Calanus* species are key species as they are extremely important as food for larger zooplankton, fish, seabirds and baleen whales. Concentrations areas for the *Calanus* are important feeding areas for seabirds and bowhead whales and are located along the west side of Store Hellefiskebanke, on Disko Banke and in Disko Bay.

Macroalgae (kelp) is abundant along the coastline where hard substrate is present and they are found in waters as deep as 61 m. The marcoalgae forests are important as nursery ground for fish and as food for various organisms. In Disko Fjord, particularly a rare red algae is found on soft and muddy seabed. These are large loose-lying coralline red algae, rhodoliths, with diameters of up to 13 cm.

Since the previous edition of the SEIA, much new knowledge on seabed fauna (benthos) have been obtained in the assessment area by Greenland Institute of Natural Resources. The diversity is very high (900 species so far) and so is the variation between the benthic communities on the seabed. Species characterizing a seabed fauna vulnerable to deep sea trawling (VME's Vulnerable Marine Ecosystems, cf. FAO 2008) have been found several times, and recently a candidate for a VME area was located just south of the assessment area. VME's have been designated on the Canadian side of Davis Strait, and areas fulfilling the VME criteria may also be identified in the assessment area.

Regarding sea ice ecology, there is new knowledge available, both in more general terms and from the assessment area.

The fish fauna in the assessment area are dominated by demersal species, where Greenland halibut is found in deep waters on the continental slope and in fjords. It does not spawn inside the assessment area, and the population is recruited from areas outside by larvae transported by the currents. Sandeel are numerous on the banks, where it is an important food item (see Box 3). Sandeel spawn in summer in contrast to almost all other marine fish in Greenland waters, which spawn in winter and spring.

In coastal waters, two important species spawn in spring: Lumpsucker and capelin. The capelin is a key species, as it occurs in dense schools and is an important food item for both seabirds and marine mammals. Arctic char also occur in coastal waters in summer, while they move into rivers and lakes for the winter.

Another ecological key species is the polar cod, which mainly is found in the northern part of the assessment area, and which is a pelagic species associated with the sea ice especially in the first life stages.

Among large crustaceans, the northern shrimp and the snow crab are common in the assessment area and both are important fishery resources, the shrimp actually the most important in Greenland.

There are many seabirds in the assessment area, both winter and summer. Since the previous edition of the SEIA, new knowledge have been obtained by tracking the movements of individual birds. Especially from breeding sites outside the assessment area, studies have been carried out in the murre colony at Appat/Ritenbenk and an aerial survey of wintering seabirds was carried out in 2017.

In total, 16 species of seabirds breed on the coasts of the assessment area. Most of these are colonial, breeding on steep cliffs (bird cliffs) or on low islands (bird islands). There are several important seabird colonies in the assessment area: The most impressive is the bird cliff at Appat/Ritenbenk, where i.e. thick-billed murres and black-legged kittiwakes breed, the islands of Grønne Ejlande, with Greenland's largest colony of Arctic tern and several rare species such as red phalarope and Ross' gull. Several small island also hold colonies of Atlantic puffins. Some of the seabirds breeding in the area are included in the national red list of threatened species, and especially the population of thick-billed murres on the Appat cliff is decreasing.

The assessment area is also of importance to non-breeding populations of seabirds in the summer and autumn. Seaducks, especially males and nonbreeders assemble in remote fjords and bays to moult, and become flightless for a couple of weeks. King eiders are the most numerous, and these birds arrive from breeding sites in Arctic Canada. Also of red-breasted mergansers, long-tailed ducks and harlequin ducks assemble on specific moulting localities.

In winter seabirds are numerous in the open water areas and in some specific areas covered with drift ice. The most important species is the king eider, and around one million birds stay in the drift ice on the Store Hellefiskebanke in the winter. These are birds which breed in Arctic Canada. Other numerous species in winter include common eider and thick-billed murre.

In spring and autumn, high numbers of seabirds migrate through the assessment area, the most numerous are thick-billed murre, little auk, black-legged kittiwake and northern fulmar.

Among the marine mammals there are five species of seals, walrus, 14 species of whales and polar bear in the assessment area. Since the previous edition of this SEIA, new knowledge on polar bear population size and their utilization of the assessment area have been published. Also for walrus there is new information on use and population size, and for harp seal, hooded seal and several whales, new data on population size have been published.

Hooded seal and harp seal are common in the assessment area in the ice free period. They whelp outside the assessment area. Ring seal and bearded seal are also common and are present in the assessment area year round. The fifth seal is the harbour seal, which today is very rare.

The walrus have a very important winter habitat on Store Hellefiskebanke. This population spend the summer around Baffin Island in Canada, and the winter in the shallow areas (< 100 m) of Store Hellefiskebanke. The population here was recently estimated at 1400 individuals.

Three of the whales are "winter whales" occurring in the area from October to June. White whale (beluga) have a very important winter habitat on Store Hellefiskebanke. Narwhals arrive to Uummannaq Fjord and Disko Bay in the early winter. In the central Baffin Bay (in an area shared by Greenland and Canada) narwhals from Canadian and Greenland summer habitats spend the winter. This Baffin Bay concentration is probably the largest assembly of narwhals in the world. The third winter whale is the bowhead whale, which have an important spring habitat in the outer Disko Bay.

The "summer whales" include the large baleen whales (blue, fin, minke and humpback), sperm whale and several other toothed whales. Harbour porpoise occur year round in the ice free waters.

Polar bears are also associated to the winter ice, and are therefore most frequent in winter and spring. The majority of the bears in the assessment area belongs to the Baffin Bay population, which was estimated at 2800 individuals in 2017. Maternity dens have not been reported from assessment area.

Nature protection and threatened species

International designations

Six areas within the assessment area are designated as wetlands of international importance under the intergovernmental environmental treaty, the Convention on Wetlands (the Ramsar Convention). These areas are also known as Ramsar sites. Another international designation is the UNESCO World Heritage Site Ilulissat Icefjord.

Other international fora (Arctic Council, UNESCO, BirdLife International) have identified other types of important ecological areas within the assessment area, e.g. an area including Store Hellefiskebanke and Disko Bay.

National legislation

According to the Nature Protection Act, several areas are protected within the assessment area (Figure 59) and also seabird breeding colonies are protected from disturbing activities in the breeding season.

According to the act on raw materials some areas are identified as "important areas for wildlife" where activities in relation to mineral exploration are regulated, in order to minimise the disturbance on sensitive birds and mammals. These areas include for example the seabird breeding colonies. Offshore seismic surveys can also be regulated in certain areas to minimise impacts on narwhals and bowhead whales.

Threatened species

Greenland issued in 2018 a new updated and enlarged list of threatened species – a red list. According to this, eight species of mammals and eleven birds occurring in the assessment area are evaluated as Near Threatened (NT) and Threatened (VU, EN, CR) (Table 7). The international red list from IUCN classify eight marine mammals and five birds from the assessment area as Near Threatened and Threatened (Table 9).

Human impacts in the assessment area

The assessment area are impacted of several human activities and the SEIA gives a brief summary of some of these, as they can interact with the impact from oil and gas activities.

Long range contamination

The levels of heavy metals (primary mercury) and POP's (Persistent Organic Pollutants) are monitored coordinated by AMAP as they bio-accumulate in top predators including humans living from hunting and fishery. Especially mercury is a concern because the levels are relatively high and may increase in the assessment area. Lead have been decreasing and there are no temporal trend in Cadmium. The levels of POP's are expected to decrease due to international regulation, but new contaminants are emerging from the industrialized areas in Europe, North America and Asia, and they appear also in Greenland.

The most toxic substances in oil are the PAH's (Polycyclic Aromatic Hydrocarbons), but the levels are in general low in the assessment area, except close to harbours.

The most toxic substances in oil are the PAH's (Polycyclic Aromatic Hydrocarbons). The levels of PAH's are in general low in the assessment area, except for harbours.

Plastic

Contamination with plastic is increasing. Micro plastic (< 5 mm) has been found everywhere in the Arctic environment including plankton and whales. Macro (> 25 mm) and meso (5-25 mm) plastic have been found in the stomach of fish, birds and whales, and seals and whales become entangled in fishing gear made of plastic. The sources of especially macro and meso plastic in the assessment area are to a large degree local, but plastic are also transported to Greenland by the currents.

Other human activities

Important activities in the assessment area today include fishery – both commercial and on subsistence basis, hunting for birds and marine mammals, shipping and tourism. The impacts from these activities can interact with the impacts from oil and gas activities (cumulative impacts), and especially with the impacts from a large oil spill.

Climate change

The temperature increases more in the Arctic (incl. Greenland) than at lower latitudes. In the assessment area, the sea ice is under reduction both temporally and spatially. This impacts the life conditions for organisms associated the sea ice, with polar bear and ivory gull as the most prominent examples. On the other hand, will warmer waters and less ice improve the conditions for other species, such as many fish, minke whale and killer whale, which extend their ranges northwards. Increasing water temperatures also result in a shift of the large Arctic *Calanus* species with the less nutritious Atlantic *Calanus* species.

Extensive changes in the ecosystems of the assessment area are therefore expected in the near future. This will imply both negative and positive impacts on the local human societies, and it will also mean that the descriptions and evaluations of this report will be outdated. To follow the changes, monitoring of and research in the ecosystems of the assessment area will be an important input to future ecosystem based management of the human activities.

Cumulative impacts

When the impacts of oil and gas activities shall be assessed, it is important to include cumulative impacts. These occur both between oil and gas related activities (e.g. multiple seismic surveys either simultaneously or consecutive) and in combination with other human activities and climate change.

Assessment of oil and gas activities in the Disko West assessment area.

See Summary Table 1, for an overview of potential impacts of oil and gas activities in the assessment area.

Exploration activities

Exploration activities are temporary, will often be spread over the entire licence area and will in the assessment area take place in the ice free seasons (summer and autumn). If no viable finds are made, all activities will be terminated and equipment will be removed. Among the most significant impacts from exploration activities are disturbance for example from seismic surveys, drilling and transportation. Walrus, white whale and narwhal are particularly sensitive to disturbing and noisy activities, but as they are winter visitors to the assessment area there will be no or only a very short overlap with noisy exploration activities. A single seismic surveys will probably make whales like minke, fin and humpback to move out of the affected area while the survey takes place, while several surveys have the potential to cause more widespread and cumulative effects. 3D-seismic surveys, which are very intensive in restricted areas, will probably cause stronger effects, but more localised. Extensive seismic surveys may possibly also make Greenland halibut to leave the area, with reduced catches as a consequence. Studies of other fish species indicate that this effect is temporary, and during the seismic surveys in the early 2000s southwest of Disko, where a large part of the offshore fishery for this species takes place, no overall reduction in catches were recorded. Fish spawning areas and areas with high larvae concentrations are considered as vulnerable to seismic surveys. Most fish in the assessment area spawn before seismic season, high larvae concentrations are not known, why seismic surveys probably will not impact the fish stocks in the assessment area.

The seismic surveys are in Greenland regulated in order not to physically harm marine mammals. Protection zones for specific whale species (narwhal and bowhead whale) and walrus have been identified in the assessment area.

The noise from exploration drilling can disturb marine mammals (especially whales) on long ranges. Most whales will avoid affected areas and there is a risk for temporary displacement from important feeding grounds.

The other significant impact from exploration activities is the release of waste materials. This concerns especially drilling mud and drill cuttings. Water based drilling mud is usually released to the seabed together with the cuttings, while oil based mud due to environmental concerns is brought to land to be treated. Water based mud can be environmentally acceptable to release, as long as the added chemicals are not hazardous and the area is not especially sensitive to sedimentation. The effects from sedimentation on the seabed will be localised to the surroundings of the well, where the fauna will be buried in mud and cuttings. It is therefore important to place release sites where effects are low and for example not close cold water corals and sponge gardens.

Another release of concern are the greenhouse gasses from fuel combustion, which is considerable for the drilling of an exploration well. The three wells drilled in 2010 in the Disko West area increased the Greenland greenhouse gas contribution that year with 15%.

Development and production

It is difficult to assess impacts of development and production activities in the assessment area.

Several activities during the development and productions phases have the potential to cause severe impacts on the environment. However, these impacts can be mitigated through thorough planning based on background information from the local environment, application of HSE-procedures (Health, Safety and Environment) and BAT (Best Available Technique) and BEP (Best Environmental Practice) and finally secured by strict authority regulation. There is however, a general lack of knowledge on cumulative and long-term impacts for example from the release of produced water even when applying the before mentioned initiatives.

Produced water is by far the largest discharge to the environment, for example is the annual release on the Norwegian sector about 148 million m^3. Even though produced water is cleaned and meet international standards, concern for long-term effects in the marine environment have been expressed. For example may produced water in ice covered waters accumulate under the sea ice and here affect eggs and larvae of the ecological key species polar cod. The best way to mitigate such effects is a zero discharge policy, where the produced water is re-injected. Another large release is drill cuttings and drilling mud as a result of the drilling of numerous new wells. In these phases the releases to the seabed will be substantially larger than during the drilling of a single exploration well (see above), and the impacts on the seabed will be much more extensive.

Energy consumption during development and production is very high, and the establishment of an oil field in the assessment area will contribute significantly to the combined releases of greenhouse gasses from Greenland. For example do a large Norwegian field release almost three times as much than the current annual release in Greenland.

Placement of infrastructure and the related disturbance can impact marine mammals so they permanently avoid the surroundings of an oil field. This is probably most serious for narwhal, white whale, bowhead whale and walrus, while seals usually are much less sensitive. Likewise will sensitive seabed communities (such as VME's) be vulnerable to installation on the seabed – e.g. pipelines.

Infrastructure on land may cause aesthetical impacts, a factor to be aware of in relation to tourism.

Traffic between oil fields and land will be strongly intensified both with helicopters and ships. Especially helicopters have a high scaring potential, and the disturbance can be reduced by establishing fixed routes and flying altitudes.

The fishery near installations such as rigs and pipelines will be limited of protections zones, usually 500 m.

The intensive shipping at a producing oil field increases the risk of introducing non-native and invasive species (Aquatic Nuisance Species – ANS). This has so far been a minor problem in the Arctic, but climate change increase the risk, and it is important that the international rules (IMO) for treatment of ballast water will be followed.

Oil spill

A large oil spill is the most harmful incidents to the marine environment in relation to oil and gas exploration and exploitation. The sources of large oil spills are either loss of well control (blowout) or wreck of tanker ships. The probability of such an incident is low, and the global trend in spilled amounts of oil is decreasing. Nevertheless, the risk is evident and the environmental impacts from a large spill can be severe and long-lasting, particularly in an Arctic environment such as the assessment area, where the risk is increased mainly because of the presence of icebergs and winter ice.

Danish Meteorological Institute (DMI) modelled the drift from seven spill sites in the assessment area (Figure 92). The results showed that oil from spill sites near the coast could affect coastal areas, while oil from spill sites far from the coast remained offshore. Oil spills in coastal areas are usually considered as more harmful than offshore spills, because the oil tend to stay in bays and fjords and toxic concentration can reach the seabed and because the biodiversity is high and concentrations of organisms can be affected. The coastal environment is also important as hunting and fishing ground for the local citizens.

An oil spill in winter can be trapped in the sea ice and transported over long ranges without being degraded and therefore affect areas far from the spill site, although sea ice also can limit the spread acting as a barrier.

There are, in the assessment area, offshore areas very sensitive to oil spills. This apply to Store Hellefiskebanke, where king eiders (1 million birds in a restricted area) and walruses (from a small discrete stock) spend the winter in cracks and lead of the drift ice. Front zones and up-welling areas where the primary production is intensive, may also be offshore areas particularly sensitive to oil spills – especially if it is a subsea spill as at the *Deepwater Horizon* incident in 2010. A study modelling the oil concentrations in the water column over Store Hellefiskebanke, showed that toxic concentrations could cover as much as 30% of the bank area after a spill.

The report concludes that a large oil spill in the assessment area has the potential to impact the entire ecology in the area, but it will off course depend on oil type, spill site, weather conditions etc. In a worst case situation, effects will be long-term and most likely longer than after the *Exxon Valdez*-incident in 1989 in Alaska, because of the Arctic conditions. Local populations of seabirds and marine mammals will be reduced and fishery and hunting will be impossible for a period in areas hit by oil.

Among the fish, the Greenland halibut stock will probably not be affected by a large oil spill, due to the water depth, but the fishery for the species may be stopped for a period. In winter the polar cod can be affected if oil accumulate under the sea ice, where polar cod egg and larvae concentrate and a high mortality may occur. There are, however, no information on polar cod spawning areas available.

Seabirds are particularly vulnerable to oil spills on the surface, and many seabird concentrations in the assessment area will have increased mortality if hit by a large oil spill.

Also marine mammals can be affected by surface oil spills. Walrus is particularly vulnerable to direct oiling as a large fraction of the populations is assembled in a small area. Seals and whales are vulnerable to inhalation of oil vapours over an oiled surface, and where seals and whales (narwhals, white whales, walrus) forced to surface in oil covered waters in drift ice will be particular exposed. How large fractions of the populations which potentially would be affected is unknown.

Polar bears are vulnerable to direct oiling, because they may ingest oil from the fur when cleaning it and oil is toxic to them. They may also ingest oil from oil-contaminated prey, or become oiled when crossing open waters between ice floes.

Fishery and hunting can be affected when oil impacted areas are closed for these activities. Such closures have in other oil impacted areas lasted for several months and up to almost two years.

A blowout on the shelf/banks will result in oil on the sea surface, even if it is pouring out from the seabed. However, in the deep waters west of the shelf, there will be a risk of oil sequestered in the water column, like it happened during the *Deepwater Horizon* spill, and this may affect especially primary production and zooplankton.

See Summary table 1 for an overview of effects of oil spills in the assessment area.

Mitigation and oil spill response

Environmental impacts from oil and gas activities shall be mitigated by including detailed background knowledge on the environment in the planning of the activities. This shall be combined with BAT, BEP, international standards (e.g. OSPAR) and guidelines (Arctic Council) to ensure that pollution from discharges to sea and atmosphere are kept within acceptable limits and minimise the risk of accidents. The authority regulation of the activities shall also be based on detailed background knowledge, which allows for exchanging the precautionary principle with empirical knowledge to the benefit of both operators and the environment.

Oil spill contingency and response

Large oil spills shall be prevented by applying the highest health, safety and environmental standards (HSE) combined with the highest technical standards (BEP and BAT). However, the risk of oil spills is always present and a fast, robust and efficient oil spill response must be in place to counteract spilled oil. Three methods have been used to counter act oil spills. Mechanical recovery, chemical dispersion and in situ burning.

Mechanical recovery was not efficient during the two large oil spills in the US. The method is moreover difficult to apply in harsh weather conditions and when the oil is to be recovered from waters with ice. It is moreover labour demanding and requires extensive logistics.

Chemical dispersion requires fast response before the oil is too weathered to be dispersed. Ice and cold conditions can extend the operational window for dispersion. Dispersion transfer the oil from the surface to the water column, where it can affect organism, which would not be affected from surface oil. The different methods requires a comparative analysis of environmental pros and cons, a SIMA (Spill Impact Mitigation Assessment) before they can be applied. Dispersion will also facilitate natural degradation of the oil, which in Greenland waters, however, seems to be very slow, because of low nutrient availability.

In situ burning has proven promising under arctic conditions, where stable ice can act as barrier to oil on the surface. The method has however, only been tried under test conditions, and it is questionable if it can be applied in dynamic drift ice, such as the sea ice in the assessment area.

The three response methods has their own environmental impacts. Mechanical recovery can in coastal habitats impact flora and fauna, dispersing agents have their own toxic impacts and in situ burning sends large amounts of soot into the atmosphere and leaves residues on surface and seabed. These environmental impacts shall be weighed to the impacts from the oil itself, on a strategic level (Environment & Oil Spill Response tool, EOS), and in an operational situation by a SIMA.

DCE and Greenland Institute of Natural Resources' recommendations on area restrictions.

The DCE and GINR recommendations on area restrictions for oil exploration (hydrocarbon licenses) in the strategy period (2020-2024) are based on three selection criteria: 1) Areas already appointed as especially valuable areas on a national scale, in terms of ecological and biological value and sensitivity to oil spills, or new valuable and sensitive areas identified in this assessment, 2) the distance of a license area to the coast and the sensitivity of the coastline, because it is difficult to protect the coast in a nearshore spill and 3) the probability of ice, because effective oil spill methods in drift ice do not exist. Moreover have there been increased international concern for the environmental implications of oil industry activities in Arctic ice-covered waters.

In the Disko West assessment area the Store Hellefiskebanke/Disko Bay was selected as an especially valuable area on a national scale (Figure 95). DCE and GINR moreover recommend to consider a coastal protection zone corresponding to zone used in northern mainland Norway (35 km off the baseline, Figure 95). Concerning the ice cover, the entire assessment area are north of the Norwegian limits for opening for oil exploration (Figure 96).

On the basis of these three criteria (primarily 3/), the fact that there are no proven methods available for handling major oil spill in drift ice and in winter darkness, DCE/GINR recommend to consider not to open the Disko West assessment area for oil exploration in the present strategy period (2020-2024), to be in line with high international (primarily Norwegian) environmental standards.

Dansk resumé

Denne rapport er en opdatering af den strategiske miljøvurdering (SMV) af olieaktiviteter i Disko West-området udgivet i 2013 (Boertmann et al. 2013). Opdateringen er foretaget, fordi Disko West-området var planlagt åbnet for *open door*-ansøgninger[2] i september 2020 (udsat til november 2020 pga. corona-situationen) Opdateringen omfatter primært indarbejdning af nye forskningsresultater fra området, publiceret siden 2013 samt af nye data fra fiskeriundersøgelserne i Vestgrønland. Der publiceres desuden løbende nye resultater og analyser fra de to store amerikanske oliespild i Alaska i 1989 (*Exxon Valdez*) og i den Mexicanske Golf i 2010 (*Deepwater Horizon*), ligesom der er mange nye resultater fra mere generelle studier af effekterne af oliespild. Sådan nye viden er også inddraget.

Disko West-området omfatter havområdet ud til den grønlandske *Exclusive Economical Zone* (EEZ) og fra 67° N i syd til 72° N i nord (Figur 1).

Denne opdaterede version er udarbejdet af DCE – Nationalt Center for Miljø og Energi og Grønlands Naturinstitut og finansieret af det tidligere Departement for Erhverv, Energi, Forskning og Erhverv (nu Departementet for Udenrigsanliggender og Energiområdet) og af Miljøstyrelsen for Råstofområdet begge under Naalakkersuisut.

Formålet med strategiske miljøvurderinger er at bidrage til grundlaget for de politiske beslutningsprocesser, ved at gøre rede for den aktuelle viden, der måtte være relevant for som basis for både myndighedsbehandlingen af ansøgninger og for myndighedsreguleringen af aktiviteter i forbindelse med efterforskning og udvinding af olie og gas. Desuden står den beskrevne viden til rådighed for de selskaber, der skal udføre miljøvurdering af deres aktiviteter (VVM).

Området, som rapporten dækker kaldes generelt for vurderingsområdet (på engelsk *Disko West assessment area*). Hele det vestgrønlandske havområde og havet ud for Nordøstgrønland er beskrevet i fem strategiske miljøvurderinger, hvoraf den seneste er en opdatering af den, der dækker Grønlandshavet. Den strategiske miljøvurdering, der dækker Davis Strait (området syd for Disko West) opdateres samtidigt med nærværende.

Rapporten her beskriver det fysiske og biologiske miljø, inklusiv beskyttede områder, truede arter, niveauer af forurenende stoffer samt udnyttelse af de biologiske ressourcer. Baseret på disse beskrivelser af den nuværende situation, vurderes de potentielle miljømæssige konsekvenser af olieaktiviteter (herunder oliespild) i området. Endelig gives en oversigt over viden, der vil være nødvendig at tilvejebringe fremover som baggrundsviden til udarbejdelsen af miljøvurderinger, miljøafvejninger, myndighedsregulering af aktiviteter, udvikling af oliespildsberedskab m.m.

2 Ved open door kan selskaber til en hver tid søge om efterforsknings- og – udvindingstilladelser i det pågældende udbudsområde. Dette i modsætning til udbudsrunder, hvor selskaberne skal søge inden en fastsat dato.

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 og placeringen af mulige oliefelter ikke kendes, er det vanskeligt konkret at vurdere eventuelle påvirkninger, og beskrivelserne her bygger derfor på erfaringer fra andre områder med så vidt muligt sammenlignelige forhold. Der er især trukket på den meget omfangsrige litteratur om de store oliespild i USA i 1989 og 2010, den norske miljøvurdering af olieaktiviteter i Barentshavet (Anon. 2003) og på Arktisk Råds *Arctic Oil and Gas Assessment* (AMAP 2010).

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

Forklaring af termer benyttet i det følgende

Påvirkningsfaktorer eller presfaktorer (*Environmental pressures*). Er de menneskelige aktiviteter der påvirker omgivelserne. Det er f.eks. fiskeri og fangst, skibsfart eller minedrift og på større skala også klimaændringerne. Undertiden bruges ordet stressorer på dansk i denne sammenhæng.

Konsekvens af (*impact*). Bruges, som effekt, men i lidt bredere betydning, som f.eks. konsekvensen på miljøet ved brug af giftige borekemikalier. Effekt eller virkning af (*effect*). Bruges om virkningen af specifikke aktiviteter eller stoffer udledt til miljøet, som f.eks. giftpåvirkning af kemikalier i boremudder eller hvordan seismisk støj påvirker havpattedyr ved bortskræmning eller midlertidigt høretab.

Følsom (*sensitive*). Er de økologiske elementers (organismer, processer) naturlige reaktion på påvirkninger udefra. Narhvaler er f.eks. følsomme over for undervandsstøj. Se også sårbar nedenfor. Grænsen mellem følsom og sårbar er dog ikke skarp.

Sårbar (*vulnerable*). Dette begreb medtager også risikoen for at blive påvirket af menneskelige aktiviteter. F.eks. er narhvaler, på grund af deres følsomhed over for undervandsstøj, sårbare over for planlagte seismiske undersøgelser. Grænsen mellem følsom og sårbar er ikke skarp.

Miljørisiko (*Environmental risk*). Beskriver sandsynligheden for og konsekvenserne af en menneskelig påvirkning af miljøet, som f.eks. en efterforskningsboring.

Miljøet

Disko West-området er beliggende i den arktiske zone og har de for denne klimatiske zone karakteristiske biologiske træk. Dvs. forholdsvis lav biodiversitet, korte fødekæder og områder med meget høje koncentrationer af organismer. Havbundens dyreliv er dog en undtagelse, idet der her er en meget høj biodiversitet. Den generelt lave biodiversitet modsvares af, at visse arter er uhyre talrige, og nogle af disse er nøglearter i det økologiske 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 vigtige forekomster af både fugle og havpattedyr.

De fysiske forhold

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 åbent vand også om vinteren, på grund af stærk tidevandsstrøm, og disse åbenvandsområder er har stor betydning for biologien og er også meget følsomme overfor olieaktiviteter og oliespild. Vinterisen til havs er ikke tæt, og der er områder med revner, sprækker og våger. Disse har visse steder stor betydning for havfugle og havpattedyr.

Kontinentalsoklen med relativt lavvandede områder – banker – er bred, op til 120 km i den sydlige del af vurderingsområdet. Der er en skrænt ud mod det dybere hav og bankerne gennemskæres af dybe trug, som giver en varieret bundtopografi. Langs bankerne, især langs ydersiden, er der *upwelling* af næringsrigt vand, som skaber gode betingelser for primærproduktionen, og dermed for de økologiske sammenhænge på og omkring bankerne.

Biologi

Primærproduktionen (planteplankton) er i vurderingsområdet høj om foråret, særligt langs kanten af drivisen (*the marginal ice zone, MIZ*) og i de tidligt isfrie områder, men også senere på sommeren i områder med *upwelling*. Det næste trin i fødekæderne er dyreplankton, og her er de store vandlopper af slægten *Calanus* meget talrige. De er flerårige, har en fast årscyklus, hvor de om sommeren befinder sig i de øvre vandlag, hvor primærproduktionen foregår, og de søger mod dybere vand for at overvintre. Disse vandlopper er en vigtig fødekilde for fisk, havfugle og hvaler, hvorfor de betegnes som nøglearter i økosystemt. Områder, hvor vandlopperne koncentreres er vigtige fødesøgningsområder for havfugle og havpattedyr (Se Box 1). Sådanne områder er lokaliseret på vestsiderne af Store Hellefiskebanke og Disko Banke og i Disko Bugt.

Fiske- og rejelarver udgør også en del af dyreplanktonnet, og de spredes vidt omkring med havstrømmene.

Makroalgerne (tang) findes langs kystlinjen tilknyttet hård bund, og de forekommer ud til ca. 50 m dybde. For nylig blev de dog fundet på 61 m dybde ved Disko. 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. Desuden bidrager makroalgerne til det partikulære organiske stof i vandet, som er vigtig føde for mange bunddyr. Udover udstrakte 'skove' af store brunalger findes der en meget sjælden forekomst af løst liggende kalkrødalger, som former kugler på op til 13 cm i diameter på bunden af Disko Fjord. Biomassen og produktionen af makroalger kan være betydelig, og de er på mange måder vigtige for de højere led i fødekæden. Der er stadig mange uafklarede spørgsmål om algerne i vurderingsområdet.

Der foreligger megen ny viden omkring dyrelivet på havbunden, som stammer fra flere forskningsinitiativer fra Grønlands Naturinstitut. Vurderingsområdets bundfauna er særdels rig (900 arter er kendt) og meget varieret. Arter, som karakteriserer de såkaldte VME (Sårbare marine økosystemer – *Vulnerable Marine Ecosystems,* jf. FAO 2008) er fundet flere steder i vurderingsområdet, og for nylig er der fundet en VME-kandidat lige syd for vurderingsområdet. Der er desuden fundet tilsvarende VME'er på den canadiske side af Davis Stræde. Det må derfor forventes, at der også kan findes VME'er på havbunden indenfor vurderingsområdet.

Der foreligger tillige ny viden om det særlige liv i og omkring havisen, mest af generel karakter men også fra selve vurderingsområdet. Den foreliggende viden giver ikke mulighed for at udpege særligt sårbare områder.

Den foreliggende viden om fisk og større krebsdyr er opdateret med nye data omkring fiskeriet.

Fiskefaunaen i offshore områderne, inklusiv fiskebankerne (de lavvandede områder – ud til 200 m dybde - på kontinentalsoklen), er domineret af bundlevende arter, som hellefisk, helleflynder, rødfisk, havkat, grønlandshaj samt andre ikke-kommercielle arter. Den vigtigste fiskeart er 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 Davis Stræde driver ind og slår sig ned. Tobis forekommer i tætte stimer på fiskebankerne og udgør et vigtigt fødemne for visse fisk, havfugle og bardehvaler (se Box 3 om studier af denne fiskeart). Tobisen er den eneste fisk i offshore-områderne, 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 og havpattedyr og den er en udpræget nøgleart i økosystemet. Fjeldørred findes også i de kystnære farvande, og vandrer op i elve for at gyde og overvintre.

En anden økologisk nøgleart blandt fiskene er polartorsk, som især forekommer i vurderingsområdets nordlige del.

Blandt større krebsdyr er særligt dybvandsrejen talrig og vidt udbredt på dybder mellem 150 og 600 m, ligesom den store grønlandske krabbe er almindelig på blød bund på dybere vand. Rejen er Grønlands vigtigste ressource.

Ny viden om havfuglene i vurderingsområdet stammer især fra sporing af fugle fra ynglekolonier udenfor vurderingsområdet, fra studier på fuglefjeldet Appat ved Ritenbenk og en omfattende optælling af vinterfugle langs kysterne.

I alt 16 arter af havfugle yngler i området (Tabel 4). 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. På øgruppen Qeqertat (Schades Øer) i Uummannaq Fjord er der også en meget stor koloni af havterne. Flere af de i kolonierne ynglende arter, er på den grønlandske rødliste over truede arter (Tabel 7). Bestanden af ynglende polarlomvier på fuglefjeldet ved Ritenbenk er i alvorlig tilbagegang.

Vurderingsområdet er også vigtigt for ikke-ynglende vandfugle i sommer og efterårsperioden. Hanner af havdykænder samles i flokke omkring midsommer for at fælde fjerdragten, og de er i en periode ikke i stand til at flyve. Særligt kongeederfugle fra de canadiske ynglepladser forekommer i store antal i visse fjorde og kystområder, ligesom hanner af toppede skalleslugere, havlitter og strømænder også samles i flokke på særlige lokaliteter.

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 kongeederfuglen, idet op til en million fugle overvintrer her. Der er tale om fugle, som yngler i arktisk Canada, og som tilbringer vinteren i Vestgrønlandske farvande.

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

I vurderingsområdet forekommer fem arter af sæler, hvalros, 14 arter af hvaler samt isbjørn. Siden den forrige strategiske miljøvurdering fra dette område er der især fremkommet ny viden om isbjørn, dens bestandsstørrelse og udnyttelse af området, om forekomst og udnyttelse af hvalros om bestandsstørrelsen for klapmyds og grønlandssæl og bestandsstørrelser for flere hvalarter.

Både grønlandssæl og klapmyds forekommer talrigt i vurderingsområdet. De opholder sig her i åbentvandsperioden. De yngler udenfor vurderingsområdet i specifikke ynglefelter på havisen, hvor de samles i større koncentrationer. Ringsæl og remmesæl forekommer hele året og yngler spredt i vurderingsområdet. Spættet sæl er i dag meget fåtallig i vurderingsområdet.

Hvalros har et meget vigtigt vinterkvarter på Store Hellefiskebanke. Der er tale om en bestand, som om sommeren opholder sig ved Baffin Island. Om vinteren søger størstedelen af bestanden til det lave (under 100 m) vand på Store Hellefiskebanke. Vinterbestanden her blev i 2012 vurderet til ca. 1400 dyr.

Blandt hvalerne er der tre vinterhvaler, som alle er knyttet til havisen: Narhval, hvidhval og grønlandshval. Hvidhval har et vigtigt vinterområde på Store Hellefiskebanke, og narhvaler forekommer dels i Uummannaq Fjord og Disko Bugt tideligt på vinteren. I Baffin Bugts drivisområder overvintrer narhvaler fra alle de canadiske og nordvestgrønlandske sommeropholdssteder, og der er tale om den største forekomst af denne art på verdensplan. Den tredie vinterhval er grønlandshvalen, som har et vigtigt forårsopholdssted i den yder del af Disko Bugt. De øvrige hvaler: vågehval, finhval, pukkelhval m.fl. er sommergæster, som opholder sig udenfor vurderingsområdet i vinterperioden. Dog forekommer marsvin året rundt i isfrie farvande.

Isbjørnen er også knyttet til havisen, og optræder derfor hyppigst i vinter og forårsperioden. Bjørnene i vurderingsområdet hører til Baffin Bugt-bestanden, som blev opgjort til ca. 2800 bjørne i 2017. Dog forekommer enkelte bjørne fra nabobestanden i Davis Stræde også i vurderingsområdet. Bjørnene følger gennem året isens udbredelse og forekommer i hele vurderingsområdet, når isen er tilstede. Hi med ungefødende hunner er ikke kendt fra området.

Naturbeskyttelse og truede arter

Internationale udpegninger

I vurderingsområdet er der seks landområder udpeget som vådområder af international betydning jf. Konventionen om vådområder af international betydning ("Ramsar-konventionen"), og Jakobshavn Isfjord og omkringliggende landområder er optager på UNESCO's liste over verdensarv.

Forskellige andre internationale fora (Arktisk Råd, UNESCO, BirdLife International) har foreslået andre typer af vigtige økologiske områder indenfor vurderingsområdet. Blandt disse er et stort område, der omfatter Store Hellefiskebanke og Disko Bugt (Figur 59).

National lovgivning

I følge Naturfredningsloven er flere fredede områder udpeget indenfor vurderingsområdet (Figur 59) og ifølge fuglebeskyttelsesbekendtgørelsen er ynglekolonier af havfugle beskyttet, bl.a. med færdselsforbud i den tid fuglene er tilstede.

Ifølge Råstofloven er tillige en del områder ("vigtige områder for dyrelivet") udpeget, hvor råstofaktiviteter er reguleret med henblik på ikke at påvirke fugle og pattedyr. De omfatter f.eks. mange af de vigtige ynglekolonier for havfugle. I nogle vigtige områder for narhvaler vil seismiske undersøgelser også kunne reguleres med henblik på at begrænse påvirkningerne på hvalerne.

Truede arter

Grønland fik en ny national rødliste i 2018, og jf. denne kategoriseres otte arter af pattedyr og elleve fuglearter fra vurderingsområdet som næsten truede (NT) eller truede (VU, EN, CR) (Tabel 7). Den internationale rødliste udpeger otte havpattedyr og fem fugle fra vurderingsområdet som næsten truede eller truede.

Menneskelige påvirkningsfaktorer (presfaktorer) i vurderingsområdet

Vurderingsområdet påvirkes af mange forskellige menneskelige aktiviteter og rapporten gør kort rede for nogle af disse, idet de kan spille sammen med påvirkningerne fra olieaktiviteter.

Langtransporteret forurening

Indholdet af tungmetaller (primært kviksølv) og POP'er (*Persistent Organic Pollutants*) er generelt stigende i organismer i vurderingsområdet og de bioakkumuleres i fødekædernes toprovdyr og i mennesker, der lever af fangst og fiskeri. Især kviksølv giver anledning til bekymring. Indholdet af POP'er, der er reguleret internationalt, forventes dog at falde, men der dukker løbende nye forurenende stoffer fra industricentrene i Europa, Asien og Nordamerika op i de grønlandske organismer.

Fra olie er PAH'er (*Polycyclic Aromatic Hydrocarbon*) de mest giftige stoffer. Indholdet af PAH bundsedimenter i vurderingsområdet er generelt lavt, men forhøjet i havneområder og også i områder, hvor råolie formodes at sive ud i havmiljøet.

Plastikforurening

Plastikforurening er af stigende betydning og giver anledning til bekymring. Mikroplastik (<5 mm) er påvist overalt i det arktiske miljø og i talrige organismer fra plankton til hvaler. Macro- (>25 mm) og meso-plastik (5-25 mm) er også påvist i fordøjelseskanalen blandt fisk, fugle og havpattedyr, ligesom sæler og hvaler kan blive viklet ind i garnrester af plastik fra fiskeri. Kilderne til plastikforurening i Grønland og vurderingsområdet er for en stor del lokale, men plastik tilføres også med havstrømme udefra.

Andre menneskelige aktiviteter

Vigtige aktiviteter i vurderingsområdet omfatter fiskeri – både på kommercielt og på husholdningsniveau – fangst af havpattedyr og fugle samt turisme. Påvirkningerne fra disse vil kunne spille sammen med påvirkningerne fra olieaktiviteter, ligesom de vil blive påvirket af f. eks. et stort oliespild i området.

Klimaforandringer

Temperaturen i Arktis, herunder Grønland, stiger uforholdsmæssigt meget sammenlignet med områder på lavere breddegrader. I vurderingsområdet reduceres havisen i både udbredelse, tykkelse og den periode den forekommer i. Det medfører ændrede betingelser for det liv, som er knyttet til havisen med isbjørn og ismåge som eksempler på arter, der påvirkes negativt. På den anden side giver den reducerede havis mulighed for at andre arter (som vågehval og spækhugger) kan udvide deres udbredelse nordpå. Højere vandtemperaturer medfører også, at de vigtige arktiske vandlopper skiftes ud med den mindre næringsrige, atlantiske vandloppe.

Der forventes derfor væsentlige ændringer i vurderingsområdets økosystemer i de kommende år. Disse kan medføre både positive og negative forhold for samfundet, og vil også betyde, at denne rapports beskrivelser og konklusioner bliver uaktuelle med tiden. Derfor bliver overvågning af og forskning i vurderingsområdets økosystemer et vigtigt bidrag til fremtidens økosystembaserede forvaltning af de menneskelige aktiviteter i vurderingsområdet.

Kumulative påvirkninger

I forbindelse med vurdering af olieaktiviteters miljøpåvirkninger skal de kumulative effekter ikke glemmes. Det er de kombinerede effekter af alle menneskelige aktiviteter i tid og rum. De kan for eksempel være kraftigere end summen af de enkelte påvirkninger (synergistiske). Flere seismiske undersøgelser samtidigt eller efter hinanden eller udledning af produktionsvand fra mange produktionsbrønde vil for eksempel give anledning til kumulative effekter. Olieaktiviteter vil også kunne give anledning til kumulative effekter fra forstyrrelser eller oliespild sammen med for eksempel fangst.

Vurdering af olieaktiviteter i vurderingsområdet

Resumétabel 1 viser en oversigt over mulige påvirkninger fra olieaktiviteter i vurderingsområdet.

Efterforskningsaktiviteter

Efterforskningsaktiviteter er midlertidige, de varer typisk nogle år og vil for det meste være spredt ud over de tildelte licensområder. De udføres desuden kun i den isfrie periode, dvs. om sommeren og efteråret, formentlig i perioden juni til oktober. Hvis efterforskningen ikke påviser olie eller evt. gas, det kan betale sig at udvinde, vil aktiviteterne ophøre og alt udstyr fjernes. Findes der derimod olie, som efter en vurderingsperiode (*appraisal*) viser sig muligt at udnytte, vil aktiviteterne overgå til en udvikling af oliefeltet med afgrænsningsboringer og udbygning af faciliteter og derpå en egentlig udvinding af den fundne olie (se nedenfor).

Blandt de væsentligste påvirkninger fra efterforskningsaktiviteter er forstyrrelser fra støjende aktiviteter (f.eks. seismiske undersøgelser, boring og helikopterflyvning). I vurderingsområdet er særligt narhval, hvidhval og hvalros sårbare over for støj, men disse arter er vintergæster, og forekommer ikke i den isfrie periode, når efterforskningsaktiviteterne foregår. Der vil være en risiko for, at de havpattedyr som er i et undersøgelsesområde vil søge bort fra vigtige fødesøgningsområder og trækruter pga. forstyrrelserne fra seismiske undersøgelser. Det forventes dog, at påvirkningen fra en enkelt seismisk undersøgelse vil være midlertidig (uger til måneder), fordi aktiviteten er midlertidig. Men kumulative påvirkninger fra flere aktiviteter kan forstærke effekterne på dyrene. Dog kan de særlige 3D-seismiske undersøgelser, give anledning til kraftigere påvirkninger af hvaler, som våge-, pukkel- og finhval i mere afgrænsede områder. Intensive seismiske undersøgelser kan formentlig få hellefisk til at søge væk fra området med faldende fangster til følge i en periode. Undersøgelser af andre fiskearter tyder på, at denne påvirkning er midlertidig og erfaringer fra seismiske undersøgelser i farvandet sydvest for Disko i 2010erne viste at fiskeriet efter hellefisk i de samme områder overordnet set ikke blev påvirket. Gydeområder og områder med høje koncentrationer af fiskelarver er særligt følsomme overfor seismiske undersøgelser, dels fordi de gydende fisk kan blive skræmt væk dels fordi fiskelarverne slås ihjel inden for nogle meter af lydkilden. I vurderingsområder gyder de fleste fisk før seismiksæsonnen, der kendes ikke til steder med høje fiskelarvekoncentrationer og det forventes derfor, at seismiske undersøgelser ikke påvirker fiskebestandene i vurderingsområdet.

Seismiske undersøgelser i Grønland er underlagt regulering, som skal forebygge egentlige skader på havpattedyr (særligt hvaler), og der er udpeget en række beskyttelsesområder for narhval og grønlandshval for at begrænse forstyrrelser i vigtige områder.

Efterforskningsboring giver også anledning til støjende aktiviteter. Maskineri og skruer, der holder en flydende platform på plads (vandet er næsten overalt for dybt til, at man kan bruge borerigge, der står på bunden) frembringer kraftig støj. Støjen kan påvirke havpattedyr på store afstande, sådan at de søger væk fra lydkilden, og særligt hvaler er følsomme. Der er derfor risiko for at blå-, fin-, våge- og pukkelhval kan blive fortrængt fra vigtige områder i sommermånederne.

Ved en efterforskningsboring benyttes boremudder til at smøre boret, kontrollere trykket i borehullet og til at transportere det udborede materiale (borespåner) op til platformen. Er boremudderet vandbaseret udledes det ofte til havet efter endt boring, mens de oliebaserede typer, som er mere miljøskadelige, i dag normalt bringes til land for at blive behandlet eller deponeret under kontrollerede forhold. I Grønland er der hidtil kun benyttet vandbaseret boremudder(WBM), og det anses for miljømæssigt acceptabelt at udlede, hvis tilsætningsstofferne er miljøvenlige. Ved de tre boringer ud for Disko i 2010 blev der i alt udledt 6000 tons boremudder og 2261 m^3 borespåner. Der må tillige kun bruges de mere miljøvenlige ”grønne” og ”gule” tilsætnings-kemikalier (jvf. OSPARs klassifikation). ”Røde” og sorte” er ikke tilladte. Dog kan der gives tilladelse til ”røde” (som er svært nedbrydelige), hvis det kan godtgøres, at brugen bidrager til på anden vis at gøre en boring mere miljø-venlig. Dette svarer til reglerne for brug af borekemikalier i Norge. Det skal dog nævnes, at man tillige benytter oliebaseret boremudder (OBM) i Norge, men under betingelse af at det deponeres/behandles på land og dermed ikke udledes til havmiljøet. Brug af OBM er siden boringerne i 2010'erne blevet muligt i Grønland. Ved udledning af vandbaseret boremudder og borespåner er der en risiko for at dække bundfaunaen i nærheden af udledningsstedet ved sedimentation af materiale og forplumring af vandet. Det er vanskeligt at vurdere virkninger af udledning af boremudder og -spåner i vurderingsområdet. Men det forventes, at udledningerne fra en enkelt efterforskningsboring kun vil give minimale og lokale påvirkninger, hvis de mest miljøvenlige typer af boremudder benyttes. Men hvis der findes indikatorarter for såkaldte VME'er (*Vulnerable Marine Ecosystems*) i området, vil de være meget sårbare. Påvirkninger kan undgås ved at undlade at udlede boremudder og -spåner, men i stedet bringe det i land eller pumpe det tilbage i borehullet ved endt boring. Men dette giver også miljøpåvirkninger, som skal afvejes mod dem fra udledningen.

Endelig er efterforskningsboringer meget energikrævende, hvilket resulterer i store udslip af drivhusgasser. De tre boringer i 2010 ud for Disko forøgede det samlede grønlandske bidrag med 15 %. Den væsentligste risiko for miljøpåvirkninger under en efterforskningsboring opstår i forbindelse med uheld (*blowout*), som medfører et stort oliespild. De mulige følger af oliespild er omtalt nedenfor.

Udvikling og produktion

Det er flere grunde til at det er vanskeligt at vurdere miljøpåvirkningerne fra udvikling og produktion i vurderingsområdet. Der er ingen erfaringer med disse aktiviteter i Grønland. Det er heller ikke kendt hvor eventuel produktion skal foregå, ligesom omfanget og varigheden heller ikke er det. Endelig er de tekniske løsninger heller ikke kendt.

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

Produktionsvand (der pumpes op sammen med olien) udgør langt den største udledning til havmiljøet. Et oliefelt kan udlede op til 30.000 m^3 om dagen, og på årsbasis udledes der på den norske sokkel 148 millioner m^3. Der er i de senere år udtrykt en vis bekymring for udledning af produktionsvand, på trods af, at det er behandlet og overholder internationale miljøstandarder. Der knytter sig desuden specielle problemer til udledning af produktionsvand i et isdækket hav, der har reduceret opblanding i overfladelaget. Her kan f.eks.

æg og larver af polartorsk blive påvirket. Miljøproblemerne ved produktionsvand kan for eksempel undgås ved skærpede krav til indholdsstoffer eller endnu bedre ved at pumpe vandet tilbage i oliebrønden (*re-injection*).

Den anden store potentielle udledning omfatter boremudder og -spåner, da der skal bores intensivt under udvikling og produktion. Miljøpåvirkningerne for en enkelt efterforskningsboring er beskrevet ovenfor. Under udvikling og produktion vil de udledte mængder blive væsentlig større, med risiko for at større områder af havbunden påvirkes. Miljøpåvirkningerne fra boremudder og -spåner forebygges bedst ved at deponere begge dele på land eller i gamle borehuller.

Energiforbruget ved udvikling og produktion er meget stort, og anlægget af et stort oliefelt i vurderingsområdet vil bidrage meget væsentligt til Grønlands samlede udledning af drivhusgasser. F.eks. udleder et af de store norske oliefelter næsten tre gange så meget CO_2 som Grønlands samlede bidrag.

Selve placeringen af installationer og de forstyrrelser, der kommer fra disse, kan påvirke havpattedyr, sådan at de fortrænges permanent fra vigtige fourageringsområder eller således, at de ændrer trækruter. I vurderingsområdet er det især narhval, hvidhval, grønlandhval og hvalros, der er på tale i denne sammenhæng, og det kan ikke udelukkes at også fangsten på disse arter påvirkes.

Bunddyrsamfund vil også være sårbare over for placering af installationer på havbunden.

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

Trafikken til og fra et produktionsområde vil intensiveres med både skibe og helikoptere. Særligt helikoptere har potentiale til at bortskræmme både havfugle og havpattedyr fra vigtige områder. Dette imødegås bedst ved at flyve ad fastlagte ruter og i fastsatte højder.

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

Produceret olie skal transporteres bort med skib, som tømmer deres tanke for ballastvand inden de laster olie. Dette vil medføre en risiko for at indføre invasive, fremmede arter til det lokale havmiljø (dvs. at de breder sig på bekostning af lokale arter). Problemet har hidtil ikke været særligt stort i Arktis, men formodes at blive større som følge af klimaændringerne. Risikoen kan formindskes ved at følge de internationale regler for udpumpning og behandling af ballastvandet.

Oliespild

De mest alvorlige miljøpåvirkninger, der kan forekomme i forbindelse med olieefterforskning og-udvinding, er store oliespild. De forekommer enten fra udblæsninger (*blowouts*), hvor kontrollen med borehullet mistes, eller fra uheld i forbindelse med opbevaring og transport af olie, f.eks. ved forlis af tankskibe. Store oliespild forekommer meget sjældent i dag, fordi teknikken og sikkerhedsforanstaltningerne hele tiden forbedres. Men risikoen er til stede, og særligt i *frontier*-områder, som de grønlandske farvande med tilstedeværelsen af en særlig risikofaktor i form af isbjerge, er muligheden for uheld og ulykker forhøjet. AMAP (2010a) vurderer, at risikoen for oliespild i Arktis er størst i forbindelse med transport af olie.

Dansk Meteorologisk Institut (DMI) har modelleret drivbanerne for oliespild i vurderingsområdet med udgangspunkt i syv spildsteder med forskellig afstand til kysten (Figur 92 og Annex C). Fra de mere kystnære spildsteder når olien ind til kysten, mens olien fra de mere fjerntliggende spildsteder forbliver langt fra kysten. Oliespild i kystnære farvande regnes generelt som meget mere ødelæggende end oliespild på åbent hav. Det skyldes at olien her kan holdes tilbage i bugter og fjorde, hvor der forekommer tætte dyrebestande, og at giftige koncentrationer kan nå havbunden og her påvirke områder med høj biodiversitet. Der er også risiko for, at olie kan fanges i bundsedimenter eller på strande med rullesten, hvorfra olie langsomt kan frigives til det omgivende miljø med risiko for langtidsvirkninger f.eks. på fuglebestande som udnytter kysterne. Dette var tilfældet i Prince William Sund, hvor der stadig efter spildet i 1989 findes olie på sådanne steder. Mange kyster i vurderingsområdet er af samme beskaffenhed som i Prince William Sund. Endelig udnyttes de kystnære farvande i vurderingsområdet af lokale indbyggere til fangst og fiskeri, aktiviteter som kan blive påvirket af et oliespild. På åbent hav er fortyndingseffekten med til at mindske miljøeffekterne af et oliespild.

Et oliespild om vinteren kan fanges af havisen og blive transporteret over lange afstande uden, at den nedbrydes væsentligt og derved give anledning til påvirkninger langt fra spildstedet. Havis kan dog også medvirke til at begrænse et spilds udbredelse sammenlignet med et spild i isfrie farvande. Den foreliggende viden om oliespilds adfærd og skæbne i isdækkede farvande er dog begrænset.

I og nær vurderingsområdet er der områder langt fra kysten, som alligevel er særligt sårbare over for oliespild. Det er først og fremmest Store Hellefiskebanke, hvor der overvintrer kongeederfugle og hvalrosser. Frontzoner mellem vandmasser, *upwelling*-områder langs kontinentalskrænten, hvor primærproduktionen er særligt høj om foråret, og hvor høje koncentrationer af planktoniske alger og dyrisk plankton forekommer i den øvre del af vandsøjlen, kan også være sårbare overfor oliespild, især hvis der er tale om udslip fra havbunden, som ved *Deepwater Horizon*-ulykken in 2010. Et studie fra Store Hellefiskebanke (Wegeberg et al. 2016) viste, at der kunne forekomme giftige koncentrationer af olie i vandsøjlen i op til 30 % af området efter et spild.

Rapporten her konkluderer at følgerne af et stort oliespild der rammer kysterne i vurderingsområdet har potentiale til at påvirke hele økologien i området. Effekterne vil naturligvis afhænge af olie-typen, spildstedet og vejret. Men et i *worst case* tilfælde vil effekterne blive langvarige og formentlig længerevarende end i Alaska efter *Exxon Valdez*-ulykken i 1989, på grund af de arktiske forhold. Lokale bestande af fugle og havpattedyr vil blive reduceret og fangst og fiskeri vil blive umuliggjort i en periode i ramte områder.

Et oliespild vil næppe påvirke bestanden af hellefisk, men fiskeriet kan blive påvirket, fordi området kan blive lukket for fiskeri. Om vinteren er der risiko for at en økologisk nøgleart som polartorsk kan blive påvirket. Dens æg og larver samles under havisen, hvor også spildt olie vil ophobes, og i tilfælde af store koncentrationer af æg og larver må høj dødelig forventes. Men der er ikke viden om polartorskens gydeforhold i vurderingsområdet.

Fugle er særligt sårbare overfor oliespild på havoverfladen, og i vurderingsområdet er der mange sårbare fugleforekomster, som vil blive udsat for høj dødelighed, hvis de bliver ramt af et spild. F. eks. store ynglekolonier af polarlomvie og havterne, forårskoncentrationer af ederfugle og polarlomvier, vinterkoncentrationer af kongeederfugle og fældende havdykænder i sensommeren.

Havpattedyr kan påvirkes af oliespild på havoverfladen. I vurderingsområdet vil hvalros være særligt udsat, fordi hvalrosserne forekommer meget koncentreret omkring et enkelt vigtigt fødesøgningsområde. En stor andel af bestanden vil derfor kunne blive påvirket af et stort oliespild. Spækhuggere (og dermed formentlig også andre hvaler) viste sig efter *Exxon Valdez*-ulykken i 1989 at være sårbare over for indånding af oliedampe over et spild, et forhold som kan blive aktuelt ved oliespild i is (se nedenfor). Her vil narhvaler, hvidhvaler og grønlandshvaler være udsatte. Hvor store andele af bestandene, der vil kunne rammes af et stort oliespild er dog vanskeligt at vurdere. Isbjørne er specielt sårbare, fordi olien ødelægger pelsens isolerende effekt, og fordi de har en tendens til at rense olie af pelsen ved at slikke den ren og derved blive forgiftet af den indtagne olie.

Et oliespild i havområder med is vil formentlig samles i åbne revner og under isflager, hvor den kan påvirke de fugle og havpattedyr, der er afhængige af åbent vand. Sæler og hvaler kan blive tvunget til at søge til overfladen i de meget begrænsede åbenvandsområder, og hvis der er olie her, risikerer de at indånde oliedampe.

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

Hvis en *blowout* sker på bankerne vil olien samles på havoverfladen uanset om den evt. strømmer ud på havbunden. Men sker det på det dybe vand ud for bankerne, er der risiko for at den kan opføre sig som olien fra *Deepwater Horizon*-ulykken i den Mexicanske Golf. Her strømmede olien ud fra havbunden på meget stor dybde (ca. 1500 m). Det resulterede i dannelsen af store skyer af dispergeret olie nede i vandsøjlen. Olien forblev her og drev vidt omkring.

De arktiske forhold i vurderingsområdet med lave temperaturer, havis, vintermørke og ofte dårlige vejrforhold bidrager til, at spildt olie nedbrydes langsomt og dermed til at påvirkningerne i miljøet forlænges i forhold til sydligere beliggende områder. Dertil begrænses også mulighederne for at bekæmpe et oliespild, særligt om vinteren.

Se også Resumétabel 1 med en oversigt over aktiviteter og vurdering af deres påvirkninger.

Forebyggelse af påvirkninger

Miljøpåvirkninger fra olieefterforskning og -udvinding forebygges bedst ved at kombinere detaljeret baggrundsviden om det miljø der arbejdes i, med grundig planlægning af alle aktiviteter. Dertil skal BAT og BEP, brug af internationale standarder som f.eks. dem som OSPAR fastsætter og internationale vejledninger (fra f. eks. Arktisk Råd) sikre, at forurening fra udledninger til luft og hav bringes ned til acceptable niveauer og at risikoen for uheld minimeres.

Myndighedernes miljøreguleringen skal også bygge på detaljeret baggrundsviden, så den kan blive så præcis som mulig og ikke blot være begrundet af forsigtighedsprincippet. Reguleringen skal sikre, at selskaberne lever op til stillede krav og standart.

Beredskab og bekæmpelse

Oliespild skal først og fremmest undgås ved anvendelse af BAT og BEP, høje sikkerhedsstandarter og kvalificeret regulering. Men er uheldet ude, kan spildt olie bekæmpes på tre måder: Mekanisk opsamling, dispergering med kemiske midler og afbrænding.

Mekanisk opsamling har ikke været særligt effektiv ved de store amerikanske oliespild i 1989 og 2010, og vanskeliggøres tillige hvis der er is i det farvand, der arbejdes i. Den kræver også omfattende logistik. Metoden er mest anvendelig ved små spild.

Kemisk dispergering kræver tilsætning af dispergeringsmidler inden olien er forvitret for meget og her kan is og kolde forhold bidrage til, at det operationelle tidsvindue forlænges. Dispergering flytter olien fra havoverfladen til vandsøjlen, og den kan her påvirke andre organismer. Metoden kræver derfor en sammenlignende miljøafvejning (SIMA, *Spill Impact Mitigation Assessment*), før den evt. kan benyttes. Men den kan også fremme den naturlige nedbrydning ved, at olien findeles i vandet. Naturlig nedbrydning har vist sig at være begrænset i grønlandske farvande, fordi indholdet af næringsstoffer i vandet generelt er meget lavt, hvilket nedsætter mikroorganismernes aktivitet.

Afbrænding har vist sig lovende under arktiske forhold, hvor stabil is kan medvirke til at holde olien indespærret. Men det er hidtil kun prøvet som forsøg. Det er også tvivlsomt om metoden overhovedet kan benyttes i dynamisk drivis, som den forekommer i vurderingsområdet.

Endelig har metoderne til at bekæmpe oliespild deres egne miljøpåvirkninger. Mekanisk opsamling på kysterne kan være meget voldsom over for flora og fauna, dispergeringsmidler har deres egne giftvirkninger og afbrænding sender store mængder sod op i atmosfæren og danner reststoffer på vandoverfladen. Forhold, som er væsentlige at vurdere effekten af, dels på et strategisk niveau (*Environment & Oil Spill Response tool*, EOS), dels i en operativ situation ved en SIMA (*Spill Impact Mitigation Assessment*).

Resumétabel 1. Oversigt over påvirkninger og vurderinger af effekter. De væsentligste aktiviteter og deres miljøpåvirkninger er vist. Pot. = potentiel (mulig). Rumlig udbredelse: *Lokal* svarer til de umiddelbare omgivelser ved aktiviteten og det område der dækkes af projektet. *Regional* svarer til den region som projektet foregår i – i dette tilfælde vurderingsområdet. Varighed: *Kortvarig* er en kortere afgrænset periode – op til nogle få år – inden at de påvirkede elementer er reetableret. Det er typisk for efterforskningsaktiviteter. *Langvarig* svarer til en længere periode og undertiden meget længere, som f.eks. den tid et produktionsfelt virker og potentielt for altid. Grad af påvirkning: *Lav* svarer til påvirkninger der ikke kan måles kort efter en aktivitet er ophørt og uden at der er opstået økologiske ændringer. *Middel* svarer til påvirkninger i lokalområdet, som kan være længe om at vende tilbage til den oprindelige tilstand, men som på grund af den begrænsede udbredelse ikke medfører væsentlige økologiske konsekvenser. *Høj* er når bestande reduceres i antal, deres reetablering forsinkes eller hvis grænseværdier for forurenende stoffer overskrides væsentligt gennem længere tid i et større område. *Ekstrem* svarer til påvirkninger på økosystemniveau, hvor mange elementer påvirkes, herunder også de økosystemtjenester som lokalbefolkningen er afhængige af.

Påvirkning	Kilde	Konsekvens	Projektfase	Rumlig udbredelse	Varighed	Sårbare elementer (VEC)	Grad af påvirkning	Bemærkning
Undervandsstøj	Seismiske undersøgelser, skibsfart	Bortskræmning af havpattedyr og fisk	Efterforskning	Regional	Kortvarig	Narhval, grønlandshval, hvidhval, hvalros, fiskeri	Pot. høj	Tilbagegang i bestande er mulige, hvis vigtige fødesøgnings- eller gydeområder forlades. Fiskeriet vil formentlig kun blive påvirket midlertidigt. Ved flere seismiske undersøgelser i samme område er der risiko for kumulative påvirkninger
			Produktion	Lokal	Langvarig			
Udledning af boremudder og borespåner	Boreskibe og -platforme	Sedimentation, opslemmet materiale, giftige kemikalier	Alle	Lokal	Langvarig	Havbundsdyr	Pot. middel	Der er risiko for kumulative påvirkninger ved flere boringer i samme område
Produktionsvand	Produktionsplatforme	Forurening	Produktion	Regional	Langvarig	Æg og larver af polartorsk, hotspots for primær produktion	Pot. høj	Der er risko for kumulative påvirkninger i tilfælde af udledning fra flere platforme
Invasive arter	Skibe	Fordrivelse af hjemmehørende arter	Alle	Regional	Langvarig	Økosystemet	Pot. middel	
Spildevand	Platforme og skibe	Gødningseffekt, kemisk forurening	Efterforskning	Lokal	Kortvarig	Økosystemet	Lav	Der er risko for kumulative påvirkninger i tilfælde af udledning fra flere platforme
			Produktion	Lokal/regional	Langvarig	Økosystemet	Pot. middel	
Udslip af drivhusgasser	Forbrug af brændstof	Klimaændringer	Efterforskning	Global	Langvarig	Det arktiske økosystem		
			Produktion	Global	Long-term			
Anlæg og bygninger	Anlæg på land og til havs (havbunden)	Tab af levesteder, dannelse af nye levesteder, æstetiske hensyn	Efterforskning	Lokal	Kortvarig	Sjældne arter med begrænset udbredelse, rige bunddyrsamfund	Lav	Eksempler på særlig sårbare forekomster: Rige bunddyrsamfund, elve med opgang af fjeldørred, sjældne planter med begrænset udbredelse, trawlfiskeri
			Produktion	Lokal	Langvarig		Pot. høj	
Transport	Skibe, fastvingefly, helikoptere	Forstyrrelse/ fordrivelse af dyr	Efterforskning	Lokal	Kortvarig	Hvalros, fældende gæs og ænder, ynglekolonier for havfugle	Lav	
			Produktion	Regional	Langvarig		Pot. høj	
Færdsel af mennesker	Primært ved installationer i land	Forstyrrelse/ fordrivelse af dyr	Efterforskning	Lokal	Kortvarig	Fældende gæs og ænder, ynglekolonier for havfugle, i land rensdyr	Lav	
			Produktion	Lokal	Langvarig		Pot. høj	
Stort oliespild	Uheld med skibe og rørledninger, blowouts fra oliebrønde ved overfladen eller havbunden	Tilsøling, forgiftning, direkte dødelighed, sublethale effekter	Boring og transport	Regional	Langvarig	Hele økosystemet, særligt sårbare er havfugle, bunddyr og fisk der gyder på lavt vand	Pot. extrem	

DCE og Grønlands Naturinstituts anbefalinger vedr. områdebegrænsninger

DCE og Grønlands Naturinstitut anbefalede i bidraget til den nye strategi om olieaktiviteter i Grønland 2020-2024 (Mosbech et al. 2019), at fortsætte med at anvende de højeste standarter omkring sikkerhed og oliespildsberedskab. Det blev også beskrevet, hvordan det endnu ikke er muligt at bekæmpe oliespild i farvande med drivis og vintermørke (som i vurderingsområdet om vinteren). Dette medfører, at der skal en væsentlig teknisk udvikling af disse metoder til, før det er miljømæssigt forsvarligt at eftersøge og udnytte olie i de grønlandske farvande hele året rundt.

Det blev desuden anbefalet at friholde nogle særligt økologisk vigtige områder for olieefterforskning, herunder området der dækker Disko Bugt og Store Hellefiskebanke (Figur 95).

I samme bidrag anbefalede DCE og Grønlands Naturinstitut også fokus på kysterne, fordi de er særligt sårbare overfor oliespild.

Endelig er der problemet med at bekæmpe oliespild i farvande med is. Efterforskning kan foretages i isfrie perioder, men udvinding vil foregå også i perioder med is. Ved at acceptere efterforskning i havområder, der er isdækkede om vinteren, vil man alligevel have bekæmpelsesproblemet foran sig.

Særligt iskantzonen er biologisk generelt meget rig sent på vinteren og om foråret med høj primær produktion, fiskelarver, havfugle og havpattedyr.

Der er stigende international bekymring over efterforskning i havområder med is på grund af problemerne med at bekæmpe oliespild på isdækkede havoverflader, og kun Rusland har i dag udvinding i deres arktiske farvande.

Der er for tiden lukket for efterforskning i de arktiske havområder ved Alaska.

Europaparlamentet har i 2017 udtrykt stor bekymring omkring boringer i "icy Arctic waters" og efterlyser et forbud (Link).

I Canada anbefaler Nunavut Impact Board at forlænge det stop for olieefterforskning, der er i Davis Stræde og Baffin Bugt med 10 år (NIRB 2019a).

I Norge besluttede Stortinget (Klima- og Miljødepartementet 2020) at fastlægge nordgrænsen for olieefterforskning ved en grænse defineret ved tilstedeværelse af is i 15 % af dagene i april (måneden med størst isdække). Den var tidligere 30 % og derfor placeret nordligere. Men den videnskabelige anbefaling fra Norsk Polarinstitutt og Havforskningsinstituttet i Bergen var, at grænsen burde være ved 0,5 % af dagene. Hvis disse grænser anlægges i de grønlandske farvande (dog i marts og ikke april, fordi marts er den måned med størst isdække i Davis Stræde og Baffin Bugt) ses det, at begge grænser ligger syd for Disko West vurderingsområdet (Figur 96).

Der er både ligheder og forskelle i økologi mellem Barentshavet og farvandet vest for Grønland, og for eksempel er iskantzonen i Vestgrønland formentlig ikke af så stor betydning som i Barentshavet.

Endelig er kystzonen i Nordnorge friholdt for olieefterforskning ud til 35 km og ved særligt følsomme områder ud til 65 km på grund af denne zones særlige sårbarhed overfor oliespild. Følges denne praksis i Disko West vurderingsområdet, vil der langs hele kysten ud mod Davis Stræde og Baffin Bugt skulle anlægges en 35 km friholdelseszone (Figur 95).

På baggrund af tre kriterier – 1/ vigtige økologiske områder, 2/ sårbare kyster og 3/ is om vinteren – og for at være på linje med de højeste internationale miljøstandarter (særligt de norske) anbefaler DCE og Grønlands Naturinstitut, at det overvejes ikke at åbne Disko West vurderingsområdet for olie- og gas aktiviteter i den løbende strategiperiode 2020-2024.

Imaqarniliaq

Nalunaarusiaq manna Qeqertarsuup kitaani uuliaqarneranik misissuinermut atatillugu avatangiisinik naliliinermik periusissiorfiusumik 2013-imi saqqummersumik nutarterineruvoq (Boertmann et al. 2013). Qeqertarsuup kitaata 2020-imi septembarimi ammasumik qinnuteqartitsinernut (*open door*)[3] ammaanneqarnera nutarterinermut pissutaavoq (Coronamik nappaalasoqarnera pissutigalugu novembari 2020-imut kinguartinneqartoq). Nutarterutaasut annermik tassaapput tamaani ilisimatusarnermi paasisat nutaat 2013-imiilli saqqummersinneqartarsimasut kiisalu Kalaallit Nunaata Kitaani aalisarnermik misissuinermit paasissutissat nutaat. Ilanngullugittaaq saqqummersinneqarput Amerikami uuliamik maqisoornerujussuarnit marlunnit, tassa Alaskami 1989-mi (*Exxon Valdez*) kiisalu Mexicop Kangerliumanersuani 2010-mit (*Deepwater Horizon*) pisunit paasisat misissoqqissaakkallu nutaat, taamattaarlu uuliaarluernerup kinguneri pillugit misissuinernit paasisat nutaat amerlaqisut ilanngussorneqarput. Taamaalilluni ilisimasat nutaattaaq ilanngussorneqarput.

Qeqertarsuup Kitaani sumiiffimmut ilaapput imartaq avammut aningaasarsiornikkut oqartussaaffimmut killeqartoq *Exclusive Economical Zone* (EEZ) kiisalu kujammut avannarpasissuseq 68° avannamullu avannarpasissusermut 72° killeqartoq (Assiliartaliussaq 1).

Suliarinera nutartigaq manna suliarineqarpoq Danmarkimi Avatangiisinik Nukissiutinillu Misissuisoqarfimmit kiisalu Pinngortitaleriffimmit, aningaasalersorneqarlunilu siusinnerusukkut Inuussutissarsiornermut, Nukissiuteqarnermut, Ilisimatusarnermut Ilisimatusarnermullu Naalakkersuisoqarfiusimasunit (maanna Nunanut allanut Nukissiuteqarnermullu Naalakkersuisoqarfinngorsimasumit) kiisalu Avatangiisinik Aqutsisoqarfimmit, tamarmik Naalakkersuisut ataaniittunit.

Periusissiorfiusumik avatangiisinik naliliinermi siunertaasoq tassaasarpoq ilaatigut naalakkersuinikkut aalajangiiniarnermut tapertaassalluni, kiisalu qinnuteqaatit oqartussanit suliarineqarnerini taavalu uuliaqarneranik gasseqarneranillu misissueqqissaarnermi qalluinermilu oqartussanit malittarisassaqartitsinermi ilisimasat tunngavigineqartut suuneri nassuiassallugit. Ilisimasallu nassuiarneqartut ingerlatseqatigiiffinnut suliaminnut atatillugu avatangiisinik naliliiniartunut (ASN) pissarsiarineqarsinnaanngortinneqartarput.

Sumiiffik nalunaarusiornermi pineqartoq ataatsimut naliliiviimmik matumani taaneqartassaaq (tuluttut *Disko West assessment area*). Kalaallit Nunaata Kitaata imartaa tamarmi kiisalu Tunup avannaata imartaa avatangiisinik naliliinerni periusissiorfiusuni tallimani allaaserineqarput, taakkunanngalu nutartigaq kingulleq Tunup avannaata imartaanut tunngasuuvoq. Periusissiorfiusumik avatangiisinik naliliineq Davis Strædimut tunngasoq (Qeqertarsuup Kitaata kujataani sumiiffik) matumunnga peqatigillugu suliarineqarpoq.

Nalunaarusiami matumani allaaserineqarput avatangiisit pissusii tassanilu uumassusillit, aamma sumiiffiit illersugaasut, uumasut navianartorsiortitaasut, sananeqaatit mingutsitsisuusut annertussusii kiisalu pisuussutit uumassusillit atorneqarnerat. Pissutsit atuuttut allaaserineqarnerat tunngavigalugu tamaani uuliaqarneranik misissuinerit (soorlu uuliamik maqisoornerit) avatangiisinut sunniutigisinnaasaat naliliivigineqarput. Kiisalu avatangiisinik naliliinermi, avatangiisitigut oqimaalutaanermi, suliat pillugit oqartussat malittarisassaqartitsineranni, uuliaarluernermut upalungaarsimanermik ineriartortitsinermi allanilu ilisimasat pisariaqartinneqartussat takussutissiorneqarput.

Uuliasiorfiup aallaqqaataaniit naggataanut ingerlasarnera naatsumik oqaluttuarineqarpoq ajornannginneralu naapertorlugu suliat pisullu misilittakkat naapertorlugit avatangiisinut sunniuteqarnerpaajusartut pingaarnerutillugit naliliivigineqarlutik. Kisiannili uuliamik qalluineq Kalaallit Nunaanni misilittagaqarfigineqanngimmat uuliasiorfiliarineqarsinnaasullu sumiissusii ilisimaneqanngimmata sunniutaajunnartut aalajangersimasumik naliliivigissallugit ajornakusoorpoq, taamaammat sumi allami

3 Open door atorneqartillugu sumiiffimmi neqeroorutitsiviusumi ingerlatseqatigiiffiit misissueqqissaarnermut qalluinermullu qaqugukkulluunniit qinnuteqarsinnaatitaasarput. Paarlattua tassaavoq neqerooruteqartitsineq, tassa ingerlatseqatigiiffiit ulloq taasaq nallertinangu qinnuteqartussaatitaasarnerat.

sanilliunneqarsinnaasunik avatangiiseqarfiusumi misilittakkat aallaavigalugit nassuiaasiortoqarpoq. Pingaartumik USA-mi uuliaarluernerujussuit 1989 aamma 2010-imi pisut pillugit allaaserisarpassuit tigusiffigineqartarput kiisalu Barentshavimi uuliasiornerni norgemiut avatangiisinik naliliisarneri (Anon. 2003) taavalu Arktisk Råds *Arctic Oil and Gas Assessment* (AMAP 2010) tigulaariffigineqartarlutik.

Sila taavalu ukiukkut upernaakkullu sikuusarnera pissutigalugu misissueqqissaarnerit juunimiit novemberimut ingerlanneqartassasut naatsorsuutigineqarpoq. Uuliasiornivilli aallartissagaluaruni ukioq naallugu ingerlasassasoq naatsorsuutigineqarpoq.

Taaguutit matuma kinguliani atorneqartut nassuiarneqarnerat

Avatangiisinut sunniisut (Environmental pressures). Tassaapput inuit suliaat avatangiisinut sunniuteqartut. Tassaasinnaapput aalisarnermit piniarnermillu sunniutit, umiarsuit angalanerinit imaluunniit aatsitassarsiornermit pisut kiisalu annerusut eqqarsaatigalugit silap pissusiata allanngornerata sunniutai.

Kinguneri (impact). Sunniutinut siammasinnerusunngorlugu taaguutigineqartoq, soorlu qillerinermi akuutissat toqunartut atorneqarnerisa avatangiisinut kingunerinut. Sunniut (effect). Suliat aalajangersimasut imaluunniit sananeqaatit avatangiisinut aniatinneqartut sunniutaat pillugit atorneqartarpoq, soorlu marraap qillerinermi perrassaatigineqartup toqunartuisa sunniutaat pillugit, imaluunniit sajuppillatsitsisarluni misissuinerup nipiliornerisa miluumasunut imarmiunut nujoqqatsitsineri pillugit imaluunniit qoqersillutik tusaasaarukkallartitsinerat pillugu.

Misikkarissut (sensitive) tassaapput uumassusileqarfiit immikkoortuisa (uumassusillit, suut piartuaarneri) avataaniit sunnerneqarnerminnut qisuariaatigisartagaat. Qilalukkat qernertat assersuutigalugu immap iluatigut nipiliornermut misikkarissuupput. Aamma matuma kinguliani innarliasunut tunngasut takukkit. Kisianni misikkarinnerup innarlianerullu killingat titarnertut nalunaatsiginngilaq.

Innarliasut (vulnerable). Taaguummi tassani sunnerneqarsinnaaneq aamma ilaatinneqarpoq, ima paasillugu uumassusilik sunniummut aalajangersimasumut misikkarittarpoq sunniummit tassannga pineqaruni. Soorlu qilalukkat qernertat immap iluani nipiliornermut misikkarinnertik pissutigalugu sajuppillatsitsisarluni misissuinernit pilersaarutigineqartunit innarlerneqariaannaapput. Kisianni misikkarinnerup innarlianerullu killingat titarnertut nalunaatsiginngilaq.

Avatangiisinut ajutoorutaasinnaasut (Environmental risk). Inuit avatangiisinut sunniinerisa ilimanassusiinik kingunerinillu nassuiaataavoq, soorlu misissueqqissaarluni qillerinerit.

Avatangiisit

Qeqertarsuup Kitaa issittumi ippoq uumassuseqarnikkullu taavani ilisarnaataasartunik ilisarnaateqarluni; Uumasut assigiinngissitaartut amerlagisassaanngillat, nerisareqatigiiaat amerlanngillat, sumiiffiit ilaat uumassusilinnik amerlasoorujussuarnik peqartarput. Immalli natermiui allaapput taakku assigiinngissittaartut amerlasoorpassuugamik. Uumasut assigiinngissitaartut amerlanngitsuinnaanerat illuatungilerlugulusooq uumasut ataasiakkaat ilaat amerlasoorujussuusarput, uumasullu taakku ilaat nerisareqatigiinnermi pingaarutilerujussuusarlutik. Tassa uumasut pingaarutillit taakku piffissami sumiiffimilu amerlassusii nerisareqatigiinni qaffasinnerusunut assut pingaaruteqartarput. Kiisalu uumassusillit amerlasuut ilisarnaatigisarpat orsulerujussuusaramik ilaatigut nerisassaqannginnerminni sillimmatigisartakkaminnik, ilaatigullu issinnerani oqorsaatigisartakkaminnik. Taama orsoqartiginerat avatangiisit mingutsinneqarneranni pingaaruteqalersarpoq minguimmi amerlaqisut orsumi arrortarmata taamalu uumasup timaani eqiterussinnaasarlutik.

Sumiiffiup naliliivigineqartup ilaa uumassuseqassuseq / uumassusileqarfiit eqqarsaatigalugit pisoorujussuuvoq. Upernaakkut sumiiffiit ilaanni naasuaraasat pinngorartut amerlasoorujussuusarput, immap natermiui assigiinngissitaaqaat aammalu timmissat miluumasullu imarmiut amerlasaqalutik.

Avatangiisit pissusii

Sumiiffimmi naliliiviusumi avatangiisit pissusii naatsumik oqaluttuarineqassapput annermik immap sikullu pissusii eqqarsaatigalugit. Sumiiffii tamanna annerusumik minnerusumiluunniit ukiukkut upernaakkullu sikuusarpoq. Iluliarpassuaqartarpoq, pingaartumik Qeqertarsuup Tunuani.

Qeqertarsuup Tunuata kujataani sineriammi sarfarnerujussua pissutigalugu imarnersaqartarpoq, imarnersallu taakku uumassuseqassusermut pingaaruteqaqaat taavalu uuliasiornermut uuliaarluernermulu misikkareqalutik. Ukiup sikua suikkaaneq ajorpoq assut quppaqartarluni aakkarnersaqartarlunilu. Sumiiffiit ilaanni tamakku timmissanut miluumasunullu imarmiunut assorsuaq pingaaruteqartarput.

Nunaviup imavimmut atanera itisoorsuunngitsoq – ikkanneqarfik – atituujuvoq naliliiffiullu kujasinnerusortaani 120 km tikillugit atitussuseqarluni. Immamut itinerusumik itiseriarfeqarpoq ikkannerillu qunnersuaasaqartiterput immap naqqata ilusaanik allanngorartitsisunik. Ikkannerit atorlugit, pingaartumik avataatigut, nillikaasumik sarfaqarpoq (*upwelling)* assut inuussutissalimmik, uumasuaqqanit naasuusarannguanillu assut pinngorarfigineqartumik, taamalu uumassusileqarfinnut ikkanneqarfinnulu eqqaaniittunut pitsaasumik atugassaqartitsiviusarluni.

Uumassuseqassuseq

Sumiiffimmi naliliiviusumi upernaakkut uumasuaqqat naasuusaaqallu assut pinngorartarput, pingaartumik sikut saatsersut sinaanni (*the marginal ice zone, MIZ*), siusissukkut imarnersaalersuni, kiisalu aasarpasinnerusukkut sumiiffinni sarfap nillikaaffiani (*upwelling*). Nerisareqatigiinni tulliuttut tassaapput planktonit uumasuaraasut, taakkunanilu illeqqat angisuut *Calanus*-ikkunnut ilaasut amerlasoorsuusarput. Taakku ukioq ataasiinaanngitsoq uumasarput, ukiup kaajallakkiartornerani aalajangersimasumik pissuseqartarlutik, aasaanerani immami qatsinnerusumiittarput, tamaani uumasuaqqat pinngorartarput, ukiuuneranilu itisioruttarlutik. Illeqqat taakku aalisakkanit, timmisanit arfernillu nerisarineqarluartuupput, taamaakkamillu uumassusileqarfinni uumasutut pingaarutilittut taaneqartarlutik. Sumiiffiit illeqqanit eqiteruffiusartut timmissat miluumasullu imarmiut neriniarfigilluagarisarpaat (Taakuuk Illerfiusaq 1). Illeraqarfiulluartut Store Hellefiskebankep kiisalu Diske Bankep aammalu Qeqertarsuup Tunuata kitaasa tungaanni naammattuugassaapput.

Aalisakkat kinguppaallu qullugiaat uumasuaqqanut ilaapput sarfamillu sumut tamaanga siammartarlutik.

Immap naasui (qeqquakkut) sineriammi manngertumik natilimmi naammattuugassaasarput, 50 meterinillu itissusilik tikillugu takussaasarlutik. Qanittukkut Qeqertarsuup eqqaani 61 meterit tikillugit itissusilimmiittut siumorneqarput. Qeqqussakkut amerlasinnaaqaat naajorartaqalutillu, sorpassuartigullu nerisareqatigiinni qaffasinnerusuniittunut pingaaruteqartarlutik. Qeqqussat uumasunut nikiuitsunut uumaffiupput, aammalu qeqquaqarfissuit aalisakkat piaraannut pingaaruteqarput kiisortunut, parnunnermut, sarfamut malinnullu illersorfigisaramikkit, kiisalu qeqqussat aamma nerisarineqartarput. Aammattaaq qeqquakkut imaani sorujuarannguanik uumassusilinneersunik pilersueqataasuupput immap naqqani uumasunut amerlaqisunut nerisaalluartuullutik. Qeqqussat amerlaqisut saniatigut aamma qaqutigoortunik immap orpiusaanik kalkiusunik 13 cm tikillugit silissusilinnik ammaloqisaajusunik Kangerlummi nassaasaqartarpoq. Immap naasui amerlasinnaasaqaat naajorartaqalutillu, sorpassuartigullu nerisareqatigiinnut qaffasinnerusunut pingaaruteqarlutik. Sumiiffimmi naliliiffiusumi immap naaneri pillugit paasinngisat suli amerlaqaat.

Pinngortitaleriffiup ilisimatusartarnerinit qassiinit pisunik immap naqqata uumasui pillugit ilisimasat nutaat amerlaqisut pigineqalersimapput. Sumiiffiup naliliiffiusup naqqa pingaarluni assigiinngissitaaqisunik uumasorpassuaqarpoq (assigiinngitsut 900 ilisimaneqarput). Uumassusillit uumassusileqarfinnut sunnertiasunut (*Vulnerable Marine Ecosystems, VME)* ilisarnaataasartut sumiiffimmi naliliiffiusumi sumiiffinni qassiini nassaarineqarsimapput, qanittukkullumi sumiiffiup naliliiffiusup kujataani uumassusileqarfik sunnertiasoq nassaarineqarsimavoq). Taamaattaaq Davis Strædep Canadamut tungerpasinnerusortaani uumassusileqarfik sunnertiasoq (VME) assingusoq nassaarineqarsimavoq. Taamaammat naatsorsuutigisariaqarpoq aammattaaq sumiiffiup naliliiffiusup iluani immap naqqani uumassusileqarfinnik sunnertiasunik nassaassaqartoq.

Aammattaaq immap sikuani tamatumalu eqqaani uumassuseqassuseq immikkuullarissoq pillugu ilisimasat nutaat pigineqalersimapputtaaq,taakkutamanuttunnganerugaluarput,aammalisumiiffimmitnaliliiffiunerusumeersuullutik. Ilisimasat pigineqartut sumiiffinnik immikkut sunnertiasunik tikkuaanissamut periarfissiinngillat.

Aalisakkat kiisalu qaleruallit annerusut pillugit ilisimasat pigineqartut nutarterneqarsimapput aalisarneq pillugu paasissutissanik nutaanik ilaartorneqarlutik.

Aalisakkat avasissumi ittut, aamma ikkannersuaqarfinni – 200 meterit tikillugit itissusilinniittut – nunaviup avammut ataneraniittut), tassaanerupput natermiut, soorlu qalerallit, nataarnat, suluppaakkat, qeeqqat, eqalussuit kiisalu aalisakkat iluanaarniutigineqarneq ajortut allat. Aalisakkat pingaaruteqarnersaat tassaapput qalerallit, nunaviup avammut atanerata sivinganerini kangerlunnilu uumaffeqartut. Qalerallit sumiiffimmi naliliiffiusumi suffineq ajorput, qalerallilli amerliartortarput Davis Strædemi kujasinnerusumiit suffisarfinniit qalerallit qullugiaasa sarfaanneqarlutik tamaani unittarnerisigut. Putooruttut ikkannersuaqarfinni amerlasoorsuakkuutaartarput taavalu aalisakkat, timmissat arferillu soqqallit ilaannut nerisaalluartuullutik (takuuk Illerfiusaq 4 aalisakkat takku misissuiffigineqarnerannut tunngasoq). Putooruttoq aalisakkani aasakkut suffisartutuaavoq.

Sinerissamut qanittumi aalisakkat pingaarutillit marluk upernaakkut suffisarput: ammassat nipisaallu. Ammassat aalisakkanit annerusunit, timmisanit miluumasunillu imarmiunit nerisaalluartuupput uumassusileqarfinnilu amerlasuuni pingaaruteqartuulluni. Eqallut aamma sinerissamut qanittumiittarput, suffiniarlutillu kuunnut majortarput ukiisarlutillu.

Uumassusileqarfinni aalisagaq pingaarutilik alla tassaavoq eqalugaq, pingaartumik naliliiviusup avannarpasinnerusortaani naammattuugassaasartoq.

Peqqunni annerusuni pingaartumik immap itisuup kinguppai amerlaarsuusarput siammarsimasarlutillu 150 aamma 600 meterinik itissusilimmi, soorluttaaq Kalaallit Nunaata assagiarsua itisuumi aqitsumik natilimmi nalinginnaasartoq. Kinguppaat Kalaallit Nunaanni pisuussutit pingaarnersaraat.

Sumiiffimmi naliliiffiusumi timmissat imarmiut pillugit ilisimasat pingaartumik naliliiffiusup avataani erniorfiini nalunaaqqutsersuisarnermit, Appani appat ineqarfissuanni misissuinernit kiisalu sineriammi timmissanik ukiisumik misissuisarnermit pisuupput.

Katillugit timmissat imarmiut assigiinngitsut 16-it tamaani erniortuupput (Tabel 5). Taakkunannga 15-it innani imaluunniit qeqertani pukkitsuni erniortartuupput. Timmissat imarmiut najugaannik assut pingaarutilinnik qassiinik tamaani naammattuugassaqarpoq, ilaatigut Appani timmiaqarfissuaq taateraat appallu piaqqiorfigisartagaat, qeqertat Kitsissuarsuit Kalaallit Nunaanni imeqqutaalaqarfiit annersarisaat, kiisalu timmissat qaqutigoortut soorlu kajuaraq naajannguarlu kiisalu qeqertannguit Rotten aamma Appalillip Ikkarlussua qilanngaqarfiusoq. Uummannap Kangerluani Qeqertani aamma imeqqutaalaqarfissuaqarpoq. Timmmissat erniortut qassiit Kalaallit Nunaanni uumasunik navianartorsiortunik nalunaarsuiffimmiipput (Tabel 7). Appani appaqarfissuarmi appat erniortut assorujussuaq ikileriarsimapput.

Aammattaaq sumiiffik naliiiffiusoq timmissanut imermiunut erniortuunngitsunut aasakkut ukiakkullu pingaaruteqarpoq. Aasarissinerani mitikkut angutivissat isaniarlutik katersuuttarput, taamaanneranilu timmisinnaaneq ajorput. Pingaartumik mitit siorakitsut Canadami erniortuusut amerlasoorsuullutik kangerluit sinerissallu ilaanni ittarput, kiisalu paat, allerit kiisalu toornaviarsuit sumiiffiit ilaanni katersuuttarlutik.

Sumiiffiup naliliiviusup kujasinnerusortaa mitit, mitit siorakitsut kiisalu appat ukiivigilluartarpaat. Pingaartumik Store Hellefiskebankip ikkannerusortaa miternut siorakitsunut pingaaruteqarpoq millionit tikillugit amerlassuseqarlutik ukiiffigisarmassuk. Timmissat taakku Canadap issittortaap erniortarput, Kalaallillu Nunaata Kitaata imartaani ukiisarlutik.

Upernaakkut ukiakkullu sumiiffimmi naliliiffiusumi timmissat imarmiut amerlasoorsuullutik aqqusaartarput, taakku Kalaallit Nunaata kitaata avannaani Canadallu issittortaani erniorfimmik kiisalu Kitaata kujasinnerusortaani Newfoundlandimilu ukiivimmik akornanni ingerlaartarput.

Sumiiffimmi naliliiffiusumi puisikkut tallimaapput, aaveqarluni, arferit assigiinngitsut 14-iullutik kiisalu nanoqartarluni. Tamaani periusissiorfiusumik avatangiisinik naliliinerup kingulliup kingorna nannut, amerlassusii sumiiffimmillu tamatuminnga atuinerat pillugu ilisimasat nutaat, aarrit taakkulu piniagaanerat kiisalu natsersuit aataallu amerlassusii kiisalu arferit qassiit amerlassusii pillugit ilisimasat nutaat pigineqalerput.

Aataat natsersuillu sumiiffimmi naliliiffiusumi amerlallutik naammattuugassaasarput. Imaanerani tamaaniittarput. Sumiiffiup naliliiffiusup avataani kitaata sikuani sumiiffinni aalajangersimasuni amerlasoorsuakkuutaarlutik erniortarput. Natsiit ussuillu ukioq naallugu naammattuugassaasarput sumiiffimmilu naliliiviusumi siammasillutik piaqqiortarlutik. Qasigissat sumiiffimmi naliliiffiusumi massakkut amerlanngitsuinnanngorsimapput.

Aarrit Store Hellefiskebankenimi pingaarutilerujussuarmik ukiisarfeqarput. Taakku aasaanerani Baffinimi Qeqertaalummiittarput. Ukiuunerani taakku amerlanersaat Store Hellefiskebankenimi ikkannerusumukaasarput (100 meterit inorlugit itissusilimmut). 2012-imi ukiisartut 1400 missaanniittutut missingerneqarput.

Arferni pingasuit ukiisartuupput, tamarmik kitaata sikuaniittarlutik: Qilalukkat qernertat qaqortallu kiisalu arfiviit. Qilalukkat qaqortat Store Hellefiskebankenimi pingaarutilimmik ukiisarfeqarput, qilalukkallu qernertat ilaatigut ukioqqaalernerani Uummannap Kangerluani kiisalu Qeqertarsuup Tunuani ittarput. Baffinip Ikerani sikuni saatsersuni qilalukkat qernertat Canadami Kalaallit Nunaata Kitaata avannaani aasisartut tamarmik ukiisarput, nunarsuarmilu peqassuseq eqqarsaatigalugu uumasut taakku assut amerlasarlutik. Arferit ukiisartut pingajuat tassaavoq arfivik, Qeqertarsuup Tunuata silarpasinnerusortaani pingaarutilimmik upernisarfeqartoq. Arferit sinneri: tikaagulliit, tikaagulliusaat, qipoqqaat allallu aasaanerani takkuttartuupput, ukiuuneranilu sumiiffiup naliliiffiusup avataaniittarlutik. Niisalli ukioq kaajallallugu sikuunngitsumi naammattuugassaasarput.

Aamma nannut kitaata sikuaniittarput, taamaammallu ukiukkut upernaakkullu takussaasarluni. Nannut sumiiffimmi naliliiffiusumi ittut Baffinip Ikerata nanorai, 2017imi 2800 missaanniittutut naatsorsorneqarsimasut. Taamaattorli sumiiffimmi naliliiffiusumissaaq nanoqatigiit allat Davis Strædimiittartut ataasiakkaat takkuttarput. Nannut sumiiffimmi naliliiffiusumi ukiup ingerlanerani sikuutillugu siku malittarisarpaat. Nannut arnavissat piaqqisartut apissiinik tamaani ilisimasaqartoqanngilaq.

Pinngortitamik illersuineq uumasullu navianartorsiortitaasut

Nunat tamalaat akornanni toqqakkat

Sumiiffimmi naliliiffiusumi nunatat arfinillit masarsoqarfittut nunat tamalaat akornanni pingaarutilittut toqqarneqarsimapput, tak. Masarsoqarfiit nunat tamalaat akornanni pingaarutillit pillugit Isumaqatigiissut (Ramsarimi Isumaqatigiissut), kiisalu Ilulissat Kangerluat nunalu tamatuma eqqaaniittoq UNESCO-p nunarsuarmioqatigiinnut kingornutassiaatut toqqagaasimapput.

Nunat tamalaat suleqatigiiffii assigiinngitsut (Issittumi Siunnersuisoqatigiit, UNESCO, Birdlife International) sumiiffiup naliliiffiusup iluani uumassusileqarfinnik pingaarutilinnik allatut ittunik siunnersuuteqarsimapput. Taakkununnga ilaavoq sumiiffik annertoorujussuaq aamma Store Hellefiskebankenimik Qeqertarsuullu Tunuanik ilalik (Assiliartaliussaq 59).

Kalaallit Nunaanni inatsisit

Pinngortitamik eqqissimatitsinermut inatsit naapertorlugu sumiiffimmi naliliiffiusumi eqqissisimatitat qassiit toqqarneqarsimapput (Assiliartaliussaq 59) aammalu timmissat illersorneqarnissaannik inatsit naapertorlugu timmissat imarmiut erniorfii illersugaaput, ilaatigut timmiaqarfinni angallanneq inerteqqutaalluni.

Aatsitassanut inatsit naapertorlugu sumiiffiittaaq allat (”sumiiffiit uumasunut pingaarutillit”) toqqarneqarsimapput, taakkunanilu timmissat miluumasullu sunnerumanagit aatsitassarsiornermi suliat malittarisassaqartitaaput. Assersuutigalugu timmissat imarmiut erniorfii pingaarutillit pineqarput. Sumiiffiit qilalukkanut qernertanut pingaarutillit ilaanni sajuppillatsitsisarluni misissuinerittaaq malittarisassiorfiusinnaassapput arferit sunnigaanerat killilersimajumallugu.

Uumasut navianartorsiortitaasut

Kalaallit Nunaanni uumasut navianartorsiortitaasut pillugit nalunaarsuiffik nutaaq 2018-imi saqqummerpoq, taannalu naapertorlugu sumiiffimmi naliliiffiusumi miluumasut assigiinngitsut arfineq pingasut kiisalu timmissat aqqanillit navianartorsiortitaasutut nalilerneqarput (Tabel 7). Nunat tamalaat navianartorsiortunik allattuiffianni miluumasut imarmiut arfineq pingasut kiisalu timmissat sumiiffimmi naliliiffiusumi navianartorsiortutut tikkuarneqarput.

Sumiiffimmi naliliiffiusumi inuit sunniineri

Sumiiffik naliliiffiusoq inuit piliaannit assigiinngitsorpassuarnit sunnerneqartarpoq nalunaarusiamilu tamakku ilaat nassuiarneqarput uuliasiornerup sunniutaanut taputartuussinnaanerat pillugu.

Ungasissumiit mingutsitsineq

Sumiiffimmi naliliiffiusumi uumassusillit saffiugassamik oqimaatsumik (annermik kviksølvimik) kiisalu mingunnik arrortikkuminaatsunik (*Persistent Organic Pollutants*) akoqariartuinnarput taakkulu nerisareqatigiinni kiisortut qullerpaat timaanni inunnilu piniarnermik aalisarnermillu inuussuteqartuni eqiteruttarput. Pingaartumik kviksølv aarleqqutaavoq. Mingunnilli arrortikkuminaatsunik nunat tamalaat akornanni inatsisitigut malittarisassaqartitaasunik akoqarnerat appariartussangatinneqarpoq, taamaattorli Europami, Asiami Amerikamilu Avannarlermi suliffissuarniit sananeqaatit pisut mingutsitsisuusut Kalaallit Nunaanni uumassusilinni takkussortuarput.

Uuliakkunni PAH-t (*Polycyclic Aromatic Hydrocarbon*) toqunartoqarnerpaajupput. Sumiiffimmi naliliiffiusumi PAH annikitsuinnaasarpoq, imaanili qaffasinnerusarpoq aammalu nunap uuliaata imaani avatangiisinut seeriviatut ilimagineqartuni.

Plasticimik mingutsitsineq

Plasticimik mingutsitsineq alliartorpoq aarlerissutigineqalerlunilu. Plasticiaqqat (5 mm-init minnerit) issittumi avatangiisini sumiluunniit innerat paasineqarpoq kiisalu uumasuaqqaniit arfernut amerlasuujullutik siammarsimaffigalugit. Angisuut (25 mm-init minnerit) kiisalu angisoorsuit (5-25 mm) aamma aalisakkat, timmissat kiisalu miluumasut imarmiut nerisaasa aqqutaanni nassaarineqartarput, kiisalu puisit arferillu aalisarnermi qassutini plasticiusuni napissinnaallutik. Kalaallit Nunaanni sumiiffimmilu naliliiffiusumi plasticimik mingutsitsinerup ilarujussua najukkameersuuvoq, plasticili aamma avataaniit sarfamit tikiunneqartarpoq.

Inuit suliaat allat

Sumiiffimmi naliliiffiusumi suliat pingaarutillit tassaapput aalisarneq – iluanaarniutigalugu kiisalu nerisassaqarniutigalugu – miluumasunik imarmiunik timmissanillu piniarneq kiisalu takornariartitsineq. Tamakku sunniutaat uuliasiornerup sunniutaanut taputartuussinnaapput, kiisalu tamaani annertuumik uuliaarluertoqarneranit sunnigaasinnaassallutik.

Silap pissusiata allanngornera

Issittoq, aamma Kalaallit Nunaat, kujasinnerusumut sanilliullugu annerusumik kiassiartorpoq. Sumiiffimmi naliliiffiusumi kitaata sikua annikilliartorlunilu saaliartorpoq, aajaarnerusalerlunilu. Uumassusilinnut kitaata sikuanut atasunut allannguisussaavoq, taavalu nannut naajavaarsuillu pitsaanngitsumik sunnigaasunut assersuutissaallutik. Illuatungaani sikup annikillinera uumasunut allanut (soorlu tikaagullinnut aarlunnullu) nutaanik periarfissaqalersitsivoq avannarpasinnerusut tikittaleramikkit. Aammattaaq immap kissarnerulernerata nassatarisaanik issittup illerai pingaarutillit atlantikup illeraanik inuussutissartaqannginnerusunik taarserneqarput.

Taamaammat ukiuni aggersuni sumiiffimmi naliliiffiusumi uumassusileqarfiit annertuumik allannguuteqarnissaat naatsorsuutigineqartariaqarpoq. Tamakku inuaiqatigiinnut pitsaasunik pitsaanngitsunillu kinguneqarsinnaapput, kiisalu nalunaarusiami allaaserisat inerniliussallu piffissap ingerlanerani atuukkunnaarnissaanik kinguneqassallutik. Taamaammat sumiiffimmi naliliiffiusumi uumassusileqarfinnik malinnaaviginninneq ilisimatusarfiginninnerlu siunissami uumassusileqarfinnik tunngaveqarluni sumiiffimmi naliliiffiusumi inuit suliaannik aqutsinermut iluaqutissaavoq pingaarutilik.

Sunniutit kattunneri

Uuliasiornerup avatangiisinut sunniutaanik naliliinermut atatillugu sunniutit kattunneri puigorneqassanngillat. Taakku tassaapput inuit suliaasa tamarmiusut piffissami sumiiffimmilu kattunneri. Taakku assersuutigalugu tamarmik immikkut sunniutaannit kattullutik sunniutaat sakkortunerusinnaapput. Sajuppillatsitsisarnerit qassiit ataatsikkut tulleriissarlutilluunniit ingerlanneqartut imaluunniit qillerivinnit amerlasuunit qilleriviit imertaannik aniatitsineq sunniutinik kattutsitsisinnaapput. Aamma uuliasiornerit sunniutaat assersuutigalugu piniarnerup sunniutaanut kattussinnaapput taamalu annerulerlutik.

Sumiiffimmi naliliiffiusumi uuliasiorluni sulianik naliliinerit

Tabelimi eqikkaavimmi 1-imi takutinneqarput sumiiffimmi naliliiffiusumi uuliasiorluni suliat sunniutigisinnaasaat.

Misissueqqissaarnerit

Misissueqqissaarnerit ingerlaavartuuneq ajorput, amerlanertigut ukiualunni ingerlasarput amerlanertigullu sumiiffimmi akuersissuteqarfiusumi tamarmi siammarsimasarlutik. Aammattaaq imaanerinnaani ingerlasarput, tassa aasakkut ukiakkullu, qularnanngitsumik juunimiit oktoberimut. Misissueqqissaarneq uuliaqarneranik gasseqarneranillu takutitsiviunngippat taamalu misissueqqissaarnernik siammaanissaq akilersinnaanngippat misissueqqissaarnermi suliat unitsinneqassapput atortullu piiaarneqarlutik. Akerlianilli uuliaqarpat piffissami nalilersuiffimmi iluaqutigineqarsinnaasutut paasineqartumik, suliat qilleriviliornermut ikaarsaartinneqassapput tassanilu uuliaqarfiup killingi paasiniarlugit qillerisoqartassaaq, atortulersuutit sullissiviillu ikkussuunneqarlutik, kingornalu uuliamik nassaarineqartumik qalluivinik aallartinneqassalluni (matuma kingulia takuuk).

Misissueqqissaarnertigut akornusersuinerit annersaat sulianit nipiliorfiusunit pisarpoq (soorlu sajuppillatsitsisarluni misissuinernit, qillerinernit kiisalu qulimiguullit angalasarnerinit). Sumiiffimmi naliliiffiusumi pingaartumik qilalukkat qernertat qaqortallu kiisalu aarrit nipiliornermut sunnertiasuupput, uumasulli taakku ukiukkut nalliuttartuupput misissueqqissaarnerullu nalaani sikuunngiffiani naammattuugassaasaratik. Sajuppillatsitsisarluni misissuinerit akornusersuinerat pissutigalugu miluumasunik imarmiunik misissuiffimmi neriniarfinnit pingaarutilinnit ingerlaarfinnillu ingalatsernissaat ilimanaateqassaaq. Taamaattorli ataasiartumik sajuppillatsitsisarluni misissuisaqattaarnerit sunniutaat ataavartuussanngitsut (sapaatit akunneriniit qaammatinut), tassa suliat ataavartuunnginnerat pissutigalugu. Taamaattorli sajuppillatsitsisarluni misissuinerit 3D-it immikkuullarissut sumiiffinni killilinni ingerlanneqartartut arfernut, soorlu tikaagulliunnut, qipoqqarnut tikaagulliusaanullu malunnaateqaqisunik sunniuteqarsinnaapput. Sajuppillatsitsisarluni misissuinerit sakkortuut aamma qaleralinnik piffissami aalajangersimasumi nujoqqatsitsisinnaapput, aalisarfinnilu pingaarutilinni tamanna pippat misissuinerit aamma aalisarnermi pisanik ikilisitsisinnaallutik. Aalisakkanik allanik misissuinermit paasinarsivoq sunniut taanna ataavartuuneq ajortoq Qeqertarsuullu kujammut kitaani 2010-ip missaani imaani sajuppillatsitsisarluni misissuinermi misilittakkat naapertorlugit paasineqarpoq qaleralinniarneq tamaani ataatsimut isigalugu sunnerneqarsimanngitsoq. Suffiviit aammalu aalisakkat qullugiaasa eqiteruffigilluartagaat sajuppillatsitsisarluni misissuinernut misikkarisuupput, ilaatigut pissutigalugu aalisakakt suffisut nujoqqatsinneqarsinnaammata ilaatigullu aalisakkat qullugiaat nipiliorfimmiit meterialunnik ungasitsigisumiittut toqunneqartarmata. Sumiiffimmi naliliiffiusumi aalisakkat amerlanerit sajuppillatsitsisarluni misissuinerit sioqqullugit suffisarput, aammalu amerlasoorsuarnik aalisakkat qullugiaqarfiusartunik ilisimasaqartoqanngilaq taamaallu naatsorsuutigineqarpoq sumiiffimmi naliliiffiusumi aalisakkat sunnigaanavianngitsut.

Kalaallit Nunaanni sajuppillatsitsisarluni misissuinerit malittarisassaqartitaapput miluumasut imarmiut (pingaartumik arferit) innarligaanissaannik pinaveersaartitsiniutaasunik, aammalu sumiiffinni pingaarutilinni akornusersugaanissaat killilersimaniarlugu qilalukkanik qernertanik arfivinnillu qassiinik illersuiveqarpoq.

Misissueqqissaarluni qillerinerittaaq nipiliorfiusarput. Maskiinat sarpiillu qillerivimmik puttasumik nikitsaaliusartut (tassami sumiiffinni tamangajanni immap naqqanut qajannaakkanik qilleriviliorfigissallugu imaq itivallaartarpoq) assut nipiliortarput. Nipi miluumasunut imarmiunut ungasissumiittunut suunniuteqarsinnaasarmat nipiliorfik ingalatsertarpaat, pingaartumillu arferit misikkarissuuput. Taamaammat tunnullit, tikaagulliusaat, tikaagulliit kiisalu qipoqqaat aasaanerani najortakkaminnit pingaarutilinnit nujutsinneqaratarsinnaapput.

Misissueqqissaarluni qillerinermi marraq perrassaatitut, qillikkap naqitsineranik aqutsinermut aammalu qillernerlukunik qilleriviup qaanut qalluinermi atorneqarpoq. Taanna imermik imerpallaateqarsimagaangami qillerinerup kingornaimaanut maqinneqarsinnaavoq, uuliamilliakullitavatangiisinutajoqutaanerusartutullumikkut nalinginnaasumik nunaliaallugit suliarineqartarput imaluunniit nakkutigisaasumik toqqortarineqartarlutik. Kalaallit Nunaanni maannamut marraat perrassaatit imermik imerpallatat kisimik atorneqartarsimapput, akuilu avatangiisinut ulorianannginnerusut ulorianannginnerusut aniatitsinissaq avatangiisitigut akuerineqarsinnaasutut isigineqartarpoq. 2010-imi Qeqertarsuup avataani pingasoriarluni qillerinermi marraq perrassaat 6000 tons kiisalu qillernerlukut 2261 m³-inik annertussuseqartut maqinneqarput. Aamma akuutissat avatangiisinut ulorianannginnerusut ″qorsummik″ ″sungaartumillu″ nalunaaqqutsikkat kisimik atorneqarsinnaaput (OSPAR-ip immikkoortiterinera takuuk.). ″Aappalaartumik″ ″qernertumillu″ nalunaaqqutsikkat akuerisaanngillat. Taamaattorli qillerinerup avatangiisinut ulorianannginnerulersinneqarnissaanut iluaqutaanissaat uppernarsarneqarsinnaappat ″aappalaartut″ (arrortikkuminaatsut) akuersissuteqarfigineqarsinnaapput. Malittarisassat taakku Norgemi qillerinermi akuutissat atorneqarnerinut malittarisassat assigaat. Oqaatigineqassaarli Norgemi marraq qillerinermi perrassaat uuliamik akulik aamma atorneqartarmat nunamut kingorna toqqortarineqarnissaa / suliarineqarnissaa taamalu imaani avatangiisinut aniatinneqannginnissaa piumasaqaatigineqartarmat. Kalaallit Nunaanni 2010-ikkunni qillerinerup kingorna ajornarunnaarsimavoq. Qillerinermi perrassaammik imermik akulimmik qillernerlukunillu aniatitsinermi maqitsiviup eqqaani marraap katersuunneratigut immallu iserissertinneqarneratigut immap naqqata uumasui sunnerneqarsinnaapput. Sumiiffimmi naliliiffiusumi marrarmik perrassaammik qillernerlunillu maqitsinerup sunniutai nalileruminaapput. Taamaattorli marraat perrassaatit avatangiisinut ulorianannginnerpaat atorneqarpata misissueqqissaarluni qillerinermit ataasiinnarmit maqitsinerit annikitsuinnarmik piffimmilu annikitsuinarmi sunniuteqarnissaat naatsorsuutigineqarput. Kisiannili sumiiffimmi uumassusileqarfiit sunnertiasut (*Vulnerable Marine Ecosystems*) nassaassaappata taakku assut sunnertiassapput. Marrarnik perrassaatinik qillernerlukunillu aniatitsinermut taarsiullugu nunaliaassinikkut imaluunniit qillerinerup kingorna qillersimasamut maqitsinikkut sunniutit pinngitsoorneqarsinnaapput. Taamaaliornerli immini aamma avatangiisinut sunniuteqarfiusarpoq aniatitsinermut sanilliullugu oqimaalutartariaqartunik.

Kiisalu qillerinerit nukerujussuarmik pisariaqartitsiviusaramik gassinik kiassiartortitsisartunik annertoorujussuarmik aniatitsinermik kinguneqartarput. 2010-imi Qeqertarsuup avataani qillerinerit pingasut Kalaallit Nunaata aniatitsineranik 15%-imik qaffatsitsipput. Misissueqqissaarluni qillerinerup nalaani avatangiisinut sunniutaaratarsinnaasoq annerpaat tassaavoq tissaluttoorneq (*blowout)*, uuliamik maqisoorujussuarmik nassataqartarpoq. Uuliammik maqisoornerup kingunerisinnaasai matuma kinguliani eqqartorneqassapput.

Ineriartortitsineq tunisassiornerlu

Sumiiffimmi naliliiffiusumi ineriartortitsinerup tunisassiornerullu avatangiisinut sunniutissaanik naliliinerup ajornakusoornera arlalinnik pissuteqarpoq. Suliat taama ittut Kalaallit Nunaanni misilittagaqarfigineqanngillat. Aamma tunisassiortoqaleriataassagaluarpat tamatuma sumi pinissaa ilisimaneqanngilaq, kiisau annertussuseriumaagaa sivisussuseriumaagaalu ilisimaneqaratik. Aamma teknikkikkut periaasissat qanoq ittuussasut ilisimaneqanngilaq.

Misissueqqissaarnerup nalaani pisartut paarlattuannik uuliasiorfimmik ineriartortitsineq uuliamillu tunisassiorneq sivisoorsuarmik ingerlasarput (ukiut qulikkaat), sulialu qassiit avatangiisinut assorujussuaq sunniuteqarsinnaasarlutik. Avatangiisit allanngortinneqannginneranni qanoq issusiinik ilisimasaqarneq tunngavigalugu pilersaarusioqqissaarnikkut, peqqissuseq, isumannaalisaaneq avatangiisillu eqqarsaatigalugit suleriaatsinik akuerisaasunik *Health, Safety and Environment* (HSE), periaatsinik pitsaanerpaanik atorneqarsinnaasunik atuinikkut (*Best Available Technique* (BAT) kiisalu avatangiisitigut suleriaatsinik atorneqarsinnaasunik pitsaanerpaanik (*Best Environmental Practice* (BEP) kiisalu oqartussat sukangasumik malittarisassaqartitsinerisigut sunniutit tamakku pinaveersimatinneqarsinnaapput. Taamaattorli suut aniatitat (soorlu tunisassiornermut ilanngullugu erngup qallorneqartup) kattullutik sivisuumillu sunniutaat siuliani periaatsit taaneqartut atorneqaraluarpataluunniit takkukkumaartut pillugit ilisimasat amigaatigineqarput.

Imeq uuliamik qalluinermi atorneqartoq imaanut aniatitsinermi annerpaajusarpoq. Uuliasiorfik ullormut 30.000 m^3 tikillugit annertutigisumik aniatitsisinnaasarpoq, ukiumullu Norgep nunavittaata avammut atanerani 160 millioner m^3 aniatinneqartarlutik. Ukiuni kingullerni erngup uuliamut ilanngullugu qaqitap aniatinneqarnera aarlerinartoqartinneqartarpoq taanna salinneqartaraluartoq nunallu tamalaat piumasaqaataat malinneqartaraluartut. Aamma erngup uuliamut ilanngullugu qaqinneqartup immami sikuusumi immap qaata aalaterneqarluni killilimmik akulerutitsivigineqartartumi aniatinneqarnera immikkut ajornartorsiutitaqarpoq. Matumani assersuutigalugu eqalukkat suaat qulliaallu sunnerneqassapput. Erngup uuliamut ilanngullugu qaqinneqartartup avatangiisitigut ajornartorsiutitai assersuutigalugu akui pillugit piumasaqaatit sakkortusinerisigut pinngitsoortinneqarsinnaapput, imaluunniit pitsaanerusumik erngup qillikkamut utertinneqarneratigut (*re-injection*).

Aniatinneqaratarsinnaasut annertuut allat tassaapput marraq perrassaat kiisalu qillernerlukut, tassami qalluiviliornerup uuliamillu qalluinerup nalaani qillerinerit amerlasussaaqimmata. Misissueqqissaarluni qillerinerup ataatsip avatangiisinut sunniutai siuliani oqaluttuarineqarput. Qilleriviliornerup qalluinerullu ingerlanerini aniatitat annerujussuussapput, taamalu immap naqqa annerusoq sunnerneqarsinnaassalluni. Marraap perrassaatip qillernerlukullu avatangiisinut sunniutaannik pinaveersaartitsiniutit pitsaanerpaat tassaapput nunamut taakkuninnga igitsiartorneq imaluunniit qilleriviusimasunut maqitseqqinneq.

Qilleriviliorneq qalluinerlu nukimmik annertoorujussuarmik pisariaqartitsiviusarput, Tunullu avannaata imartaani uuliaqarfissuarmi qillerivik Kalaallit Nunaata gassinik kiassiartortitsisartunik aniatitsineranut tamarmiusumut annertuumik ilasaataassaaq. Assersuutigalugu Norgemi uuliasiorfiit angisuut ilaat ataaseq Kalaallit Nunaanni aniatinneqartut pingasoriaatingajaanik annerusumik CO_2-mik aniatitsisarpoq.

Atortulersuutit imminni inissisimanerat kiisalu taakku akornusersuinerat miluumasunut imarmiunut ima sunniuteqarsinnaapput allaat uumasut taakku neriniarfigisartakkaminnit nujoqqavissinnaallutik imaluunniit ingerlaartarfii allanngorsinnaallutik. Sumiiffimmi naliliiviusumi pingaartumik qilalukkat qernertat, qilalukkat qaqortat, arfiviit aammalu aarrit tamatumani eqqartorneqarput, uumasullu tamakku piniarneqarnerisa ajornakusoornerulersinnaanera ilimagineqaratarsinnaavoq.

Immap natermiui, soorlu uumassusileqarfiit sunnertiasut (VME) aamma immap naqqani atortulersuutinik inissiinermik innarlerneqarataannaapput.

Nunami atortulersuutinik inissiisoqarpat taakku nunap pissusianut sunniutaat nalilersorneqassapput minnerpaatinniarneqassallutillu, tassami sumiiffiit takornariarfissaqqissusiat inissiinikkut annikillisarneqartussaammat.

Qalluivimmit tassungalu umiarsuit qulimiguullillu atorlugit angallanneq annerulissaaq. Pingaartumik qulimiguullit sumiiffinni pingaarutilinni timmissanik miluumasunillu imarmiunik nujoqqatsitsisinnaaput. Aqqutini aalajangersimasuni qutsissutinilu aalajangersimasuni ingerlaartarnikkut sunniutit pinaveersimatinneqarsinnaapput.

Qilleriviliorfiusuni qalluiffiusunilu aalisarneq immap naqqani atorlulersuutit eqqaanni (milluaaviit sullullillu) qilleriviillu assigiingitsut aalisarneq killeqassaaq. Nalinginnaasumik atortulersuutit taama ittut avataat 500 meterisut annertutigisoq tikillugu isumannaallisaavittut / matusatut killilerneqartarpoq.

Uulia qallorneqartoq umiarsuit atorlugit assartorneqartussaavoq, taakkulu uuliamik usilersulersigatik imeq pertujaallisaatertik maqeqqaartarpaat. Taamaaliornikkut uumassusillit allanertat uumasunik tamaaniittunik ingiaasinnaasut imartamut tikiuttoorneqaratarsinnaapput. Issittumi tamanna maannamut annerusumik ajornartorsiutaasimanngilaq, kisiannili silap pissusiata allanngoriartornera ilutigalugu ajornartorsiut annerulerumaartoq ilimagineqarpoq. Erngup pertujaallisaatip maqinneqartarnera suliarineqartarneralu pillugit nunat tamalaat malitassaat malinneqarpata taamaalisoqaratarsinnaanera ilimananngilnnerulersinneqarsinnaavoq.

Uuliamik maqisoorneq

Uuliasiornermit avatangiisinut sunniuteqarsinnaasut annersaat tassaapput uuliamik maqisoornerujussuit. Tamakku pisarput tissaluttoornikkut *(blowouts)*, tassa qillerivik aqunneqarsinnaajunnaaraangat pisartut, imaluunniit uuliap toqqortarineqarnerani angallanneqarneraniluunnit ajutoornerit, soorlu uuliamik usisaassuit uumiarnerini. Uuliamik maqisoornerujussuit ullumikkut akuttortissimaqaat atortorissaarutit isumannaallisaatillu pitsanngorsartuarneqarnerat pissutigalugu. Ajutoorsinnaanerli atuuttuaannarpoq, pingaartumik siusinnerusukkut uuliasiorfiusimanngitsuni, soorlu Kalaallit Nunaata imartaani ilulissat navianartorsitsivigisartagaanni ajutoorsinnaaneq qaninnerussaaq. AMAP (2010a) naliliivoq Issittumi uuliamik maqisoortoqarsinnaanera uuliamik assartuinermi ilimanaateqarnerpaajusoq.

Danmarkimi Silasioqarfeqarfik (DMI) kiisalu sumiiffimmi naliliiffiusumi maqisoortoqarpat tissukarfissaat maqisoorfissat arfineq-marluk assigiinngitsunik sinerissamut ungasissusillit aallaavigalugit naatsorsorsuisimavoq (assiliartaliussaq 92). Sinerissamut qanittumi maqisoornerit sinerissamut tikiuttarput, alisinnerusumili maqisoorfiit sinerissamut qanillisaratik. Sinerissamut qanittumi maqisoorneq avataani maqisoornermiit aseruinerujussuusartutut isigineqartarpoq. Tassunga pissutaavoq uuliap kangerliumanerni kangerlunnilu uneralersinnaanera taavalu immap qaaniitammut naqqata tungaanut uuliap akuitoqunartoqaqisut unerarsinnaallutik. Aamma uulia marrarmut imaluunniit sissamut ujarattuumut unerarsinnaavoq taamalu kigaatsumik avatangiisinut seererusaarsinnaalersarluni sivisoqisumik sunniuteqalersinnaalluni, soorlu timmissanut sineriassiortartuusunut. Tassalu Prince William Soundimi taama pisoqarsimammat 1989-imi maqisoornerup kingorna suli tassa sumiiffinni taama ittuni uuliaqarpoq. Sumiiffimmi naliliiviusumi sinerissat ilarpassui Prince William Sounditut pissuseqarput. Kiisalu sumiiffiup naliliiffiup sineriaa tamaanimiunit piniarfiullunilu aalisarfiuvoq, suliallu taakku uuliaarluernermit sunnigaasinnaapput. Imaannarmi uuliap arrornera uuliaarluernerup avatangiisinut sunniutaanik annikillisitsissaaq.

Uuliaarluerneq ukiukkut immap sikuaniilersinnaavoq annerusumillu nungujartorani ungasissorsuarmut ingerlanneqarsinnaalluni taamalu maqisoorfimmiit ungaseqisumi sunniuteqarsinnaalluni. Immalli sikua immamut sikuunngitsumut sanilliullugu aamma maqisoornermik killiliisinnaavoq. Taamaattorli immami sikuusumi uuliaarluernerup qanoq pissuseqarnera qanorlu naggateqarnissaa ilisimasaqarfigilluarneqanngilaq.

Sumiiffimmi naliliiffiusumi tamatumalu eqqaani sineriak uuliaarluernermut aamma misikkarereeqaaq. Siullermik pingaarnermillu Store Hellefiskebanke mitit aarrillu ukiiffigisartagaat. Erngit aporaaffii, sarfap nillikaaffii (*upwelling)* nunap avammut atanerata killinganiittut, upernaakkut uumasuaqqanit pinngorarfilluartartut, kiisalu naasuaqqat uumasuaqqallu erngup ikerani allami ittut uuliaarluernermut misikkarissinnaapput, pingaartumik immap naqqaniit maqisoortoqalersimappat, soorlu *Deepwater Horizonimi* 2010-imi ajutoorneqarmat taama pisimasoq. Store Hellefiskebankemi misissuinermi (Wegeberg et al. 2016) paasineqarpoq maqisoortoqarpat sumiiffiup 30 %-iani immap ikerani uulia toqunartutut kimitussuseqarluni naammattuugassaasinnaasoq.

Nalunaarusiami uani inerniliunneqartoq tassaavoq sumiiffimmi naliliiffiusumi sinerissamut eqquisumik annertuumik uuliaarluerneq sumiiffiup tamatuma tamarmi uumassusileqassusianut sunniuteqarsinnaasoq. Qanoq sunniuteqarnissaanut soorunami uuliap qanoq ittuussusia, maqisoorfiup sumiissusia silalu apeqqutaassapput. Pisulli ajornerpaaffianni (*worst case) Exxon Valdezip* 1989-imi ajutoornerata kingorna Alaskami pisuniit sivisunerullutillu ajornerussagunarput issittumiinnera pissutigalugu. Tamatuma timmisai miluumasuilu imarmiut ikilissapput taavalu sumiiffinni eqqugaasuni aalisarneq piniarnerlu ajornarallassallutik.

Uuliaarluernerli qaleraleqassusermut sunniuteqarunnangilaq, kisiannili aalisarneq sunnigaasinnaavoq sumiiffiup aalisarfigeqqusaajunnaarsinnaanera pissutigalugu. Ukiuunerani uumassusileqarfimmi uumasut pingaarutillit soorlu eqalukkat sunnigaasinnaapput. Taakku suaat qullugiaallu immap sikuata ataani katersuuttarput, taakkunanilu uuliarluerneq unerassaaq, taavalu suaat aalisakkallu qullugiaat amerlasuuppata toqorarujussuartoqarnissaa naatsorsuutigisariaqarpoq.

Timmissat immap qaani uuliaarluinermut misikkareqaat, sumiiffimmilu naliliiffiusumi misikkarissunik timmiaqarfippassuaqarpoq, uuliaarluerfiugunik assorsuaq toqorarfiusussaasut. Assersuutigalugu appat imeqqutaallallu erniorfissuaqarput, upernaakkut mitit appallu katersuuttartorsuupput, mitit siorakitsut ukiumi katersuuttarlutik ukiassalersumilu qeerlutuukkut alluumasartut isasarlutik.

Miluumasut imarmiut immap qaani uuliarluernermit sunnigaasinnaapput. Sumiiffimmi naliliiffiusumi aarrit navianartorsiortinneqarataannaapput neriniarfik pingaarutilik ataaseq amerlaqalutik katersuuffigisarmassuk. Taamaammat uumasut ilarpassui uuliaarluernermit annertuumit sunnigaasinnaassapput. Aarluit (taamalu arferit aamma allat) 1989-imi *Exxon Valdez*-ip ajutoornerata kingorna paasineqarput uuliarluernerup kingorna uuliap aalarnerinik najuussuinermikkut misikkarissuusut, uuliamillu maqisoortoqarpat taamaalisoqarataanaavoq (matuma kingulianiittoq takuuk). Matumani qilalukkat qernertat qaqortallu eqqugaassapput. Uumasulli ilaat qanoq amerlatigisut uuliaarluernerujussuarmit eqqugaassanersut naliluruminaappoq. Nannut pingaarlutik eqqortiasuupput uulia meqquinik oqorunnaarsitsisarmat, aammalu meqqutik aluttorlugit salittarmatigit taamaalillutillu uuliamit iiorakkaminnit toqunartutortinneqassallutik.

Immami sikulimi uuliaarluertoqarpat uulia qularnangitsumik sikup ikersisimanerini puttaallu ataanni katersuutissaaq, taamalu timmissanut miluumasunullu imarmiunut immamik ammaannartumik isumalluuteqartunut sunniuteqarsinnaassalluni. Puisit arferillu ammanersanut amerlanngitsunut allatut ajornartumik anersaariartortariaqartassapput, taakkunanilu uuliaqarpat uuliap aalarnerinik najuussueratarsinnaapput.

Sumiiffiit uuliamit sunnigaasut aalisarnermut piniarnermullu matuneqarpata aalisarneq piniarnerlu sunnigaasinnaapput. Matusisoqartarpoq aalisakkat pisat nioqqutigineqartullu uuliaarluersimasut (assersuutigalugu uuliasunnilersimasut) taamaattussatulluunniit pasineqaannartut pinngitsoorumallugit. Uuliaarluineq pissutigalugu aalisarnerup qaammaterpassuarni unitsinneqartarnera assersuutissaqarpoq. Aamma uuliaarluernerup kingorna piniagassat piuminaallinerunissaat ilimanaateqarsinnaavoq, kiisalu puisit amii tunisassaajunnaarsinnaapput uuliaarluersimagunik.

Ikkannersuarni maqisoortoqarpat (*blowout*) immap naqqaniilluunniit aniagaluaruni immap qaanut katersuutissaaq. Ikkannersuilli avataanni immami itisuumi maqisoortoqarpat Mexicop kangerliumarnangani *Deepwater Horizon*-imi uuliap pissusilersorneratut pissuseqarsinnaavoq. Tassami ajutoornermit uuliaarluernerujussuaq immap naqqanit itisoorsuarmit aallaaveqarpoq (1500 meterit missaannit). Tamatuma kingunerisaanik immap ikera annertoorujussuaq uuliaarlernersaqalerpoq. Uulia tamaaneerusaaginnarpoq sumorsuarlu siammarluni.

Sumiiffiup naliliiffiusup issittumiinnera, tassa nillernera, sikuusarnera, kaperlattarneralu silarlukkajuttarneralu pissutigalugit uulia maqisuugaq kigaatsuinnarmik nungujartortarpoq taamalu kujasinnerusumiittunut sanilliullugu avatangiisinut sunniinera sivisunerusarluni. Tamatuma saniatigut uuliaarluernerup akiornissaa killeqartarpoq, pingaartumik ukiuunerani.

Aammattaaq takuuk tabel 1 eqikkaaviusoq sulianik kiisalu taakku sunniutaannik naliliiviusoq.

Sunniutinik pinaveersaartitsineq

Uuliaqarneranik misissueqqissaarnermit qalluinermiillu avatangiisinut sunniutit pitsaanerpaamik pinaveersaartinneqarsinnaapput avatangiisit suliffiussat sunnigaannginnerini avatangiisit pillugit ilisimasanik sukumiisunik pigisaqarnikkut kiisalu suliarineqartussat pilersaarusioqqissaarnerisigut. Tamatuma saniatigut periaatsinik kiisalu avatangiisitigut periaatsinik pitsaanerpaanik atuinikkut, kiisalu nunat tamalaat piumasaqaataanik, soorlu OSPAR-ip aalajangersagaanik nunallu tamalaat ilitsersuutaannik (soorlu Issittumi Siunnersuisoqatigiit) malinninnikkut silaannarmut imaanullu aniatitsinerit akuerineqarsinnaasumut killilerneqarsinnaaput ajutoortoqarsinnaaneralu ilimanannginnerulersinneqarsinnaalluni.

Aammattaaq oqartussat avatangiisitigut aqutsinerat avatangiisit allanngortinneqartigatik qanoq issusii pillugit ilisimasanik sukumiisunik tunngaveqassaaq malittarisassat eqqorluartooqqullugit aammalu mianersuussinissaannarmik tunngaveqaqqunagit. Malittarisassaqartitsinikkut ingerlatseqatigiiffiit piumasaqaatigineqartunik malinninnissaat qularnaarneqassaaq.

Tabel eqikkaaviusoq 1. Sunniutinut malunniutinillu naliliinernut takussutissiaq. Suliat taakkulu avatangiisinut sunniutaat takuinneqarput. Taamaaratarsinnaasoq. Siammasissusia: Najukkami tassaavoq suliap piffiata eqqaa. Nunap immikkoortua tassaavoq nunap immikkoortua suliniutip ingerlanneqarfigisaa – matumani tassaalliuni sumiiffik naliliiffiusoq. Sivisussuseq: Sivikitsoq tassaavoq piffissaq killilik – ukiut qassinnguit tikillugit – sunnikkat pissusitoqqamissut ileqqinnissaasa tungaannut. Misissueqqissaarluni suliat taamaakkajupput. Sivisooq tassaavoq piffissaq sivisunerusoq, ilaanni sivisoorujussuusartoq, assersuutigalugu uuliamik qalluiffiup piffissaq sunniuteqarfigisaa kiisalu sunniuteqartuaannarfigerataanaasaa. Sunniutip annertussusia: Annikitsoq tassa suliap uninnerata kingunitsianngua sunniutit uuttorneqarsinnaannginnerat uumassusileqarfiillu allannguuteqannginnerat. Akunnattoq tassaavoq najukkami sunniutit, pissusitoqqamissut eqqilernissaasa tungaanut piffissaq sivisusinnaavoq, kisiannili sumiiffimmi killilimmi pinerat pissutigalugu uumassusileqarfinnut annerusumik kinguneqanngitsoq. Annertooq tassaavoq uumasoqatigiit ima ikilitigigaangata naqqeqqinniarnerisa kinguarsarneqarnerat imaluunniit sananeqaatit mingutsitsisuusut pillugit killiliussat annertuumik sumiiffimmilu annertuumi sivisunerusumik qaangersimaneqarnerat. Annertoorujussuaq tassaavoq uumassusileqarfiit immikkoortortaat amerlasuut sunnersimaneqarnerat, aamma uumassusileqarfiit tamaani najugaqartut isumalluutigisaat.

Sunniut	Aallaavik	Kinguneri	Suliap killiffia	Siammarsimanera	Sivisussusia	Eqqorneqariaannaat (VEC)	Sunniutip annertussusia	Nassuiaat
Immap iluani nipiliorneq	Sajuppillatsisisarluni misissuineq, umiarsuit angallanerat	Miluumasut imarmiut aalisakkallu nujoqqatsinneqarnerat	Misissueqqissaarneq	Nunap immikkoortuani	Sivikitsumik	Qilalukkat qernertat, arfiviit, qilalukkat qaqortat, aarrit, aalisarneq	Annertusinnaasoq	Uumasoqatigiit ikileriarsinnaapput neriniarfiit suffisarfiilluunniit qimanneqarpata. Aalisarneq ataavartuunngitsumik sunnerneqassagunarpoq Piffimmi ataatsimi sajuppillatsisisoqartarpat sunniutit kattussinnaaput.
			Qalluineq	Najukkami	Sivisuumik			
Marrarmik perrassaammik qillernerlukunillu aniatitsineq	Umiarsuit qilleriviit qilleriviillu	Marranngornerit, nigguusartikkat, akuutissat toqunartullit	Tamarmik	Najukkami	Sivisuumik	Immap natermiui	Akunnassinnaasoq	Piffimmi ataatsimi qillerinerit qassiiuppata sunniutit kattussinnaapput
Produktionsvand	Uuliamik qalluiviit	Mingutsitsineq	Qalluineq	Nunap immikkoortuani	Sivisuumik	Eqalukkat suaat quperluusaallu, uumasuaqqat naanerillu pinngorarfigilluagaat	Annertusinnaasoq	Piffimmi ataatsimi qillerivinnit aniatitsinerit qassiiuppata sunniutit kattussinnaapput
Uumasut tikiussat	Umiarsuit	Tamatuma uumasuisa ingiarneqarnerat	Qalluineq	Nunap immikkoortuani	Sivisuumik	Uumassusileqarfik	Akunnassinnaasoq	
Imikoorut	Qilleriviit umiarsuillu	Naggorissaatitut sunniunneri, akuutissanik mingutsitsineq	Misissueqqissaarneq	Najukkami	Sivikitsumik	Uumassusileqarfik	Annikitsoq	Piffimmi ataatsimi qillerivinnit aniatitsinerit qassiiuppata sunniutit kattussinnaapput
			Qalluineq	Najukkami/Nunap immikkoortuani	Sivisuumik	Uumassusileqarfik	Akunnassinnaasoq	
Gassinik kiatsinnartunik aniatsineq	Maskiinat	Sila pissusiata allanngorneri	Misissueqqissaarneq	Nunarsuarmi	Sivisoorsuaq	Issittumi uumassusileqarfik		
			Qalluineq	Nunarsuarmi	Sivisoorsuaq			
Sanaartukkat illullu	Nunami immallu naqqani sanaartukkat	Uumaffiit annaaneqarnerat, nutaanik uumaffeqalernerat, isikkui		Najukkami	Sivikitsumik	Uumassusillit qaqutigoortut killilimmik siammarsimasut, immap natermiorpassui	Annikitsoq	Uumasoqarfiit innarliasut assersuutissat: Koraleqarfiit 2017-imi nassaat, eqaluit majortarfii, kujasinnerusumi kilisanneq
			Qalluineq	Najukkami	Sivisuumik		Annertusinnaasoq	
Assartuineq	Umiarsuit, timmisartut, qulimiguullit	Uumasut akornusersorneqarnerat / nujoqqatsinneqarnerat	MIsissueqqissaarneq	Najukkami	Sivikitsumik	Aarrit, nerlerit qerlutuullut isasut, timmissat imarmiut piaqqiorfii	Annikitsoq	
			Qalluineq	Nunap immikkoortuani	Sivisuumik		Annertusinnaasoq	
Inuit angallannerat	Annermik nunami atortulersuutit	Uumasut akornusersorneqarnerat / nujoqqatsinneqarnerat	Misissueqqissaarneq	Najukkami	Sivikitsumik	Aarrit, nerlerit qerlutuullut isasut, timmissat imarmiut piaqqiorfii	Annikitsoq	
			Qalluineq	Najukkami	Sivisuumik		Annertusinnaasoq	
Uuliaarluerneq annertoq	Umiarsuarni sullilinnilu ajutoornerit, uuliaqarfiit immalluunniit naqqani tissaluttoornerit	Ipertiterineq, toqunartoqalersitsineq, toqqaannartumik toqorartut, toqunanngitsumik sunniutit	Qillerineq assartuinerlu	Nunap immikkoortuani	Sivisuumik	Uumassusileqarfiit ilivitsut, innarlianerpaapput timmissat imarmiut, natermiut aalisakkallu ikkattumi suffisartut	Ingasassinnaasoq	

Upalungaarsimaneq akiuiniarnerlu

Uuliaarluerneq siullermik periaatsinik pitsaanerpaanik aammalu avatangiisitigut periaatsinik (BAT aamma BEP) pitsaanerpaanik atuinikkut, qaffasissunik tunngavissarissaartunillu malittarisassiornikkut pinngitsoortinneqassaaq. Uuliaarluernerilli pippata pingasuitsigut akiorneqarsinnaapput: katersuineq, akuutissat atorlugit siammartitsineq aammalu ikuallaaneq.

Katersuinerit Amerikami 1989-imi 2010-imi uuliaarluernerujussuarni iluatsingaarfiusimanngillat imarlu suliffiginiagaq sikuuppat katersuinerit ajornakusuussallutik. Aamma assartuinerujussuaq pisariaqassaaq. Periaaserli uuliaarluernerni annikitsuni annermik atorsinnaavoq.

Akuutissat atorlugit siammartitsinermi uulia imerpallappallaartinnagu akuutissat siammarterutissat atortariaqarput, tamatumanilu sikut nillerneralu piffissamik suleriarfiusinnaasumik sivitsuisinnaapput. Siammartitsinikkut uulia immap qaaniit ikeranut nuutsinneqassaaq, ikerinnarmiinnerniilu uumassusilinnut allanut sunniuteqarsinnaalluni. Periaaseq taanna atussagaanni atulertinnagu avatangiisit sanilliussilluni oqimaalutarneqartariaqarput ((SIMA, *Spill Impact Mitigation Assessment*),). Aammali uuliap annikitsuaranngorlugu imermi siammarneratigut isumaminik nungujartortinneqarnissaa sukkanerulersinneqarsinnaalluni. Uuliap isumaminik ungujartortarnera Kalaallit Nunaata imartaani killeqarpaseqaaq immap inuussutissartakitsuararsuunera taamalu uumasuarakinnera pissutigalugu.

Ikuallaaneq issittumi isumalluarnaateqartoq paasineqarsimavoq, taamaaliornerilu sikup aalaakaasup uulia uninngatissinnaavaa. Maannamullu taamaallaat misileraanikkut misilittarneqarsimavoq. Aamma nalorninarpoq sumiiffimmi naliliiviusumitulli saatsersunik sikulimmi ilumut periaaseq atorneqarsinnaanersoq.

Kiisalu, uuliaarluernermik akiuiniutit imminni avatangiisinut sunniuteqartarput. Sinerissami uuliamik katersuineq naanernut uumasunullu assorsuaq sakkortusinnaavoq, siammarterutit imminni toqunartoqarput kiisalu ikuallaaneq paarujussuarmik silaannarmut qangatakkaatitsiviusarpoq immallu qaani kinnganeqalersitsisarluni. Pissutsit tamakku periaatsinik atuinnginnermi nalilersussallugit pingaaruteqaqaat (*Environment & Oil Spill Response tool*, EOS), ilaatigullu suliat ingerlannerini atornissaat nalilersugassallutik (*Uuliaarluernerup sunniutaanik minnerpaatitsiniutinik naliliinerit*, (*Spill Impact Mitigation Assessment*) SIMA).

Sumiiffinnik killiliineq pillugu Danmarkimi Avatangiisinik Nukissiutinillu Misissuisoqarfiup kiisalu Pinngortitaleriviup kaammattuutaat

2020-2024-imi Kalaallit Nunaanni uuliasiorluni suliani periusissamut (Mosbech et al. 2019) nutaamut ilanngussaminni Danmarkimi Avatangiisinik Nukissiutinillu Misissuisoqarfiup kiisalu Pinngortitaleriviup kaammattuutigaat isumannaallisaanermi uuliaarluernissamullu upalungaarsimanermi piumasaqaatit qaffasinnerpaat atorneqarnerat ingerlaqqissasoq. Aamma nassuiaatigineqarpoq immami saatsersunik sikulimmi kaperlanneratalu nalaani (soorlu sumiiffimmi naliliiviusumi ukiuutillugu taamaattartoq) uuliaarluernermik akiuinissaq suli ajornartoq. Tamatuma malitsigisaanik Kalaallit Nunaata imartaani ukioq kaajallallugu uuliaqarneqarneranik misissueqqissaarnissaq qalluinissarlu avatangiisitigut illersorneqarsinnaalissappata periaatsini tamakkunani atortorissaarutitigut annertuumik ineriartortitsisoqaqqaartariaqarpoq.

Kiisalu kaammattuutigineqarpoq uumassusileqarfiit immikkut pingaarutillit qassissuit uuliaqarneranik misissueqqissaarfigineqassanngitsut, soorlu Qeqertarsuup Tunua kiisalu Store Hellefiskebanke (Assiliartaliussaq 95).

Ilanngussakkut tassuunattaaq Danmarkimi Avatangiisinik Nukissiutinillu Misissuisoqarfiup kiisalu Pinngortitaleriviup kaammattuutigaat sinerissat uuliaarluernermut misikkarilluinnarnerat pillugu immikkut aamma isiginiarneqassasut.

Kiisalu immami sikulimmi uuliaarluernermik akiuiniarneq ajornartorsiutitaqarpoq. Sikoqartinnagu misissueqqissaarnerit ingerlanneqarsinnaaput, qalluinerli sikuunerata nalaanissaaq ingerlasassaaq. Imartani ukiukkut sikuusartuni misissueqqissaarneq akuerigaani akiuiniarnissamut ajornartorsiornissaq naatsorsuutigineqareersinnaavoq.

Pingaartumik sikup sinaava ukiukkut kingusissukkut upernaakkullu naasuaraasat, aalisakkat qullugiaasa pinngoraleruttorfianni taavalu timmiaqarlunilu imarmiunik miluumasoqaleruttorfiani uumassusinittarpoq.

Sumiiffinnik killiliinermi nunat tamalaat malittarisassaat

Imartani sikuusuni uuliaarluernermik akiuiniarnerup ajornakusoornera pissutigalugu imartani sikusartuni uuliaqarneranik misissueqqissaartarneq nunani tamalaani aarlerigineqariartuinnarpoq, Ruslandilu kisiartaalluni ullumikkut issittumi imartamini qalluisuuvoq.

Alaskami Issittup imartaani massakkut uuliaqarneranik misissueqqissaarneq matoqqatinneqarpoq.

E2017-imi Europaparlamentip issittup imartaani sikusartumi qillerinernik aarleqquteqarnerarpoq inerteqqutaalernissaanillu ujartuilluni (Link).

Canadami *Nunavumi Sunniutinik Naliliisarfik* (*Nunavut Impact Board)* Davis Strædemi Baffinillu Ikerani uuliaqarneranik misissueqqissaarnernik unitsitsinerup ukiunik qulinik sivitsorneqarnissaanik kaammattuuteqarpoq (NIRB 2019a).

Norgep inatsisartui (Silap Pissusaanut Avatangiisinullu Immikkoortortaq 2020) aalajangerput uuliaqarneranik misissueqqissaarfiusartut avannamut killeqarfiat tassaassasoq apriilip (qaammatip sikoqarnerpaaffiusartup) ulluisa 15%-iisa sikunik naammattuugassaqarfiat. Taamaammat siusinnerusukkut atugaq 30 % avannarpasinnerusumi inissisimavoq. Bergenimili Norgemiut Issittumik Ilisimatusarfiata Immanillu Ilisimatusarfiata ilisimatuussutsikkut kaammattuutigaat killeqarfik tassaasariaqartoq ullut 0,5 %-imik sikoqarfigisaat. Killiliussat taakku Kalaallit Nunaata imartaani (kisianni apriilimi pinnani marsimi, tassami marsi Davis Strædimi Baffinillu Kangerliumarngani sikuunerpaaffiusarmat) taava killeqarfiit taakku marluk Qeqertarsuup Kitaani sumiiffiup naliliiffiusup kujataaniissasut takuneqarsinnaavoq (Assiliartaliussaq 96).

Barentshavimi kiisalu Kalaallit Nunaata kitaata imartaani uumassusileqarfiit assigiissuteqarlutillu assigiinngissuteqarput, assersuutigalugu Kitaani sikup sinaa Barentshavimisulli pingaaruteqartiginngilaq.

Kiisalu Norgep avannaani sineriammiit 35 km tikillugu uuliaqarneranik misissueqqissaarfigineqartussaanngilaq kiisalu sumiiffiit uuliaarluernermut misikkarilluinnartuugaangata avammut 65 km killiliiisoqartarluni. Periaaseq taanna Qeqertarsuup Kitaani sumiiffimmi naliliiviusumi atorneqarpat Davis Strædep Baffinip Kangerliumarngatalu tungaanut sineriak tamarmik 35 km-inik misissueqqissaarfiusussaanngitsumik killiliivigineqassaaq (Assiliartaliussaq 95).

Inerniliussaq

Pissutsit pingasut pissutigalugit – uumassusileqarfiit pingaarutillit, sinerissat innarliasut kiisalu ukiukkut sikuusarnera – aammalu nunat tamalaat akornanni (pingaartumik norgemiut piumasaqaataat) avatangiisitigut piumasaqaatit qaffasinnerpaat malikkumallugit Danmarkimi Avatangiisinik Nukissiutinillu Misissuisoqarfiup kiisalu Pinngortitaleriviup kaammattuutigaat piffissami ingerlaavartumik periusissiorfiusumi 2020-2024-imi Qeqertarsuup Kitaani sumiiffimmi naliliiffiusumi uuliasiorluni gassisiorluniluunniit sulianik ammaassinissaq isumaliutigineqassanngitsoq.

1 Introduction

In 2006, the Disko West area was opened for oil and gas exploration and a strategic environmental impact assessment (SEIA) was prepared (Mosbech et al. 2007a) as a part of the opening process. Licences were granted in 2007 and 2008 and five exploration wells were drilled in 2010 and 2011. The SEIA was updated in 2013 primarily with data obtained through a dedicated research programme, based on a data gab analysis and carried out by Aarhus University and Greenland Institute of Natural Resources (Boertmann et al. 2013). In relation to the opening of the Disko West area for 'open door' applications in September 2020 (postponed to November 2020, due to the Covid-19 situation) the 2013-edition of the SEIA needed an update being more than 5 years old (Mosbech et al. 2019).

This update was funded by the former Ministry of Industry, Energy, Science and Labour (today Ministry of Foreign Affairs and Energy) and the Environmental Agency for Mineral Resource Activities (EAMRA) of the Greenland Government and prepared by DCE – Danish Centre for Environment and Energy at Aarhus University and the Greenland Institute of Natural Resources (GINR).

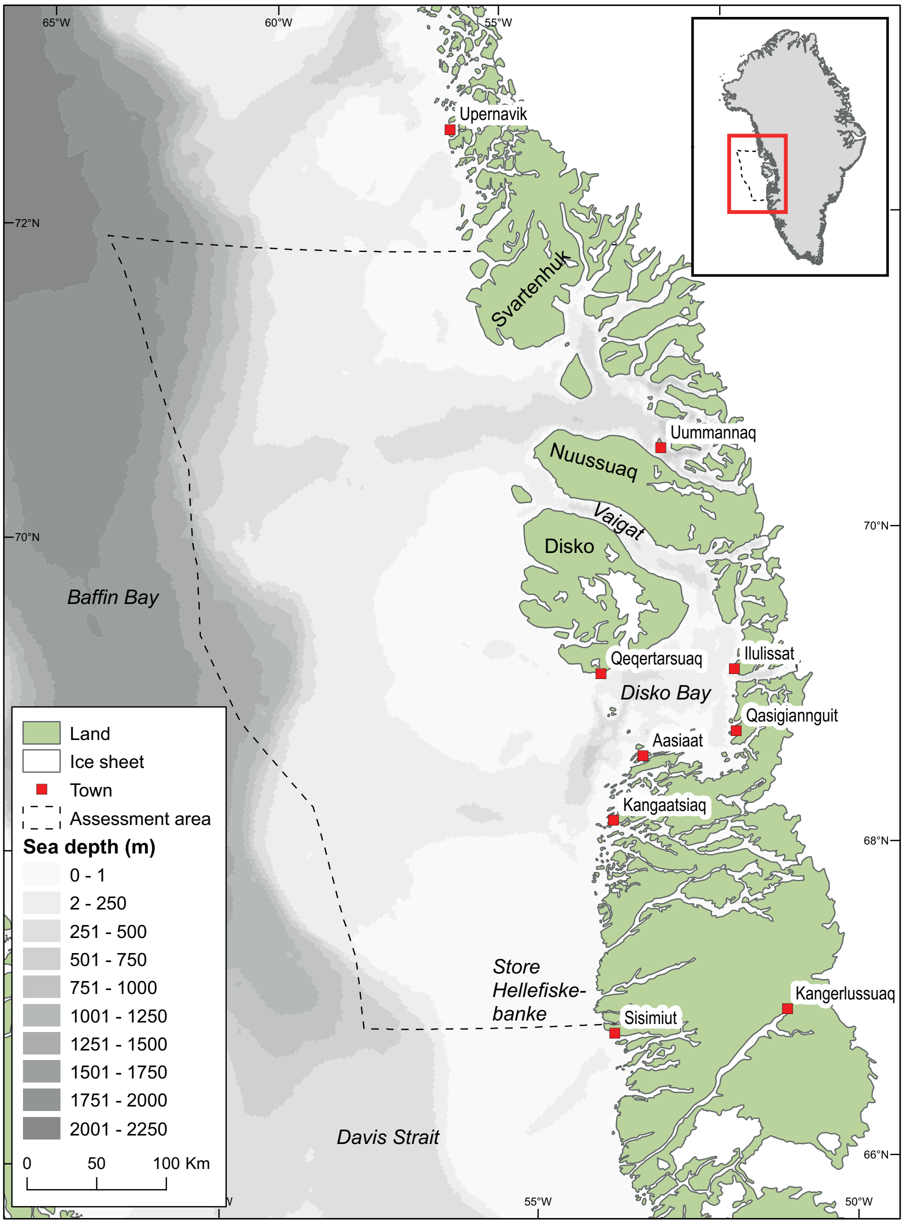
It is important to stress that a SEIA does not replace the need for site-specific Environmental Impact Assessments (EIA's). The SEIA provides an overview of the environment in the assessment area and adjacent areas which may potentially be impacted by the activities, and it identifies major potential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

An important issue in this Arctic context is climate change, which affects both the physical and the biological environment. For example, the sea ice cover is shrinking in both space and time, which in turn will impact the ecology and in particular the wildlife dependent on the ice, such as seals, polar bears and ivory gulls. Even though the new data included in this assessment is up to date, the environmental changes will proceed. The potential development of a producing oil field may begin more than 10 years from a licence is granted, and by then environmental conditions may 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 oil and gas activities, particularly from accidental oil spills originating from activities in the licence round area (Figure 1). This area will be referred to as 'the assessment area'. However, the oil spill trajectory models developed by Danish Metrological Institute (DMI) indicate that oil may drift further, outside the boundaries of this area, into the Canadian EEZ and northwards into the assessment area of the SEIA covering the eastern Baffin Bay (Nielsen et al. 2008, Boertmann et al. 2017).

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



The land areas are not included in the present report, but a SEIA of onshore exploration and exploitation activities on Disko Island and Nuussuaq Peninsula (adjacent to the assessment area) has been prepared (Wegeberg et al. 2016a).

1.2 Impact assessment methodology

The assessment includes activities associated with the full life cycle of an oil field, i.e. from exploration to decommissioning, see Chapters 6 and 7.

Exploration activities are expected to take place in the open water window that is from June through November, while production activities, if initiated, are likely to take place throughout the year.

Since it is not practically possible to evaluate all ecological components in the area, the concept of Valued Ecosystem Components (VEC) has been applied (see also Chapter 1.2).

The potential impact on VEC's of activities during the various phases of the life cycle of a oil and gas license area are summarised in a series of tables in

Chapter 7 (Tables 19, 20, 21). The tables are based on worst-case scenarios for impacts, under the assumption that current guidelines for the various activities, as described in the text, are in force.

Potential impacts listed in these tables are assessed under three headings: displacement, sub-lethal 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. Sub-lethal effects include all notable fitness-related impacts, except those that cause immediate mortality of adult individuals. This category thus includes impacts that decrease fertility or cause mortality of juvenile life stages. Sub-lethal effects and direct mortality are classified as none, insignificant, minor, moderate or major. A dash (–) is used when it is not relevant to discuss the described effect (if no species or ecological components are vulnerable to a given activity).

The scale of a potential impact is assessed as local or regional. Impacts may be on a larger scale than local either if the activity is wide-spread or impacts populations originating from a larger area (for example migratory birds), or a large part of a regional population (for example a large seabird colony).

It should be emphasised that quantification of the impacts on ecosystem components is difficult and, in many cases may have very high uncertainties. There are too many unknowns, for example, the spatial overlap of expected activities can only be estimated as no licences are active in the area. Another unknown is the physical properties of potentially spilled oil. On the other hand, knowledge concerning important ecosystem components and how they interact has been improved since the previous edition of this assessment. Finally, climate change is now seriously impacting ecosystem functioning, potentially altering many of the interactions.

Relevant literature regarding toxicology and ecotoxicology of petroleum related compounds and their effects, as well as the sensitivity of organisms to disturbance is included. Conclusions from various sources – the Arctic Council Oil and Gas Assessment (AMAP 2010a), the extensive literature from the *Exxon Valdez* oil spill in Alaska in 1989 (e.g. Shigenaka 2014, Esler et al. 2016), the increasing literature from the *Deepwater Horizon* spill in 2010 (e.g. Beyer et al. 2016) as well as from the Norwegian SEIAs of oil and gas activities, for example in Lofoten-Barents Sea (Anonymous 2003) – have been drawn upon. See also Chapter 6 for more detailed accounts of the effects of the two spills *Exxon Valdez* and *Deepwater Horizon*.

Since the first version of this report, the assessment area have been included in reports describing effects of oil spills in particularly sensitive areas (Store Hellefiskebanke), of shipping and in a regional designation of important biological areas (Christensen et al. 2015, 2016, 2017, Wegeberg et al. 2016a, b). Also the AMAP (2017) report on 'Adaptation Actions for a Changing Arctic. Perspectives from the Baffin Bay/Davis Strait Region' include the assessment area with many different and highly relevant topics.

Many uncertainties remain and expert judgement or general conclusions from research and EIA's carried out in other Arctic areas have been applied in order to evaluate risks and to assess the impacts. Uncertainties in the assessments are inevitable and this is conveyed with phrases such as "most likely" or "most probably".

For all species with well-established vernacular names – mammal, bird and most fish – English names are used throughout; the scientific Danish and Greenlandic names for those species are listed in Annex A.

Please consult Annex B for a comprehensive list of abbreviations and acronyms used in this report.

1.2.1 Glossary to some terms used in the SEIA

Environmental pressures. These are the results of specific human activities in the environment. The activities can for example be hunting and fishing, shipping or mineral extraction and on a larger scale also climate change. The term 'stressor' is often used in this context.

Environmental impact. Or only impact is the way a specific pressure act on the environment. It is less specific than effect, and used in the sense of impact on an environmental element for example the impacts of a seismic survey on the population of narwhals. See also environmental effect.

Environmental effect. Or only effect is the result of a specific impact for example the toxic effect of a chemical in the drilling mud or the effect of noise generated by a seismic survey such as displacement or temporal hearing loss. See also environmental impact. Effects and impacts are to some extend synonyms.

Sensitive. This is an intrinsic characteristic of the ecological elements (organisms, processes – VEC's), independent of human activities. For example narwhals are particularly sensitive to underwater noise. See also vulnerable, a term which sensitive to some degree overlaps with in meaning.

Vulnerable. This term includes the risk of being exposed to an impact, why it is a combination of being sensitive and risk of being impacted. For example, narwhals - because they are sensitive to underwater noise - will be vulnerable to a planned seismic activity. See also sensitive, a term, which vulnerable to some degree overlaps with in meaning.

Environmental risk. This describes the likelihood and consequence of an impact on the environment as a result of a human activity, for example from exploration drilling.

The terms petroleum, hydrocarbons and oil and gas are often used more or less as synonyms. In this report, oil and gas will be used when referring to activities, petroleum when referring to oil related substances (e.g petroleum hydrocarbons) and hydrocarbons when referring to specific compounds (e.g. polycyclic aromatic hydrocarbons).

2 Physical environment

Christian Mohn (AU), David Boertmann (AU) & Michael Dünweber (AU)

This section provides a short account of some of the most important physical components of the assessment area. Other components are treated by the Danish Meteorological Institute (Valeur et al. 1996, Pedersen et al. 2011). Information can also be found in the oil spill sensitivity atlases prepared for the assessment area (Clausen et al. 2012) and in the AMAP assessment 'Adaptation Actions for a Changing Arctic, Perspectives from the Baffin Bay/Davis Strait Region' (Brown et al. 2017).

The assessment area covers the north-eastern Davis Strait and the south-eastern Baffin Bay (Figure 1). 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 surface 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 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 and inland permafrost is also widespread. West of Disko Island, the sea-ice normally forms in November and melts early June, depending on the severity of the winter (Pedersen et al. 2011). 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 coastline in the Disko West Assessment Area (67°-72° N) is traversed by numerous fjords, many of them acting as direct links between the inland ice sheet and the ocean. Moreover, many islands are scattered directly off the coast resulting in an extremely long coastline and a variety of shallow benthic habitats. The continental shelf extends up to c. 200 km offshore. A mix of shallow banks (< 50 m) and deep troughs (>300 m) results in a highly complex bathymetry in the shelf area. Off the continental slope, the southern part of the assessment area consists of the Davis Strait sill (< 1000 m depth), bordering on the Baffin Bay (up to >2000 m depth) to the north. This sill influence the water exchange and particular prevents exchange of deep waters between the Baffin Bay basin and the Labrador basin.

2.1 Weather and climate

The weather in this region is determined by the North American continent and the North Atlantic Ocean. However, the Greenland Ice Sheet and the 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 including the assessment area. Also more local phenomena such as fog or polar lows are common features near the West Greenland shores. The probability of strong winds increases close to the Greenland coast and towards the Atlantic Ocean. Detailed descriptions on local weather can be found in the sensitivity map of the region (Clausen et al. 2012).

2.2 Oceanography

2.2.1 Currents

The classical view of the general large-scale circulation in waters west of Greenland is presented in Figure 2. The circulation between the northern Labrador Sea and the Baffin Bay follows a counter-clockwise pattern and is intensified along the western boundary (Curry et al. 2014). Cold *Arctic Water* flows southward in the western Baffin Bay and leaves Davis Strait as the broad and surface-intensified *Baffin Island Current*. Along West Greenland, the eastern boundary of the Davis Strait is characterised by two principal current systems, the *West Greenland Current* and the *West Greenland Slope Current*. The *West Greenland Current* is an extension of the *East Greenland Current* with substantial supplies from the *East Greenland Current* coastal inflow and glacial runoff (Sutherland & Pickart 2008). The *West Greenland Current* carries low salinity water northward along the inner West Greenland shelf in near-surface layers (0-150 m). On its way north, this water is further diluted by run-off water from the various fjord systems. The *West Greenland Slope Current* originates in the northern North Atlantic and Irminger Sea. It carries relatively warm and high salinity water northward along West Greenland up to Thule (Qaanaaq) in the depth range 150–800 m. At approximately 64° N, the bulk of the North Atlantic inflow passing South Greenland is deflected westward towards the northwestern Labrador Sea (Curry et al., 2014). The Arctic outflow along the western boundary of Baffin Bay and Davis Strait, the *Baffin Island Current*, merges with the outflow from Hudson Strait and the westward retroflection of the Atlantic inflow to feed the southward flowing *Labrador Current* (e.g. Straneo & Saucier 2008).

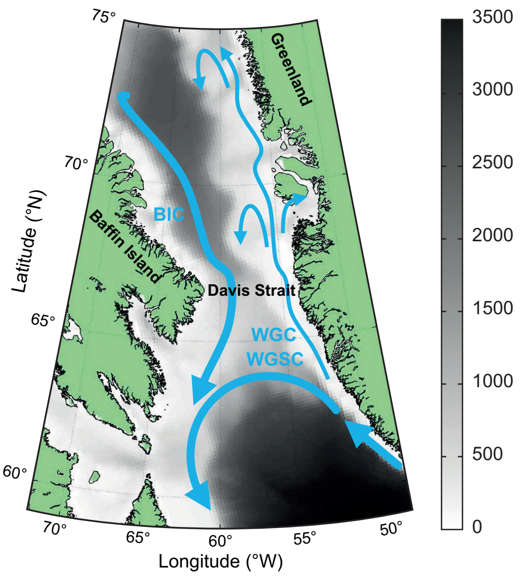


Figure 2. The classical view of the general circulation through Davis Strait along West Greenland, Baffin Bay and in the northwestern North Atlantic based on Curry et al. (2014). Cold Artic Water (AW) leaves Davis Strait as the broad, surface-intensified Baffin Island Current (BIC). The colder, less saline West Greenland Current (WGC) flows northward on the West Greenland inner shelf. The warmer, more saline West Greenland Slope Current of North Atlantic origin largely follows the continental slope in the depth range 150-800 m and is deflected westward at approximately 64° N latitude. The bulk of the Atlantic inflow is deflected westward at approximately 64° N latitude. Grey contours show the bathymetry derived from the TOPAZ4-Hycom model bathymetry in m (from the Copernicus web-site Link). The blue rectangle indicates the location of the assessment area.

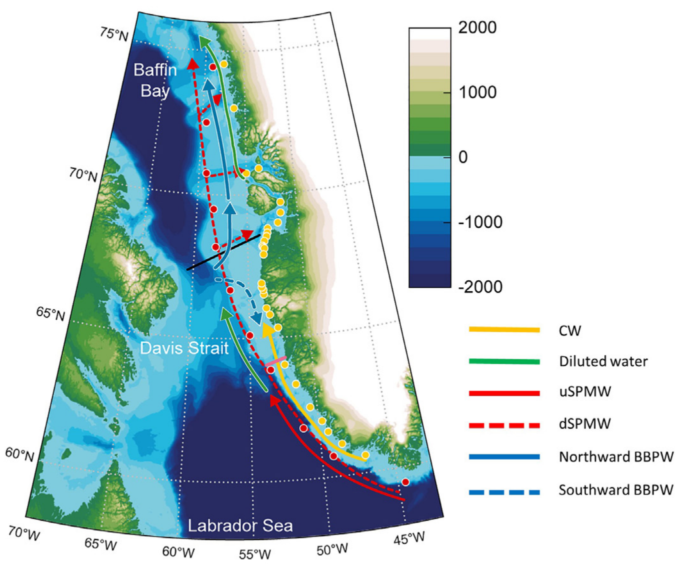


Figure 3. Updated view of water masses and circulation in the Davis Strait and West Greenland coastal system after Rysgaard et al. (2020, their Figure 1). Red dots show sampling stations on the continental slope, yellow dots show sampling stations along the coast section (see description in Rysgaard et al., 2020). Red lines show the distribution of warm upper Subpolar Mode Water (uSPMW) associated with the WGSC. Dotted red lines show distribution of deep Subpolar Mode Water (dSPMW). Blue lines show the distribution of cold Baffin Bay Polar Water (BBPW). Broken blue line shows the southward transport of BBPW. Yellow line shows the distribution of Southwest Greenland Coastal Water (CW). The suggested circulation system in 2016 is indicated by arrowheads representative of early summer.

Recent research has revealed a new and updated picture of water mass distribution and currents along the West Greenland coastal system between Cape Farewell (59° N) and Melville Bay (75° N) based on one of the first near-synoptic hydrographic assessments ever conducted in the area (Rysgaard et al. 2020). The main findings of the study are a distinct north-south division of water masses and flow patterns, but also a division of water mass properties between slope and coastal areas (see Figure 3). Warmer upper Subpolar Mode Water (uSPMW) associated with the *West Greenland Slope Current* is blocked by Southwest Greenland coastal waters and diluted *Baffin Bay Polar Water* and was not identified north of 64° N. In contrast, *deep Subpolar Mode Water* was found to continue northward via deep open pathways and enter coastal fjords. The blockage of uSPMW in the *West Greenland Current* is associated with the presence of a previously undetected southward flow of cold and saline *Baffin Bay Polar Water* at the SW Greenland continental shelf (Rysgaard et al. 2020).

Along the Greenlandic west coast the current patterns tend to follow the bathymetry along the coast (Ribergaard et al. 2004, Rysgaard et al. 2020). 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 (Figure 4). The southern part of the assessment area, south of the entrance to Disko Bay is characterised by shallow regions and islands, which affect the current pattern at the entrance to the Bay to a large extent (Söderkvist et al. 2006).

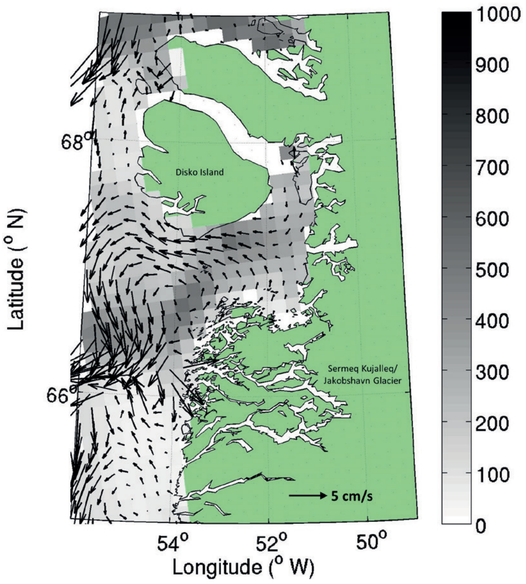


Figure 4. Near-surface circulation in the assessment area (Disko Bay and the West Greenland shelf) averaged over a period of 5 years (2013–2017). Currents are obtained from the TOPAZ4-Hycom coupled hydrodynamics sea-ice model (from the Copernicus website Link). Grey contours show the bathymetry (m).

Disko Bay is a semi-enclosed bay located on the west coast of Greenland at approximately 69° N. It is bounded by Disko Island to the North and by the Greenland coast and a variety of fjords and inlets to the East. Water mass properties, circulation and biological production in Disko Bay is strongly influenced by the combined effect of oceanic inflow from the Davis Strait and freshwater discharge from Jakobshavn Glacier, the most ice productive glacier in the Northern Hemisphere (Motyka et al. 2011). The circulation in Disko Bay is directed counter-clockwise and mainly driven by a combination of inflow of coastal shelf waters such as *Baffin Bay Polar Water* and *deep Subpolar Mode Water* from the *West Greenland Current* (Rysgaard et al. 2020) and inflow of coastal shelf waters and local processes (Hansen et al. 2012b). Surface waters in the bay in summer are dominated by a mixture of glacial melt water and waters from Baffin Bay. This leads to a decrease of surface water salinities from the oceanic areas outside the bay, to more coastal areas close to Jakobshavn Glacier (Hansen et al. 2012b). Near-bottom waters in the bay are dominated by higher salinities of Atlantic origin waters carried northward by the *West Greenland Current* and diverted into Disko Bay by topography. The injection of warmer and saltier bottom waters into Disko Bay has intensified since the late 1990s in connection with a weakening of the *Atlantic meridional overturning circulation* (Böning et al. 2016).

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).

2.2.2 Fronts

Frontal systems are areas where different water masses meet with sharp boundaries and steep property gradients between them. This could result in upwelling events where cold nutrient rich water is forced upwards to near-surface layers, or constitute sharp transitions between different water masses and ice edges inclusive the marginal ice zone (Mortensen et al. 2011). Tidally driven periodic upwelling and downwelling often occurs along the steep sides of the banks (Pedersen et al. 2005). Model simulations predict that upwelling frequently occurs west of the banks, both north and south of the entrance to Disko Bay and at the slopes of Store Hellefiskebanke and that there are strong vertical water movements on the banks as well (Figure 5, 6, 7). The upwelling events inside the Disko Bay and along the west coast of Disko Island are mainly wind driven during northerly and north-westerly winds (Söderkvist et al. 2006).

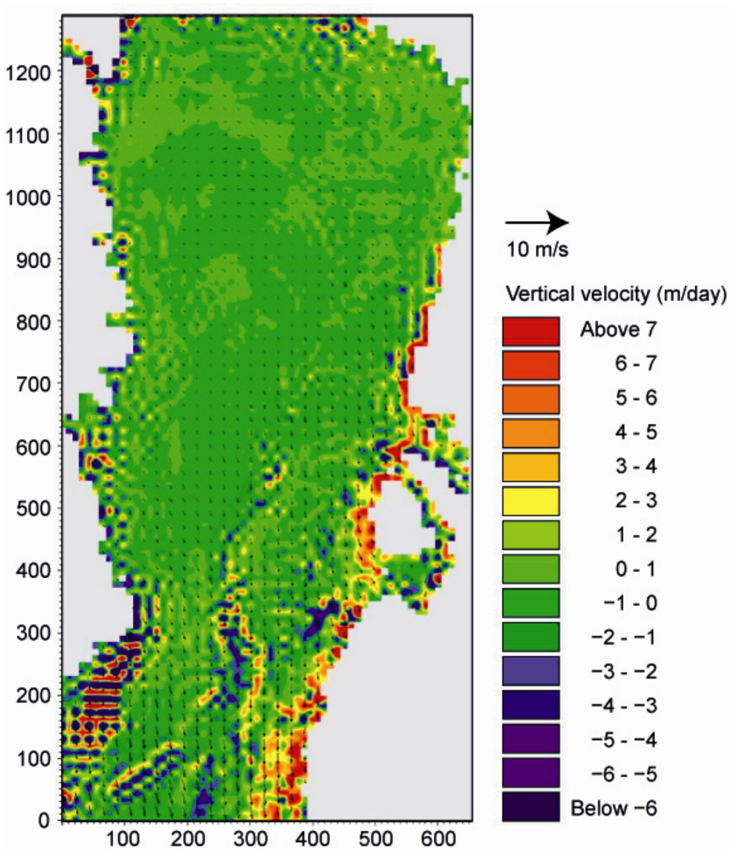


Figure 5. Daily mean value of vertical water velocity and wind speed in Baffin Bay on the 24th of April, 2005. Model results based on DMIs Hybrid Coordinate Ocean Model (HYCOM). The colour scale shows the upwelling velocity in metres per day and the arrows show wind speed. High vertical velocity suggests 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 (300, 300). Large vertical velocities as presented here is a very common model feature during late winter and spring 2005. The model set up is described in detail in Ribergaard et al. (2006). Figure from Söderkvist et al. (2006).

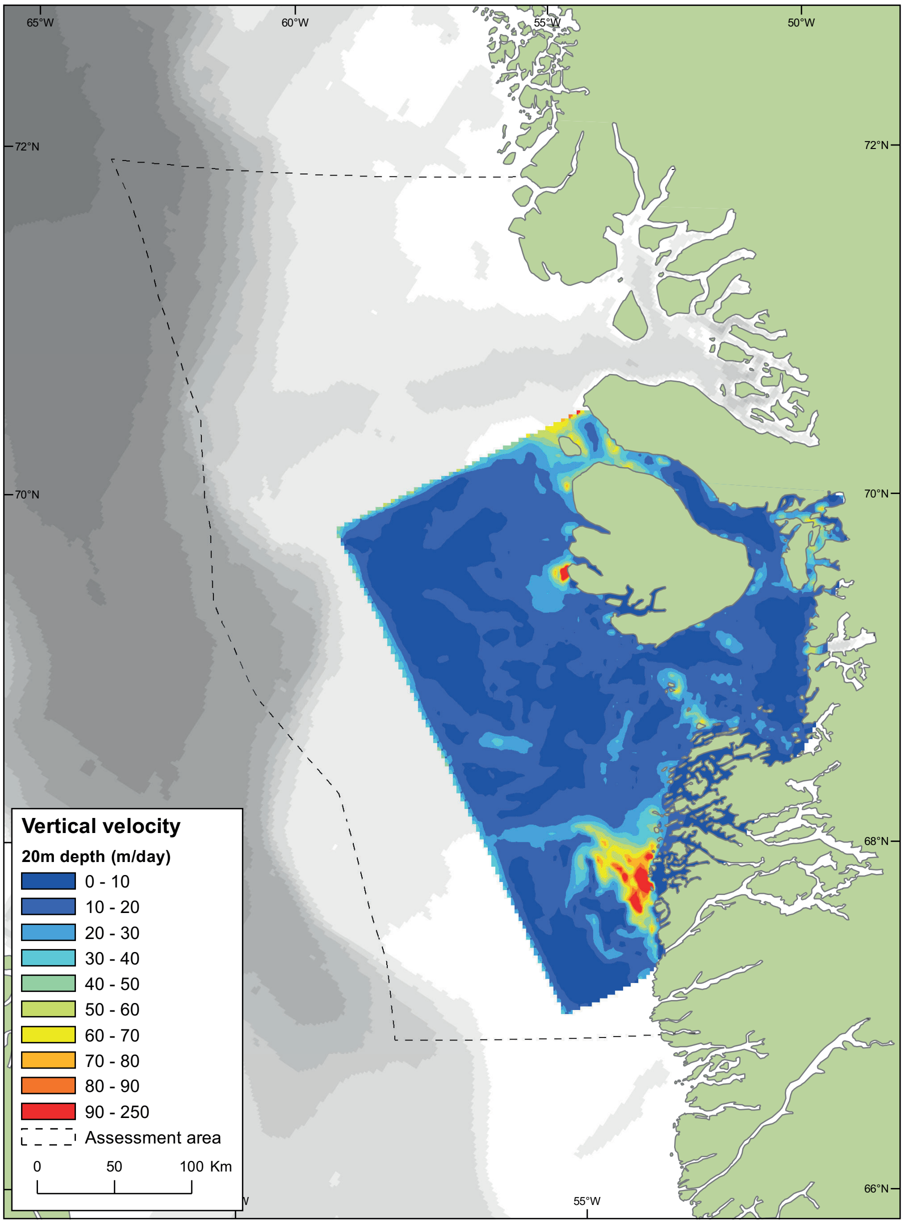


Figure 6. Areas with high rates of upwelling and downwelling as indicated by the standard deviation (sd) of the vertical speed in metres per day (m d^{-1}). The sd is calculated based on all the raw hourly data from the fine scale Danish Meteorological Institute (DMI)-model (DIS) within the period from April 1st to May 31st 2005 (at 20 m depth), in total 1463 time steps of 1 hour. Data is from DCE and DMI.

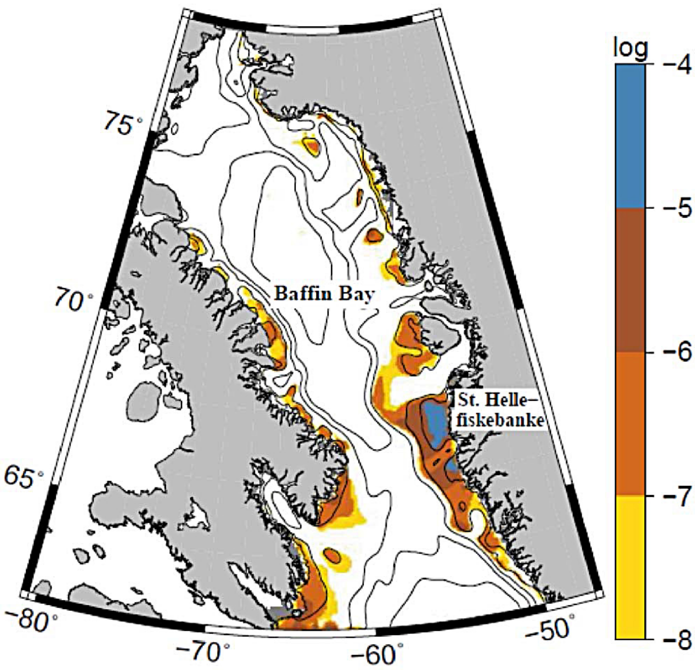


Figure 7. Results of modelling of vertical movements in the water columns caused by the tide. The highest values are found on the fishing banks especially Store and Lille Hellefiskebanke and along the shelf breaks (From Wegeberg et al. 2018).

2.2.3 The seabed

The seabed is described in Chapter 3.4.1 on the benthic fauna.

2.2.4 The coasts

The coasts south of Disko Bay are dominated by bedrock shorelines with many skerries and archipelagos resulting in an extremely long coastline and a variety of shallow benthic habitats (see Figure 8). 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 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).

2.3 Sea ice conditions

Sea 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 sea ice. However, there is usually open water throughout winter along the southwest Greenland coast at least north to Sisimiut and often as far north as Disko Island. Ice also forms locally throughout the winter in most fjords. Generally freeze-up begins at the inner parts of the fjords in November/December, but very low temperatures can significantly affect the ice formation, or a thin ice cover can be reduced by very strong winds in the fjords throughout the winter (Nazareth & Steensboe

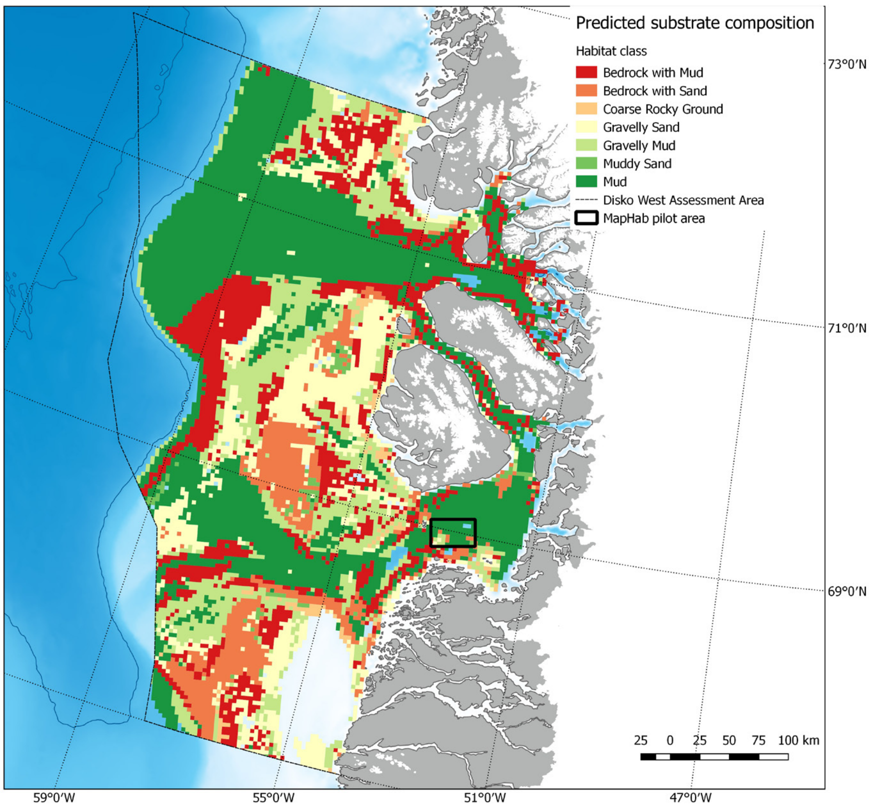
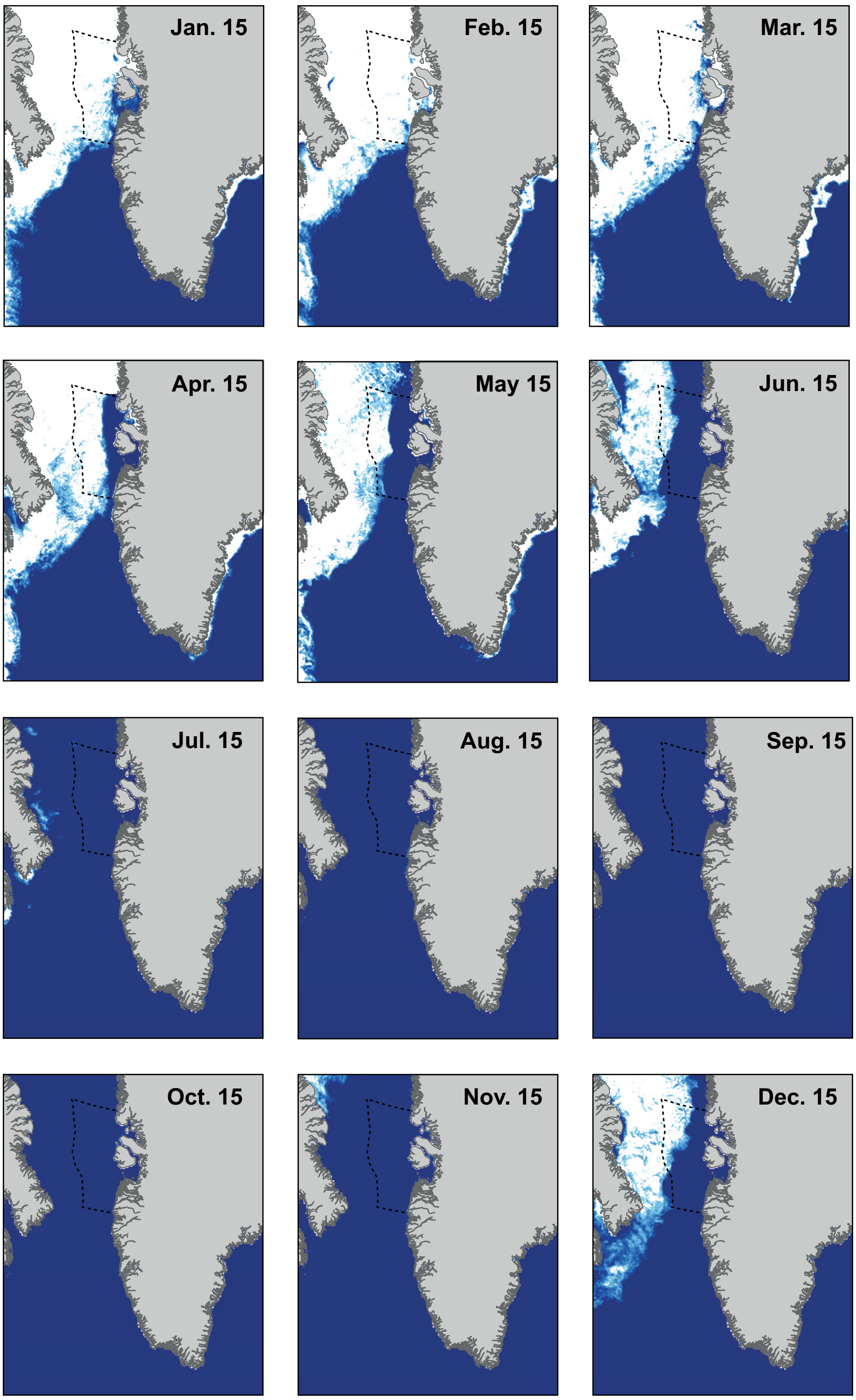


Figure 8. Map of predicted surface substrates in the Disko West Assessment Area developed with an image survey and a Support Vector Machine (SVM) habitat classification model approach. Grid cell size is 3.5 x 3.5 km. Modified from Gougeon et al. (2017). Black rectangle shows the area illustrated in Figure 20.

1998, Mortensen et al. 2011). 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. However, the ice conditions in the assessment area are strongly impacted by climate change, which reduce both the amounts of ice and the duration of the ice cover (Figure 9), a general trend throughout the Arctic (Perovich et al. 2019).



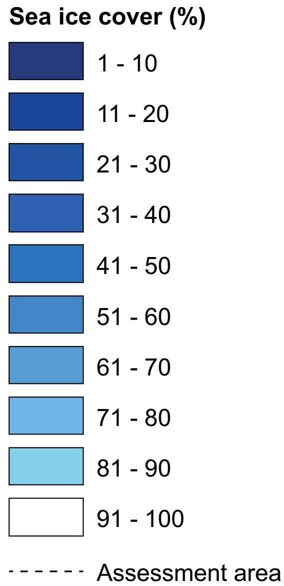


Figure 9. The monthly sea ice cover in 2019, January–December. White colour indicate the very dense ice (91–100% cover), while light blue indicates somewhat looser ice. Open water and very loose ice (0–10% cover) is dark blue. Data is from AMSR-E satellite data (Link) (Spreen et al. 2008).

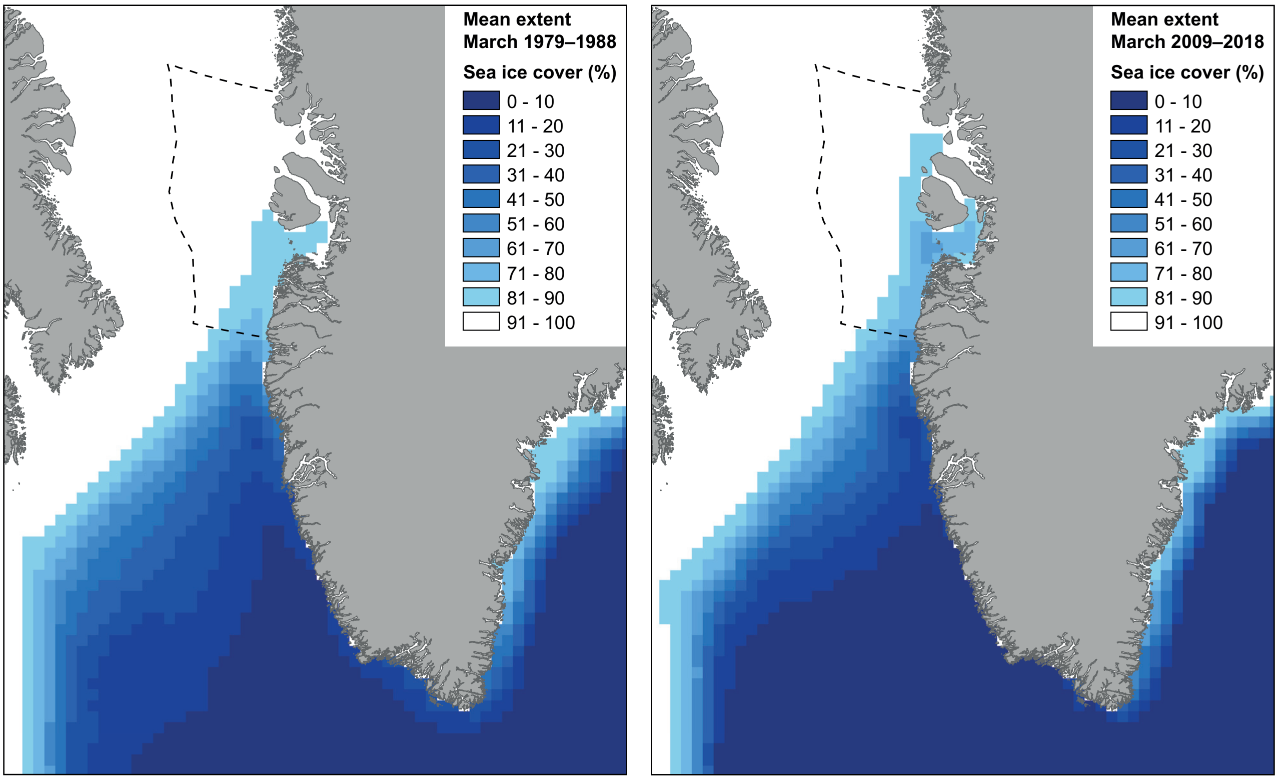


Figure 10. Mean sea ice extent as percentage ice cover in West Greenland waters in March. Left panel: in the period 1979-88. Right panel: in the period 2009-2018. White colours indicate highest percentage ice cover while dark blue indicates ice free waters and very low ice cover. Data sources NSIDC sea ice index (Link), (Fetterer et al. 2017).

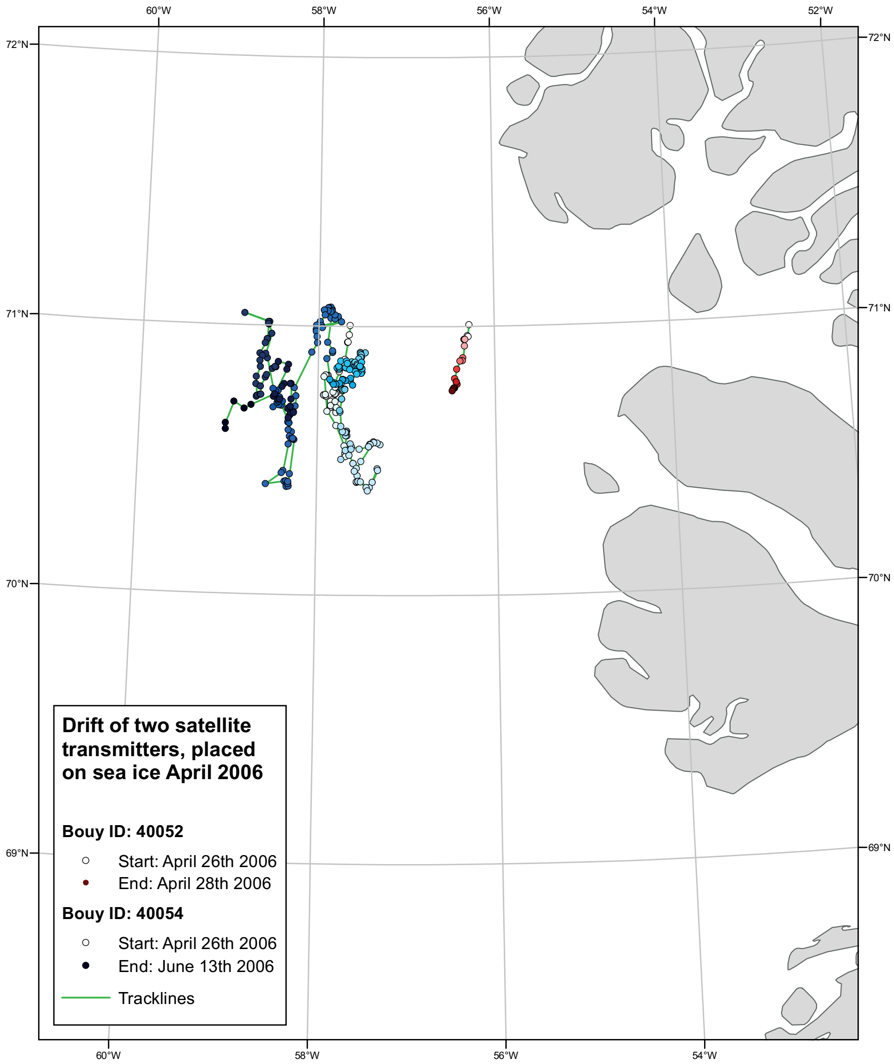
2.3.1 The West Ice and drift patterns

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 west of Disko Island (Pedersen et al. 2011) (Figure 10). 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 m as a result of melting and break up by waves. These floes are however, often consolidated, forming extensive areas without any open water (Pedersen et al. 2011).

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. However, only small amounts of the thicker drift ice from Lancaster Sound and Nares Strait reach the assessment area. During winter and early spring, this ice primarily is conveyed south along Baffin Island to Davis Strait and Labrador Sea.

The sea-ice drift pattern was studied in the northern part of the assessment area in April when two satellite transmitters were deployed on ice west of Nuussuaq Peninsula. Their purpose was to track the movements of the drift ice. One was tracked until June, when it had moved 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 (DMI unpublished, at the request of the Greenland Government, (Figure 11)). Further studies are needed on this subject.

Figure 11. Drift of two buoys equipped with satellite transmitters deployed in the drift ice in April 2006. One stopped transmitting after only two days, when it had moved 21 km to the south. The other was tracked until 13 June. The track of this buoy is approx. 500 km long, but overall it only moved 66 km towards southwest. Source DMI (study carried out at the request of Government of Greenland and GEUS).



2.3.2 Polynyas and shear zone

Polynyas are open waters in otherwise ice-covered waters. They are predictable in time, and are of high ecological significance (Smith & Barber 2007). 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, and this is also very important to marine mammals and seabirds, particularly in spring when populations are migrating northwards. In this shear zone, open water gradually extends northwards during the spring (Laidre et al. 2008).

The entire open water area along the southwest Greenland coast acts as a large polynya despite that it is open to the south, but further north along the coast there are several areas where open water is always present, 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 the 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.

2.3.3 Icebergs

Icebergs originate from glaciers calving in the sea and their size is extremely variable from bergy bits and growlers to enormous bergs. Icebergs are described by their size according to the classification in Table 1.

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

Once an iceberg is free floating, meteorological and hydrographic factors begin to affect it, and they are carried by ocean currents directed by the integrated average of the water motion over the whole draft of the iceberg.

2.3.4 Iceberg sources

Marine terminating glaciers are numerous in West Greenland; however, the most productive glaciers are concentrated from Disko Bay and northwards. In general, icebergs can be met 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 12).

Melville Bay, to the north of the assessment area, is a major source for icebergs. Over 10,000 icebergs are calved from 19 major marine terminating glaciers each year (Figure 13). The volume produced in this region was estimated

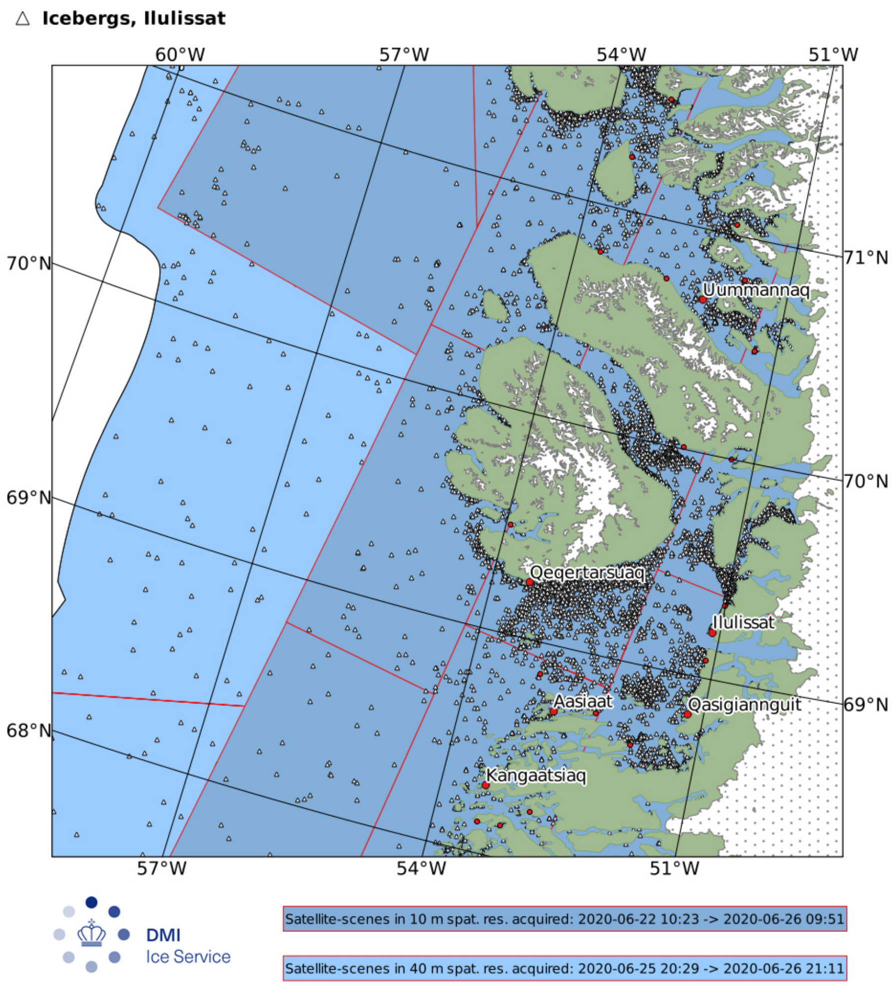
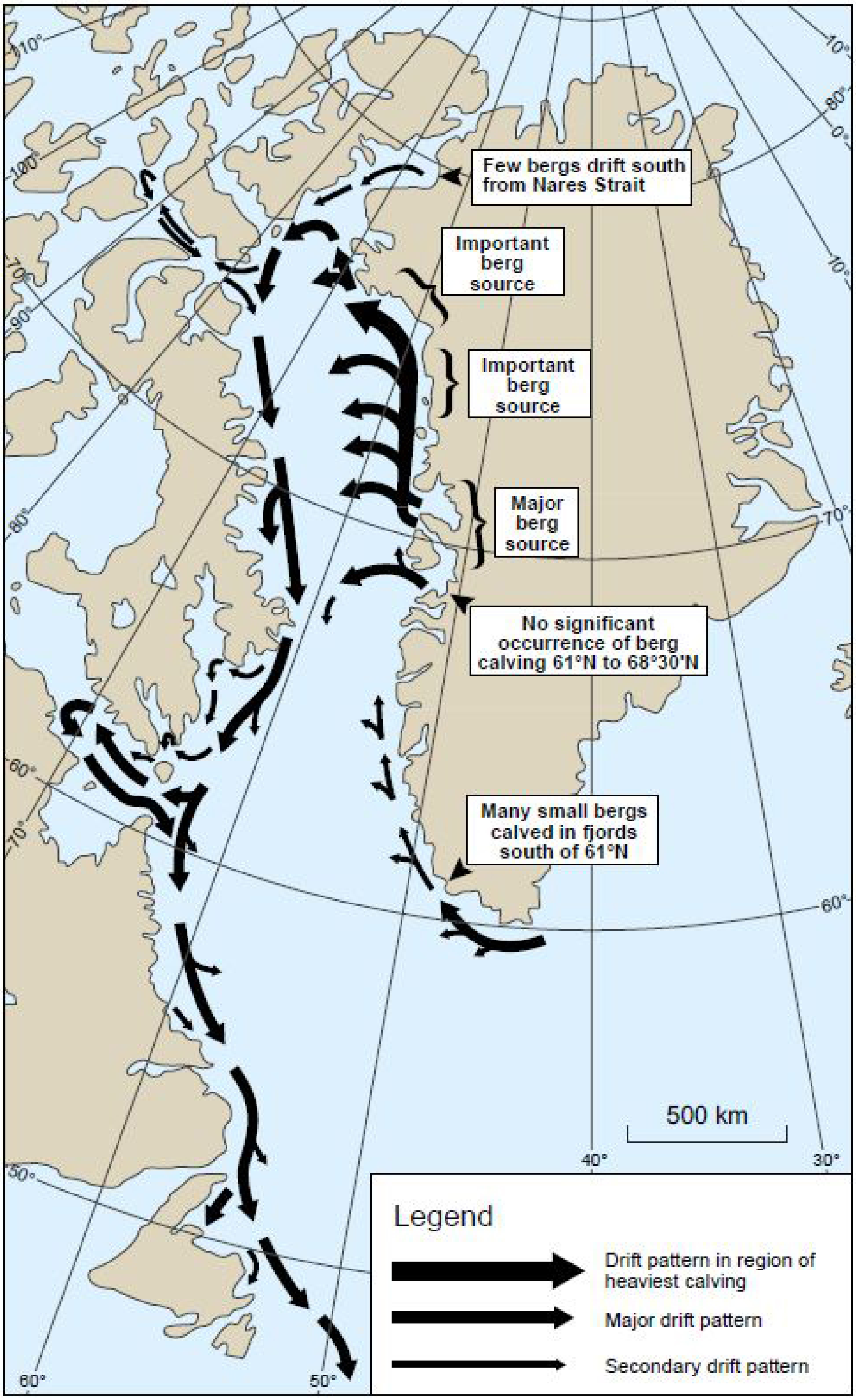


Figure 12. Distribution of icebergs in the assessment area on 26 June 2020. Frome the Polar Portal.dk web site Link.

Figure 13. Major iceberg sources and general drift pattern in the West Greenland Waters. Data source: The US National Ice Center (NIC) and Valeur et al. 1996.



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 important for the iceberg input to the northern Davis Strait and Baffin Bay. The most active glacier is located near Ilulissat – the Jakobshavn Glacier – 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 vary though, up to as high as 40,000 (Pedersen et al. 2011). These estimates may be outdated, due to the general warning of the Arctic, increasing the production of icebergs.

2.3.5 Iceberg drift and distribution

The drift pattern of the icebergs in the assessment area is generally with the surface currents from south to north. 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 67° N. Many icebergs produced in the Disko Bay enter the Baffin Bay, 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. Icebergs south of Sisimiut are generally 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 (Karlsen et al. 2001, and references therein).

2.3.6 Iceberg dimensions

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

The measurements of iceberg drafts north of 62° N indicate that a draft of 230 m will only be exceeded very rarely; however, no systematic ‘maximum draft measurements’ exist and the extremes remain unknown. Several submarine cable breaks have occurred at water depths of about 150-200 m; the maximum depth recorded was 208 m, southwest of Cape Farewell. The large icebergs originating in Baffin Bay are expected to have a maximum draft of about 250-300 m. The largest icebergs recorded in a study in Baffin Bay in 1997 were characterised by a draft of more than 260 m, a mass of up to 90 million t and a diameter of more than 1,400 m. Icebergs from the productive Jakobshavn Glacier pass a sill which allows for a maximum draft of 250 m (Motyka et al. . 2011).

3 Biological environment of the Disko West assessment area

3.1 Primary productivity

Thomas Juul-Pedersen (GINR), Karl Zinglersen (GINR) & Michael Dünweber (AU)

3.1.1 General context

Phytoplankton (microscopic algae) are the most important primary producers in offshore waters and they determine the production capacity of Arctic marine food webs. The two main factors controlling primary productivity in Arctic marine ecosystems are solar input (light) and nutrient availability in the water column. The primary productive season in Arctic waters with seasonal sea-ice is initiated by a moderate under-ice and sea-ice primary production (See Chapter 3.5). Subsequently, an intense surface phytoplankton bloom follows in spring, i.e. spring bloom, which may trail the ice-edge during ice break-up. Summer conditions often depict a prolonged moderate phytoplankton production, which progress deeper in the sunlight part of the water column (photic zone) due to the advancing depletion of surface nutrients. Finally, autumn is characterized by decreasing seasonal incoming solar radiation inhibiting the phytoplankton and ending the primary productive season in Arctic waters.

The species diversity of Arctic phytoplankton is generally lower compared to lower latitude systems (Ibarbalz et al. 2019). Nevertheless, regional species diversity of phytoplankton in Arctic waters typically encompasses hundreds of different species forming complex community structures. The phytoplankton species composition changes rapidly between seasons, facilitated by their short generation time, as well as reflect interannual variability (e.g. Krawczyk et al. 2015). Studying the complexity of phytoplankton species composition and community structures has improved in the last decade with the implementation of genetic analysis techniques combined with traditional microscopic analysis. Thus, understanding the patterns and changes in phytoplankton species composition and community structure, combined with environmental factors and drivers, has proven a valuable tool in studying the effects of climate change (CAFF 2017).

Few time series (monitoring data) exist on phytoplankton productivity and species composition from Arctic waters; the Greenland Ecosystem Monitoring (GEM) programme maintain time series on key marine parameters including phytoplankton from Qeqertarsuaq and Nuuk on the west coast of Greenland and Zackenberg in northeast Greenland (www.gem.dk).

3.1.2 Primary productivity in the Disko West area

The early onset of primary production while the Baffin Bay is still ice covered, within (ice algae) and underneath (phytoplankton) the ice, contribute a relatively small fraction of the annual production (Oziel et al. 2019, Chapter 3.5). Nevertheless, this ice associated production represent an important early food source for ice associated animals as well as for pelagic and benthic communities, particularly during ice melt when ice algae is released and rapidly sinks towards the bottom (Juul-Pedersen et al. 2008).

The spring bloom is characterized by a peak in the phytoplankton biomass and production in the water column. The onset of the spring bloom is determined by withdrawal of the sea-ice (West Ice) covering the Davis Strait and Baffin Bay along with the seasonally increasing solar input and stabilisation of the water column by ice meltwater (Randelhoff et al. 2019). The timing of the spring bloom may vary between years depending on the time of ice break-up, but is typically initiated in late April and develops through May (Figure 14). The phytoplankton biomass develops exponentially during spring and quickly depletes nutrients in the surface layers limiting or inhibiting shallow primary production in summer (Figure 15). The West Greenland shelf region, including the assessment area, experiences a weak stratification of the water column which allows winter mixing of high-nitrate Atlantic-derived waters promoting spring primary production (Randelhoff et al. 2019). In contrast, primary production in the western part of Baffin Bay, Arctic-derived waters, is hampered by reduced nutrient replenishment due to a stronger stratification of the water column. The spring bloom also represents an important event for the primary consumers (zooplankton), hence the timing of this bloom, and changes hereof, can potentially affect the zooplankton community with possible cascading effects up through the food web (Chapter 3.2).

A progressive nutrient depletion develops in surface waters after ice break-up, and this forces the phytoplankton deeper in the water column towards the lower limit of solar input (i.e. the photic zone). A month after the ice retreat, or ca. 100 km from the ice edge, the phytoplankton biomass has moved down to 40-50 m trailing the depleting surface nutrients (nitrate) in Baffin Bay (Randelhoff et al. 2019). This deep phytoplankton biomass in summer remains largely undetectable on remote sensing (satellite) products (e.g. June-August in Figure 14), thus potentially underestimating a significant fraction of the phytoplankton biomass and primary production in summer. In order to accurately estimating annual primary productivity, it is therefore necessary to use or supplement with in situ measurements covering this deeper pro-

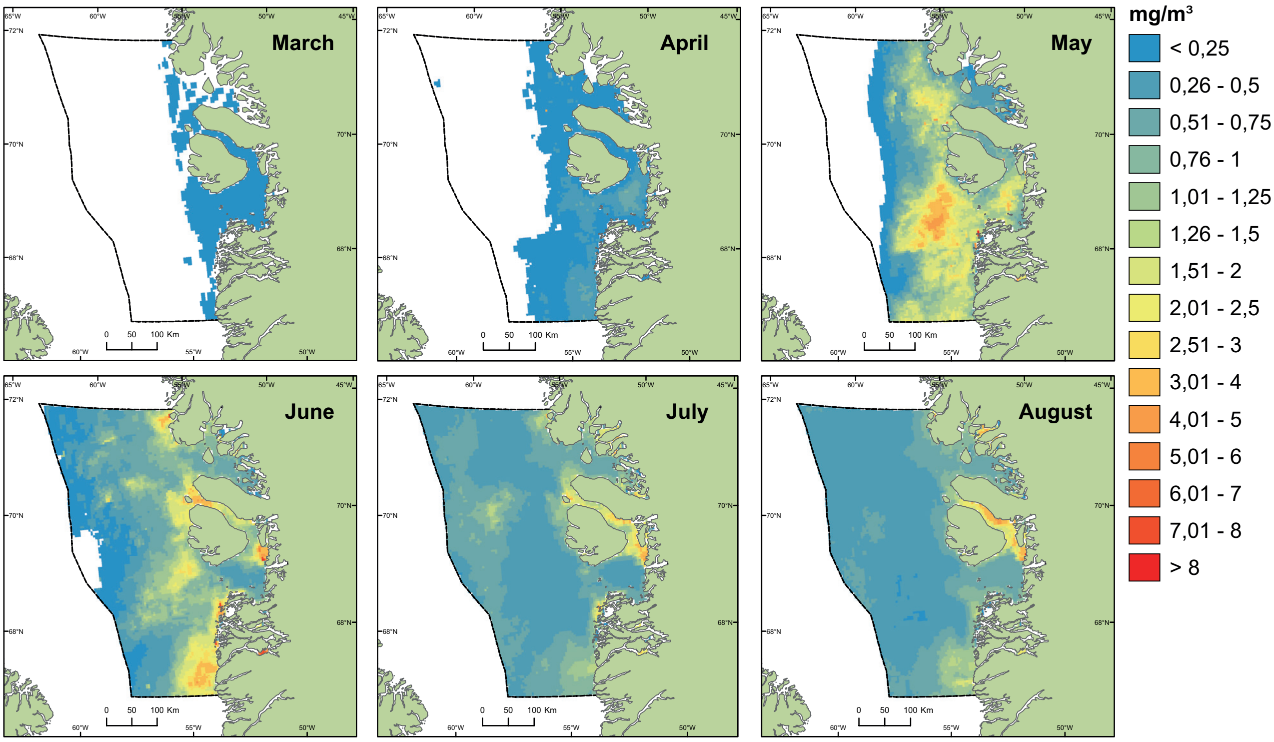
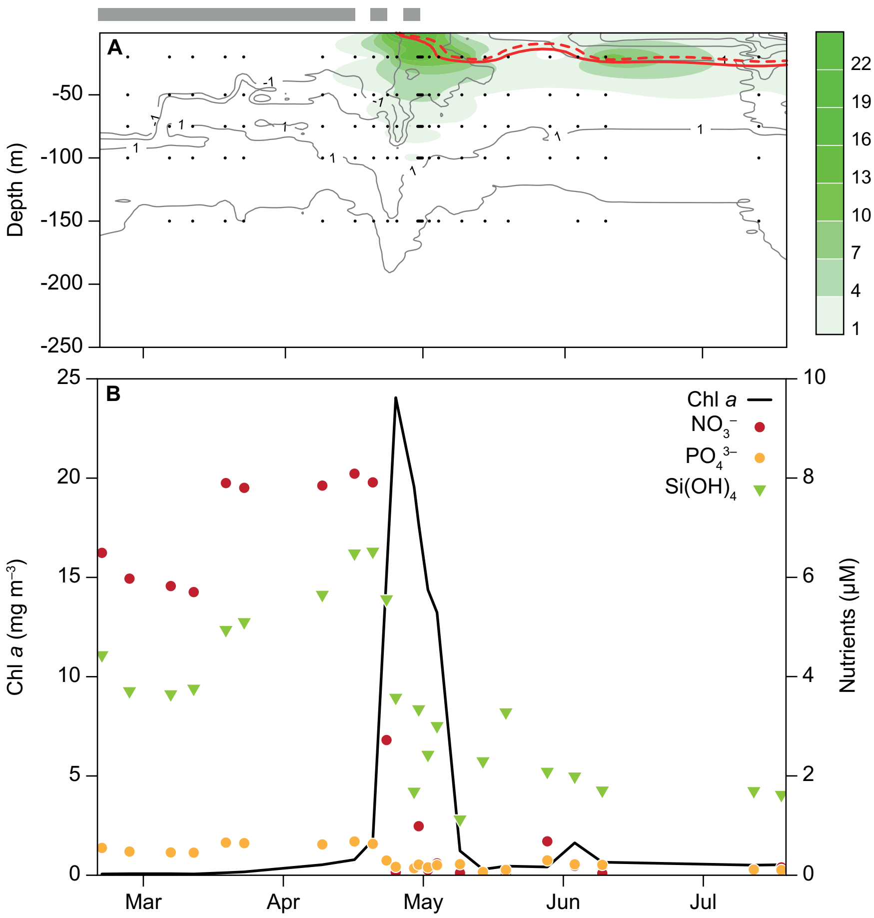


Figure 14. Monthly average sea surface chlorophyll *a* (chl. *a*) concentrations (mg m^{-3}) in March, April, May, June, July and August from 2015-19. Data are presented as a monthly average from MODIS level 3 aqua with a 4 km cell size. The colours indicate different chl. *a* concentrations: blue areas – very low; red – high chl. *a* concentration; white – no data. (Data source: NASA Goddard Space Flight Center, Ocean Ecology Laboratory, Ocean Biology Processing Group; (2020): Chlorophyll Concentration, OCI Algorithm, Ocean Color Data, NASA OB.DAAC. doi: 10.5067/AQUA/MODIS/L3M/CHL/2018. Accessed on 7 Apr. 2020).

Figure 15. Water column characteristics off Arctic Station, Qeqertarsuaq, in Disko Bay, West Greenland in 2008 studied by Dünweber et al. (2010). Upper panel (**A**): Isolines are water temperature (°C) and the green coloration illustrates chlorophyl *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). Black dots: 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.



duction. Deep phytoplankton biomass and production has been observed in Davis Strait in October, extending the primary productive season from March to October in West Greenland waters (pers. comm. Thomas Juul-Pedersen).

The annual phytoplankton productivity in the waters off West Greenland is generally equal to or even higher than the production at lower latitudes (60-120 g C m^{-2} yr^{-1} for eastern Baffin Bay; Stein & Macdonald 2004). This regionally high primary productivity has a positive cascading effect up through the food web, sustaining highly productive marine ecosystems. Interannual variation in winter sea-ice conditions (West Ice) in the assessment area, combined with the highly seasonal solar input, dictates the onset and duration of the primary productive season, while the nutrient availability and replenishment determines the magnitude of primary productivity (Figure 14).

In addition to the magnitude of primary productivity, it is important to know the proportion of organic carbon available to pelagic consumers such as zooplankton, fish, marine mammals and sea birds, how much is recycled through the pelagic food web (microbial loop) 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).

At ice edges, the phytoplankton bloom may occur earlier than in ice-free waters due to the stabilising effect of the ice and meltwater on the water column. However, at sites where nutrients continuously are brought to the uppermost water layers, for example by hydrodynamic discontinuities such as upwelling or fronts (see Chapter 2.2.2), primary production and hot spots may occur throughout the summer.

Box 1. Coupling lower trophic level to seabird distribution

Michael Dünweber, Sanne Kjellerup, Doris Schiedek, David Boertmann, Anders Mosbech & Kasper L. Johansen

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 (Figure 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 (Figure 2). Surface chl. *a* concentration based on remote sensing satellite data from September 2009 (Figure 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).

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 (Figure 4). *Calanus* represented the main species on the CS (0-50 m depth stratum; Figure 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* (Figure 7).

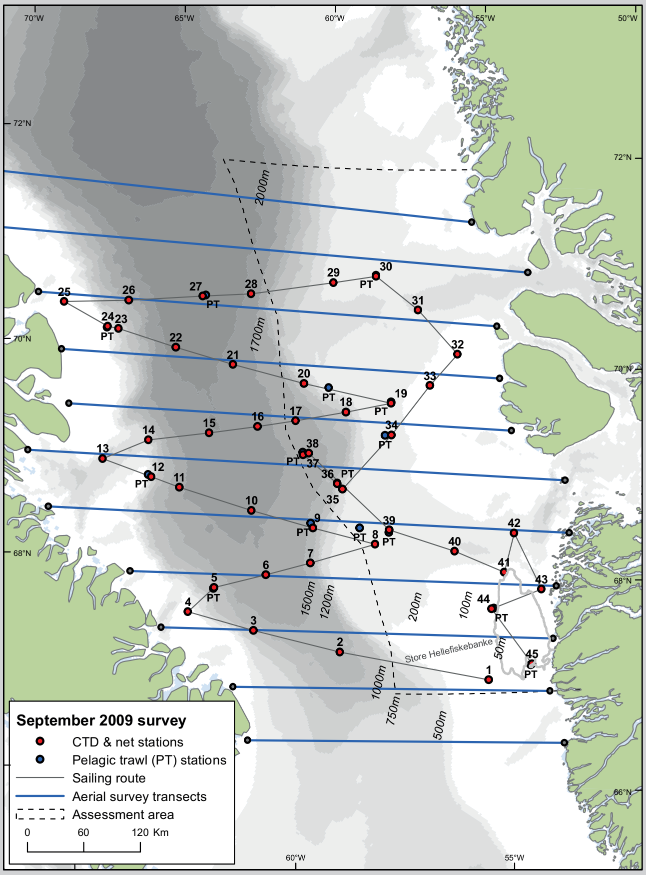


Figure 1. Map showing the ship-based transects (red line) and the aerial transects (blue line) during the Disko West survey in September 2009. Station numbers and positions of CTD measures and zooplankton samples (red dots, n=45), pelagic trawls- PT (blue dots, n=15).

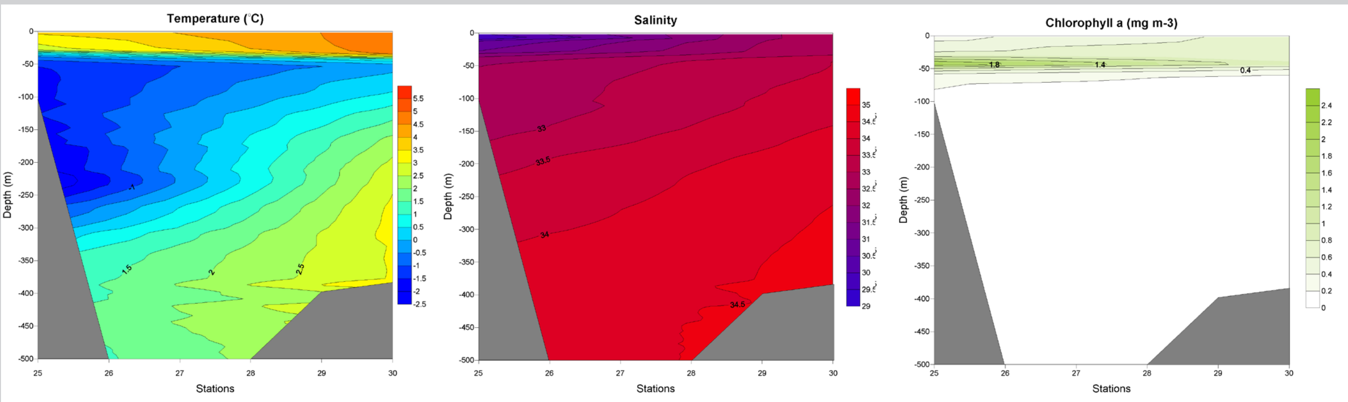


Figure 2. Transect performed during the ship based survey in September 2009 documenting temperature (ºC), salinity and chlorophyll a (chl. *a*) concentration (mg m^{-3}); see **Figure**1 for transect station numbers. Relative warm surface waters (up to 5-6 ºC) and salinity around 30 is typical during 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 ºC) 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.

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

The occurrence and distribution of juvenile polar cod (*Boreogadus. saida*) (Figure 4.2.4.8) was estimated in the survey area to approximately 97 × 10^9 individuals or equivalent to 56 x 10^3 tonnes. 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 (Figure 4.2.4.9 and 4.2.4.10).

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 (Figure 11). In order to gain a better overview of the seabird distributions, an aircraft based survey was performed simultaneously, applying the same observations methods (Figure 12).

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 (Figure 13).

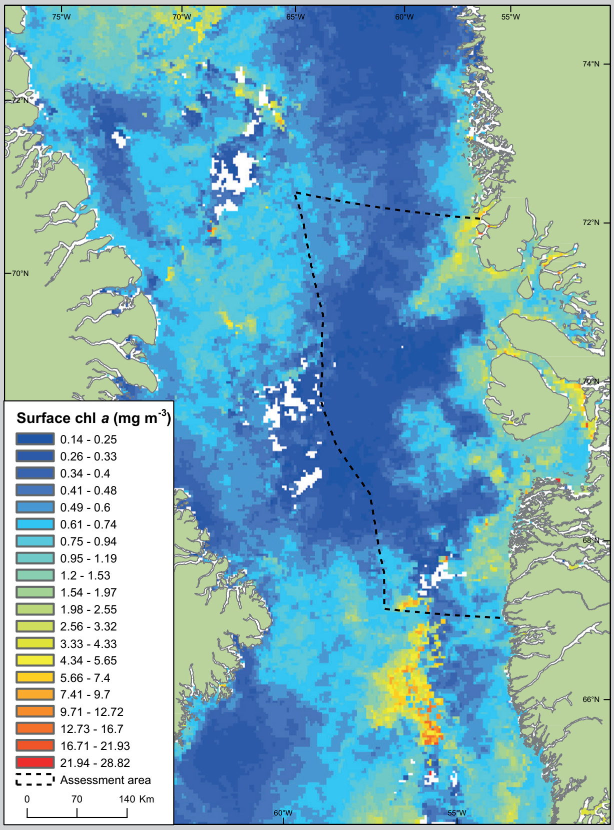


Figure 3. Sea surface chlorophyll *a* (chl. *a*) concentrations (mg m^{-3}) in September 2009. Data are presented as a monthly average from MODIS level 3 aqua. The colours indicate different chl. *a* concentrations: blue areas - very low; red - high chl. *a* concentration; white - no data. The chl. *a* 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).

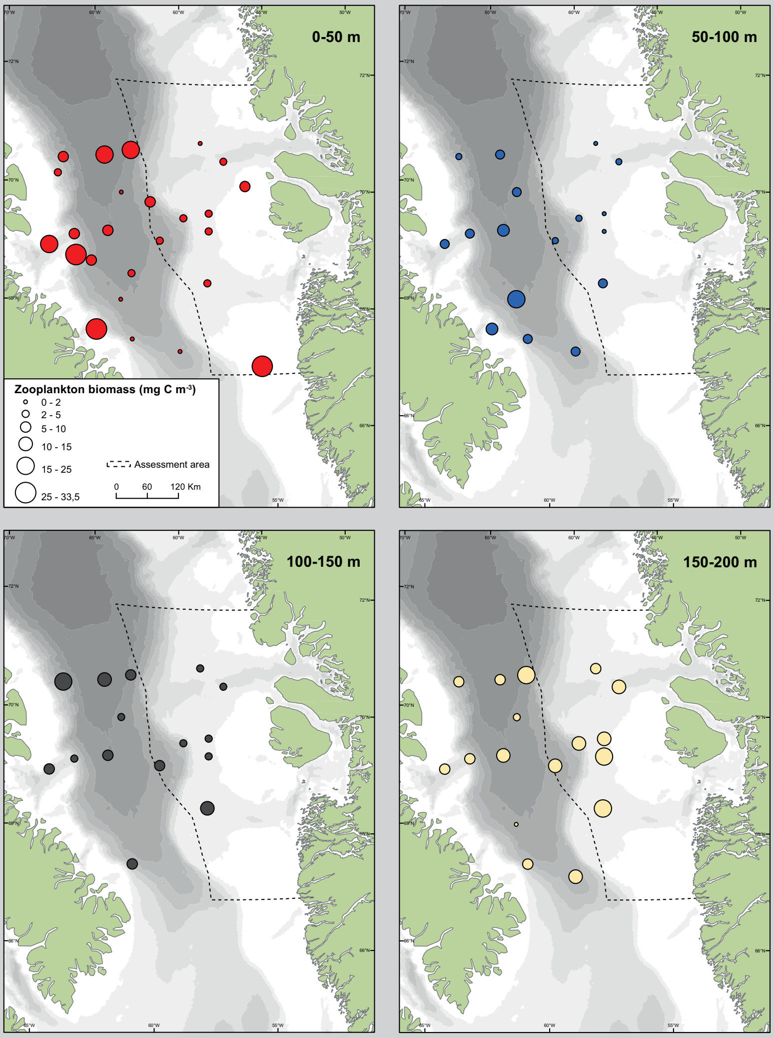


Figure 4. Zooplankton biomass (mg C m^{-3}) during the Disko West survey in September 2009 in 0-50 m, 50-100 m, 100-150 m and 150-200 m water depth. In general, the highest zooplankton biomass was found on the shelf-breaks, mainly on the Canadian shelf-break (0-100 m). On the Greenland shelf-break, the 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.

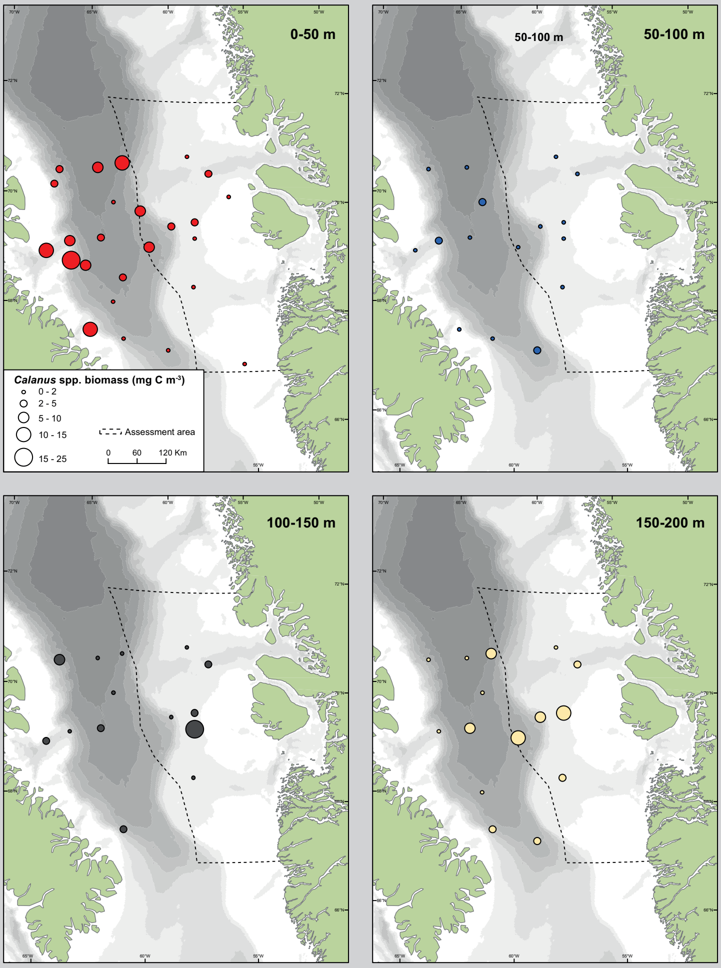


Figure 5. *Calanus* spp. biomass (mg C m-3) during the Disko West survey in September 2009 in 0-50 m, 50-100 m, 100-150 m and 150-200 m water column. In the surface layer (0-50 m), a relatively high *Calanus* spp. biomass was observed on the Canadian shelf-break compared to the Greenland shelf-break. *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.

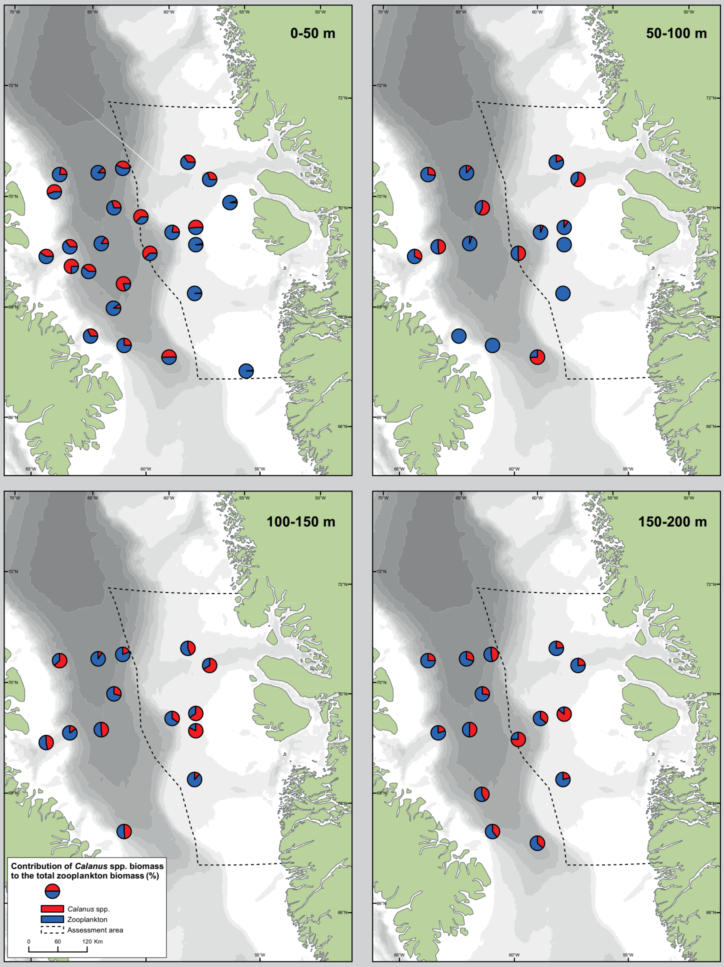


Figure 6. Pie chart of relative zooplankton biomass distribution (%) in the water column during the Disko West survey in September 2009; *Calanus* spp. (red colour) compared to the remaining zooplankton assemblage (blue) in the 0-50 m, 50-100 m, 100-150 m and 150-200 m column.

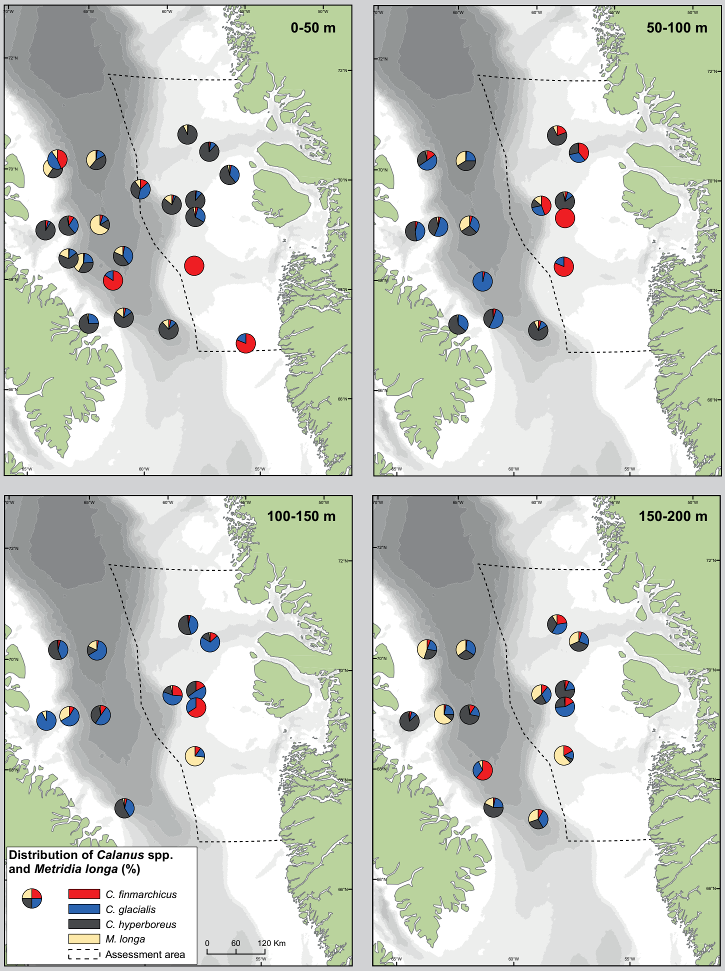


Figure 7. Pie charts of *Calanus* spp. and *Metridia longa* relative biomass contributions (%) during the Disko West survey in September 2009 in the 0-50 m, 50-100 m, 100-150 m and 150-200 m depth strata. *C. finmarchicus* is dominating the *Calanus* biomass along the Greenland coast from 68º to about 69º 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.

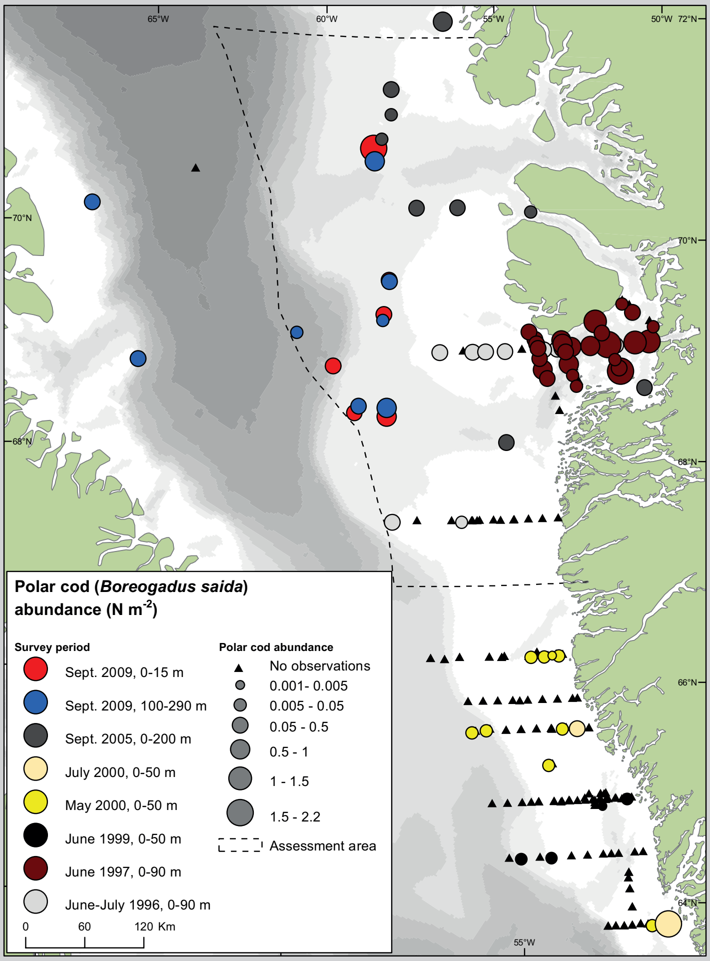


Figure 8. Abundance (N m^{-2}) of larvae and juvenile polar cod during the Disko West survey in September 2009 (red and blue dots) and during other surveys. Dark grey dots - September 2005 (Bergstöm & Vilhjalmarsson 2007), yellow, pale green, black, dark-red and light-grey dots - May-July 1996-2000 (Munk 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 Figure 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.

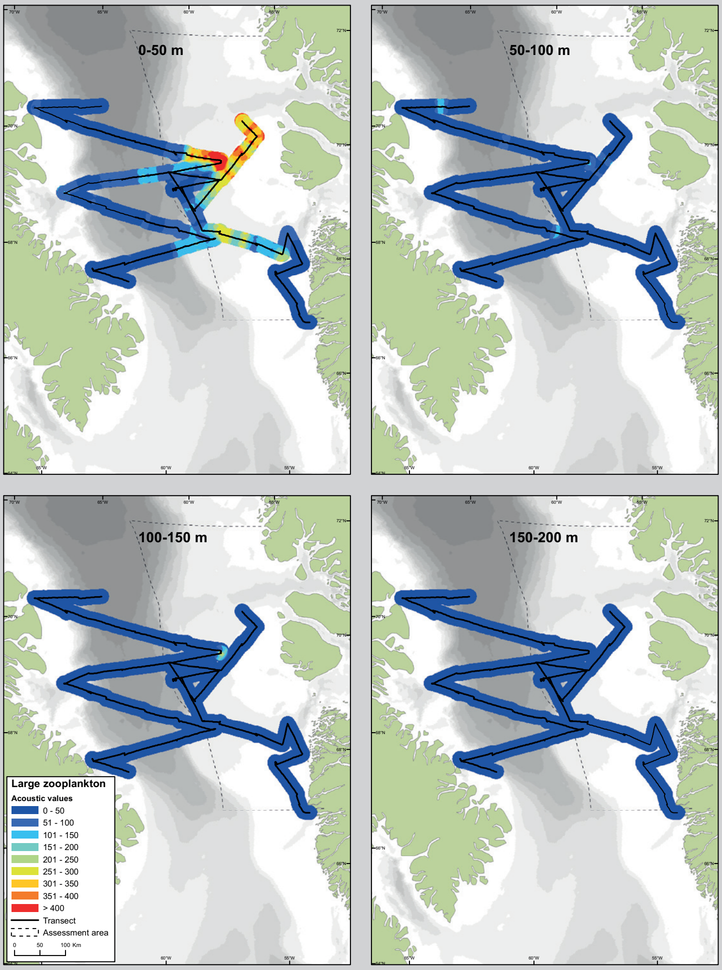


Figure 9. Spatial distribution of larger zooplankton (i.e. mainly *Themisto libellula*, size > 5 mm) based on relative acoustic values (SA-values) in the 0-50, 50-100, 100-150 and 150-200 m water columns. Acoustical separation between the different zooplankton groups (e.g. amphipods, euphausiids or copepods) 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 (S_v, 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 S_v 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 S_v 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.

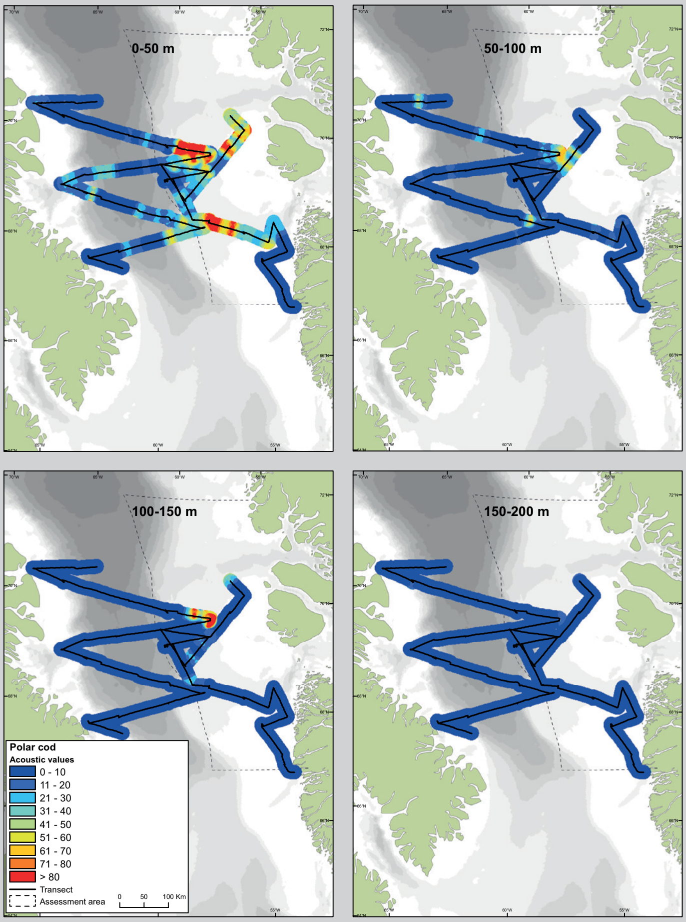


Figure 10. Spatial distribution of juvenile polar cod based on relative acoustic values (SA-values) in the 0-50, 50-100, 100-150 and 150-200 m columns. The distribution of juvenile polar cod is very similar to those of the large zooplankton (see Figure 9) and the distribution of the total acoustic registrations 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).

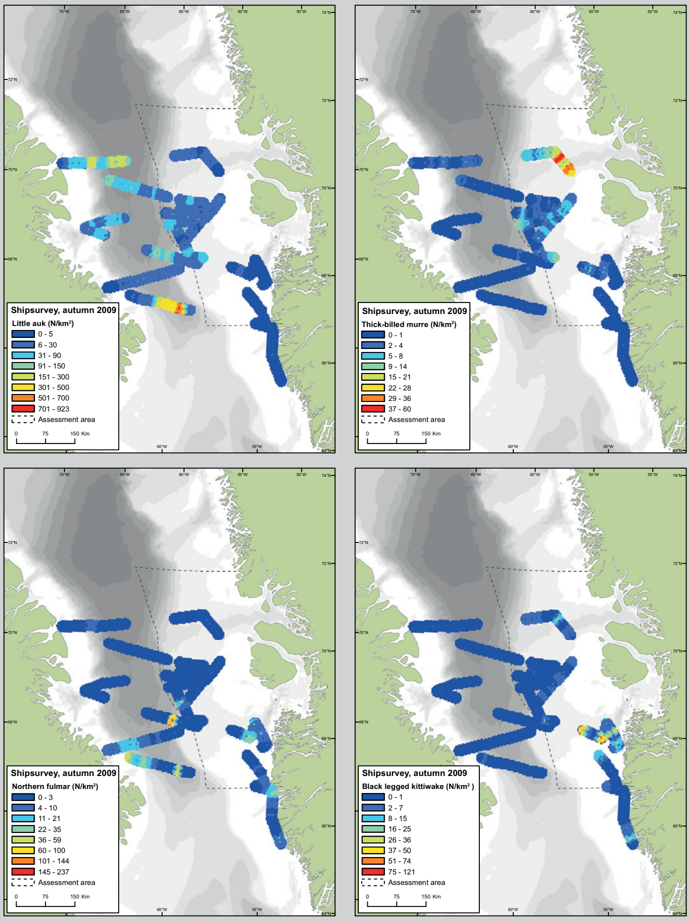


Figure 11. Densities (n/km²) of the most numerous seabird species recorded during the ship based survey in September 2009. Little auk was the most numerous species (n = 29,000 individuals, on transect) and they were mainly found and concentrated in parts of the Canadian shelf. These post breeding birds 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.

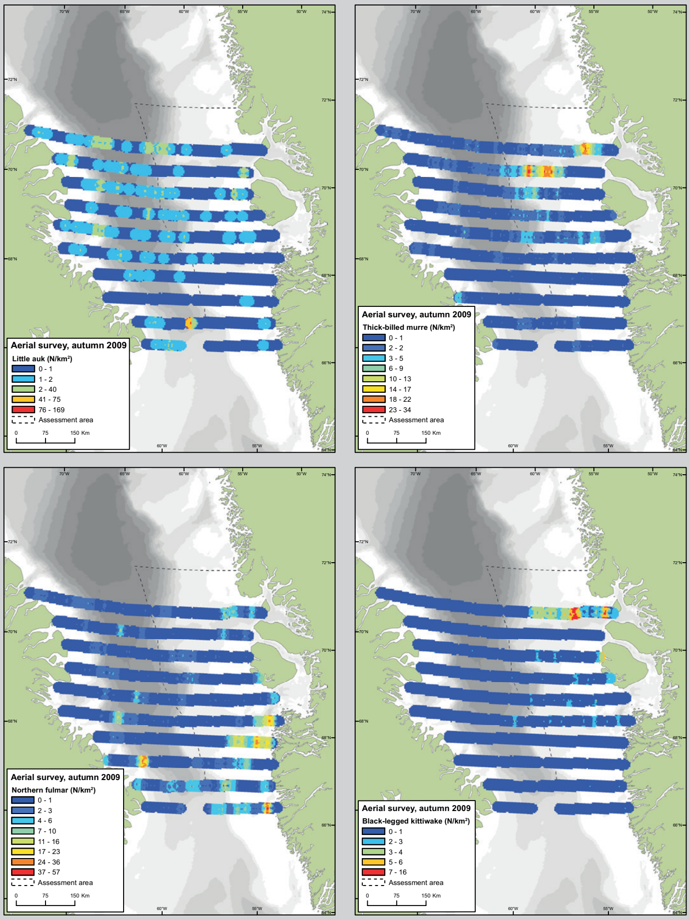


Figure 12. Densities (n/km²) of the most numerous seabird species recorded during the aircraft based survey in September 2009. Little auks (n = 550 individuals on transect) were more dispersed than observed during the ship based survey, but generally found outside the shelf waters. Thick-billed murres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

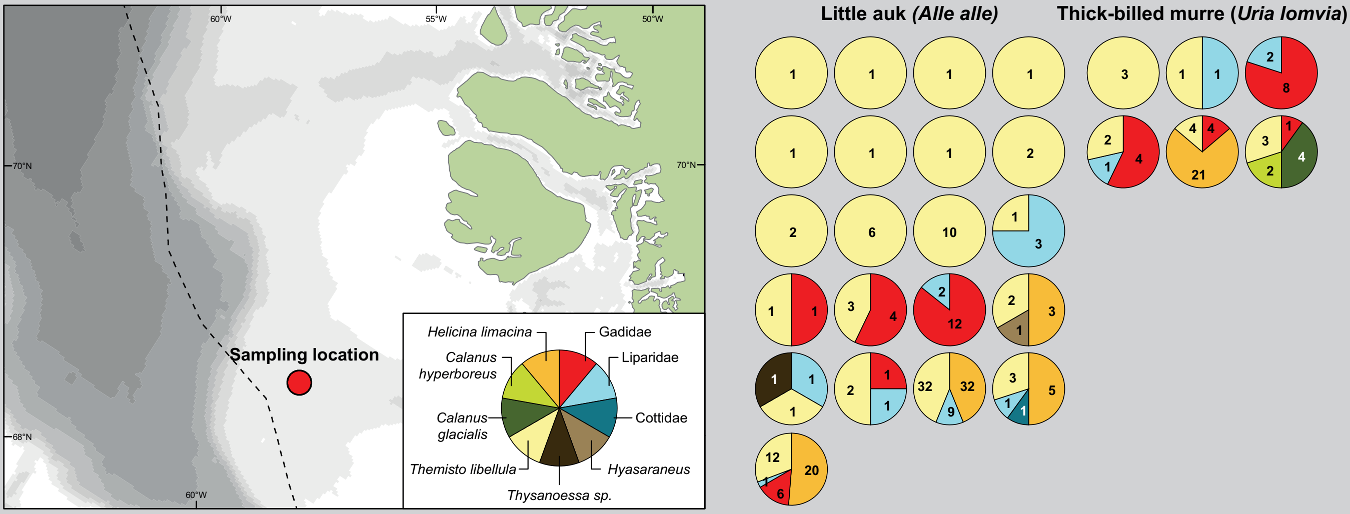


Figure 13. Pie charts of stomach contents of individual little auks (n = 21) and thick-billed murres (n = 6) collected during the Disko West survey in September 2009. Values inside pies indicate numbers of individuals of the different species (n Ind^{-1}) present in the stomachs; the different colours 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 Figure 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.

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 (Figure 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.

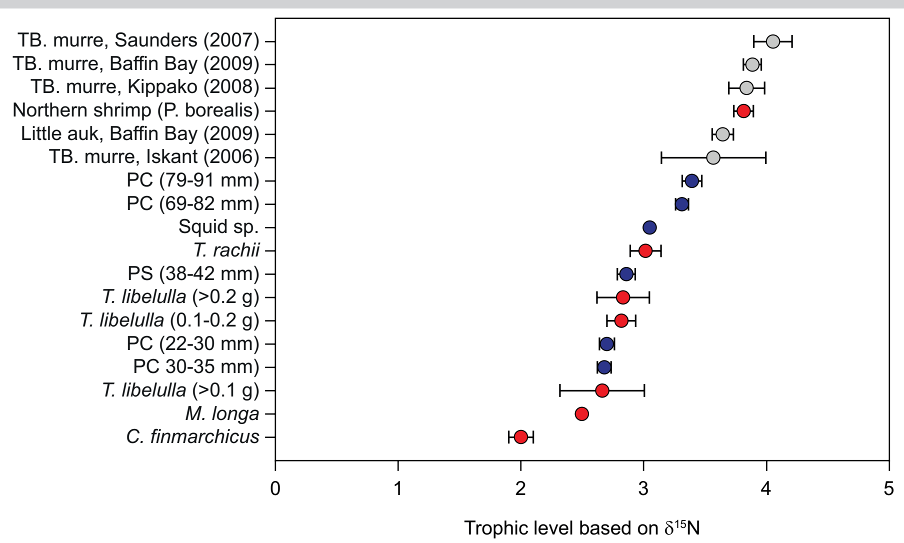


Figure 14. Trophic levels of selected zooplankton species and seabirds based on stable isotope analyses. Thick-billed murre (TB. Murre) and little auk are represented from different areas along West Greenland e.g. Saunders Island (Thule), Baffin Bay (September 2009 survey), Kippako (Upernavik) and marginal 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).

Upwelling can be predicted in time and are persistent over long periods, although those driven by the tidal currents vary with the tidal cycle, and others are wind driven and vary with the wind conditions. Upwelling areas are for example found at the north-eastern corner of Store Hellefiskebanke and in outer Disko Bay and around Hareø (Figures 5, 6). Upwelling areas may, besides enhanced production, also retain copepods which are utilised by fish larvae (Munk et al. 2003, Simonsen et al. 2006).

However, the production is not restricted to the upwelling points in the area. Simulation of the tidal dynamics indicates complete vertical mix of the water body across the bank, and this may explain the high primary production in the entire bank area (Wegeberg et al. 2016a).

3.1.3 Primary productivity at polynyas, shear and marginal ice zones

In polynyas (Chapter 2.3.2), the primary production starts earlier than in ice-covered areas. Continuous upwelling or mixing of nutrient-rich waters within polynyas often result in a higher annual primary productivity, compared to surrounding seasonally ice covered areas (150 g C m^{-2} yr^{-1} for North Water Polynya north of the assessment area (Stein & Macdonald 2004)). Because of their high primary productivity and the associated food web, polynyas 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 grounds 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 small polynyas (e.g. in the mouth of Vaigat) are usually present (Chapter 2.3.2). At the marginal zone of the West Ice, primary production during the spring bloom is very intense and the associated food web attracts species higher in the food web including seabirds and marine mammals (Wassmann et al. 2002, 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 ship-based surveys of biological oceanographic sampling on transects from open water and into the drift ice at the marginal ice zone. Sampling included CTD measurements, i.e. depth distribution of salinity and temperature, fluorometer measurements i.e. indicating depth distribution of phytoplankton biomass (chlorophyll *a*), and water samples for nutrients and chlorophyll *a* (chl. *a*) as well as net hauls for zooplankton composition and biomass. At the northern parts of Store Hellefiskebanke, the phytoplankton 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 tenfold, indicating initiation of the spring phytoplankton bloom during the study period (Söderkvist et al. 2006, Mosbech et al. 2007a, Frederiksen et al. 2008). North of Store Hellefiskebanke, in Disko Bay and west of Disko Island, the phytoplankton bloom starts when stratification is 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 phytoplankton 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 feature for the high productivity in the assessment area in spring. The melt water stabilise the water column and thus the marginal ice zone hosts a community of specialised algae and grazers on the underside of the sea-ice (Frederiksen et al. 2008).

3.2 Zooplankton

Eva Friis Møller (AU) & M. Dünweber (AU)

3.2.1 General context

Zooplankton provides the principal pathway to transfer energy from primary producers (phytoplankton) to consumers at higher trophic levels, such as fish e.g. polar cod, seabirds or marine mammals. For instance, the bowhead whale or seabirds such as the little auk is specialised feeders on large copepods of the genus *Calanus* (Karnovsky et al. 2003, 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 to the seabed (Turner 2002, and references therein). During winter *Calanus* migrate to deep layers of the water column to hibernate (Falk-Petersen et al. 2007). This may also provide an important contribution to the benthic ecosystem.

3.2.2 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*. Three *Calanus* species exist in the Arctic: *C. finmarchicus*, *C. glacialis,* and *C. hyperboreus*. The first is primarily associated with North Atlantic waters, while the two latter are considered Arctic species (Falk-Petersen et al. 2007). While the three species share the same general life cycle and morphology, there are important differences, particularly in size and phenology (Swalethorp et al. 2011). All three species feed on algae and protozoa in the surface layers during spring and summer, and accumulate surplus energy in form of lipids that 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 to 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 the consumer 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 (*Balaena mysticetus*) and the northern right whale (*Eubalaena glacialis*), which eat mainly *Calanus* (Hoekstra et al. 2002, Zachary et al. 2009). Consequently, many biological activities in the Arctic – e.g. spawning and growth of fish – are synchronised with the life cycle of *Calanus*. In larvae of the Greenland halibut and sandeel from the West Greenland shelf, various copepods species, including *Calanus* were the main prey item during the main productive season (May, June and July). They constituted between 88 % and 99 % of the ingested prey biomass (Simonsen et al. 2006).

Vertical distribution of the *Calanus* species is strongly influenced by ontogenetic vertical migrations that occur between the dark winter season and the light spring/summer season when they move into surface depths (Falk-Petersen et al. 2009). During summer and autumn, *Calanus* initiates 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).

3.2.3 Zooplankton in the Disko West area

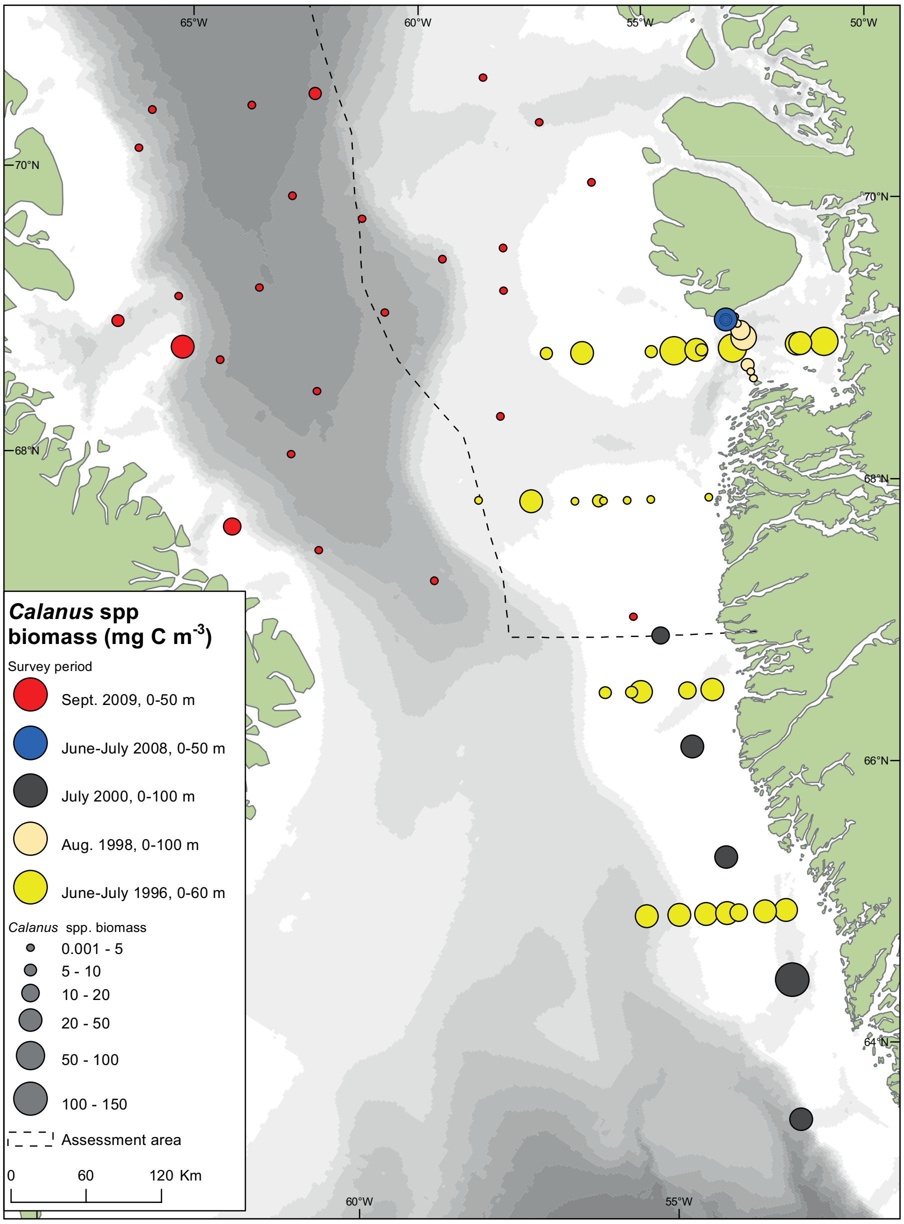
The zooplankton communities in the waters off West Greenland are dominated by the large copepods of the genus *Calanus* (incl. their larval stages) during the greater part of the year (Pedersen & Smidt 2000, and references therein). Investigation performed in the Disko Bay area clearly corroborates the hypothesis that most of the biological activity in the surface layer 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 16).

A recent analysis of 13 years of data from Disko Bay, Western Greenland, from the period 1992 to 2018 showed a significant change in the *Calanus* community composition during May and June (Møller & Nielsen 2019). In the 1990s, the three *Calanus* species contributed equally to the copepod biomass. With the reduction in sea ice cover, however, the two Arctic species have declined, and the North Atlantic *C. finmarchicus* now dominates the biomass. Because of the species shift, the *Calanus* community is now dominated by smaller individuals, and the lipid content of *Calanus* females during spring and summer has decreased by 34%. Furthermore, during the last decade there has been a large annual variation in population size, *Calanus* virtually being absent in some years (Møller & Nielsen 2019).

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 lower trophic levels (e. g. fish and zooplankton). In the North Water Polynya (NOW), northern Baffin Bay about 80% of the world's population of little auk are found during the breeding season (Kampp et al. 2000, Egevang et al. 2003) largely feeding *Calanus* spp. (Karnovsky et al. 2003, Karnovsky et al. 2008), and the high abundance of little auks here during summer has been related to the phenology of *Calanus* (Møller et al. 2018).

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 and the potential linkage to higher trophic levels are described in Box 1. Briefly, concerning the zooplankton, on the Greenland Shelf, most *Calanus* were late

Figure 16. *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; Yellow dots: August 1998 (Møller & Nielsen 2000) at 0-100 m; Pale green 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.



copepodite stages and most were found well below the photic zone, suggesting they were in diapause. On the Canadian Shelf, there were relatively more *Calanus* in the near-surface layers (Kjellerup et al. 2015).

Similarly, ecological network analysis indices has revealed significant differences in the functioning of the eastern and western Baffin Bay food webs. The eastern are suggested to contain a more specialized food web that constrains carbon through specific and efficient pathways, leading to segregation of the microbial loop from the classical grazing chain. In contrast, the western food web was suggested to have redundant and shorter pathways that caused a higher carbon export, especially via lipid and microbial pumps, and thus promoted carbon sequestration (Saint-Béat et al. 2020).

3.2.4 Zooplankton dynamics in the coastal areas

The possible link between hydrographical processes and plankton variability were studied in the Disko Bay and across important banks off the west coast of Greenland (Munk et al. 2003). That study found a close relationship between plankton distribution and hydrographical fronts. They found also evidence that specific plankton communities were established in different areas of the important 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 stages of fish.

Other important areas of potential high biological activity are the upwelling areas. Møller & Nielsen (2000) revealed a three time higher biomass of meso-zooplankton close to the island 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.

3.2.5 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 by an acoustic survey in September 2005 by Bergström & Vilhjalmarsson (2007) as well as their association to large baleen whales in West Greenland (Laidre et al. 2010a). 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 17). Capelin was absent on the banks, but present in the fjords and

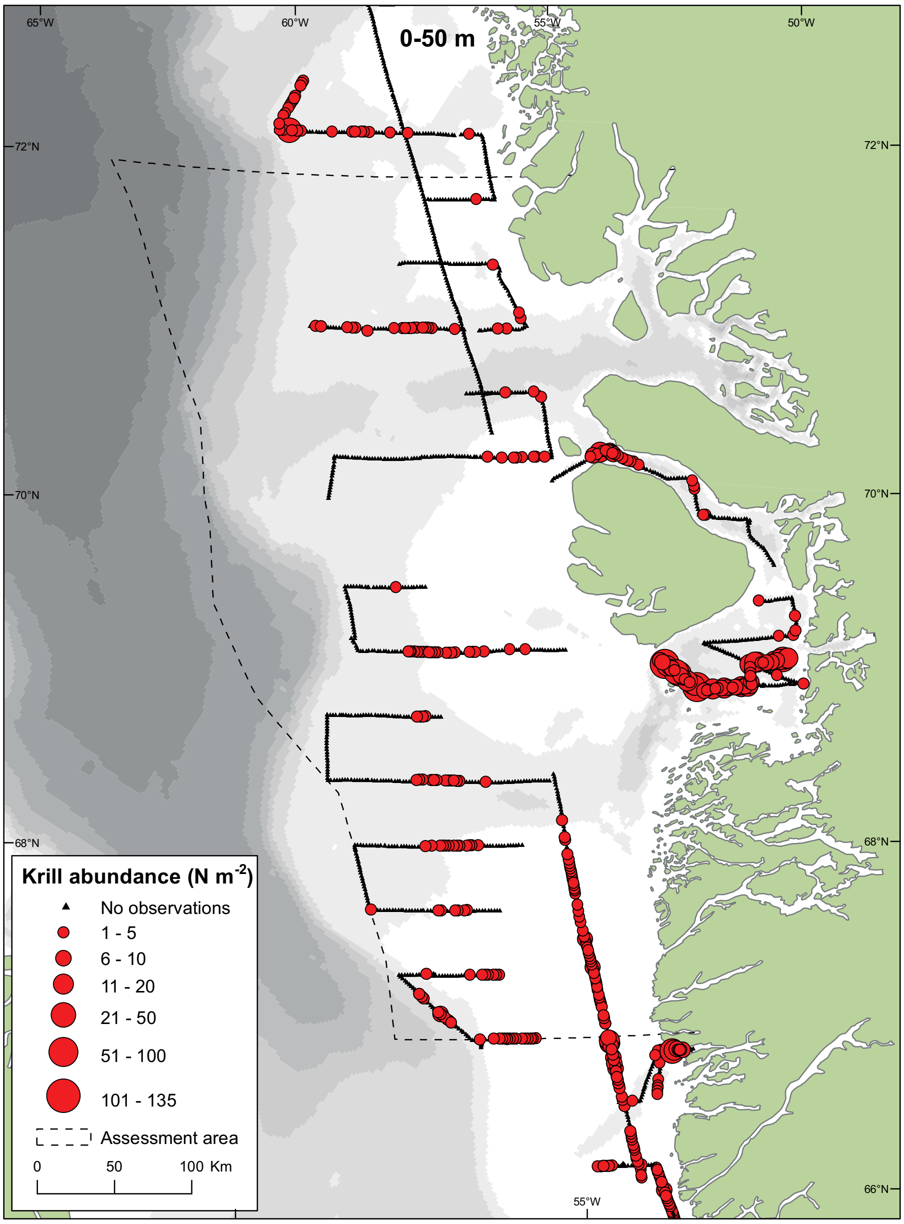


Figure 17. Krill abundance (N m^{-2}) in the 0-50 m water column in September 2005 estimated from acoustic measurements (data GINR). High krill abundance, mainly (*Meganyctiphanes norvegica*), is evident in the Disko Bay (Bergström & Vilhjalmarsson 200

near shore areas (between 70° and 60° N) (Figure 18). 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 indicate that the productive cycle in Disko Bay is highly pulse-like, which is characteristic for Arctic marine ecosystems. Moreover, the important sites for the development of 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.

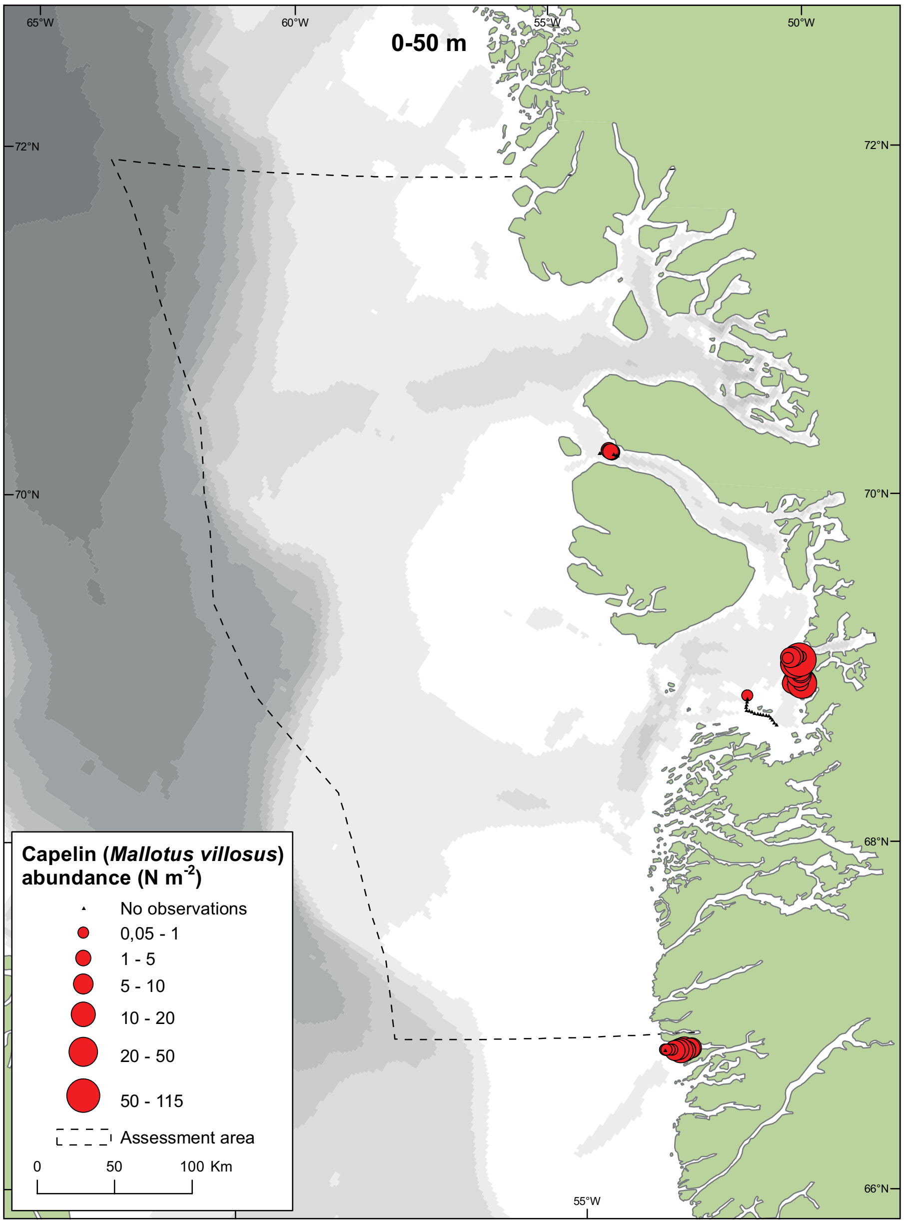


Figure 18. Capelin abundance (N m^{-2}) in the 0-50 m column in September 2005 estimated from acoustic measurements. Survey routes are shown in Figure 17. High capelin abundance was found in some fjord systems (Bergström & Vilhjalmarsson 2007).

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 and in the Disko Bay area (Pedersen & Smidt 2000). Shrimp larvae are usually released from the females at water depths, which are much shallower (< 150 m) 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).

3.2.6 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.

3.3 Benthic flora

Susse Wegeberg (AU)

Shorelines with a rich macroalgae flora are of high ecological importance. The littoral- and sublittoral canopy of macroalgae is of structural importance for a range of organisms by providing substrate for sessile animals, shelter from predation, protection against wave action, currents and desiccation. Macroalgae may act as a direct food source for, e.g., marine macrofauna, such as snails (Bertness et al. 1999, Lippert et al. 2001), but may be more important as a source of particulate organic matter fueling the benthic communities locally and also on larger depth outside the photic zone (Fredriksen 2003, Renaud et al. 2015, Gaillard et al. 2017). Especially during the dark winter period when phytoplankton is absent, an increased dependence on kelp carbon as a food source for macrofauna has been identified (Dunton & Schell 1987).

However, some shorelines and seabeds are unsuitable for macroalgal growth, because of lack of or instable substrate or because of physical parameters such as wave action and ice scouring. Such shorelines will therefore naturally sustain a relatively lower production or may appear as barren grounds. Thus to identify important areas and areas sensitive to oil spill, establishing a robust baseline on littoral- and sublittoral communities is essential.

3.3.1 Benthic vegetation communities in the assessment area

The marine macroalgae are found along the Greenland shorelines with hard and stable substratum, such as stones, boulders and rocky coasts. The vegetation is distinctly divided in zones, which are most pronounced in areas with high tidal amplitudes. In the littoral zone, the vegetation is alternately immersed and emersed, and, in the assessment area, characterized by brown fucoid algae species. The majority of the macroalgal species grows, however, below the low water mark, and the kelp species such as *Agarum chlatratum, Alaria esculenta*, and *Saccharina* spp. may create kelp forests within water depths with sufficient light. A more detailed description of the macroalgal flora in the assessment area including a check-list and distribution data of the marine algae in the Disko West area were compiled by Wegeberg (2013), including a mapping survey of the submerged macroalgal vegetation performed in the assessment area in 2009 (Hansen et al. 2013b). However, floristic and ecological investigations of the marine benthic flora in the assessment area is still limited, as well as in most of Greenland, although surveys relevant for the assessment area have been performed in recent years (Thyrring et al. in prep., Krause-Jensen et al. 2019, Marbà et al. 2017).

Studies of marine vegetation in the area date back to the late 18th century, with these early studies being mainly floristic. Marine macroalgae were collected on different expeditions to Greenland during the 19th century, and were identified and described by Rosenvinge (1893, 1989). However, due to regular courses for students at University of Copenhagen based at the Arctic Station in Qeqertarsuaq, the marine flora in proximity to the station has been more intensely studied in recent decades ((Düwel & Wegeberg 1992), (Hansen & Schlütter 1992)). A new species, *Stictyosiphon arcticus*, was for example described based on collections from Disko Fjord (Pedersen & Kristiansen 1992).

More recent studies and monitoring programmes have focused on ecological and climatic drivers and included studies on depth distribution and production (biomasses and growth rates).

The sublittoral vegetation was studied in 2009, and data on the sublittoral macroalgal coverage, substratum type and sea urchin densities estimated by SCUBA divers and from underwater videos in 33 transect lines perpendicular to the Greenland coast from Sisimiut to Nuussuaq was obtained (Hansen et al. 2013b, Krause-Jensen et al. 2019). The study documents occurrences of dense kelp forests in the area, especially at rocky coasts where sea urchins were absent. Hence, the study showed a clear positive correlation between macroalgal coverage and presence of suitable/stable substratum, but a negative correlation between macroalgal coverage and water depth as well as grazing pressure by sea urchins in the assessment area.

Sea urchin grazing may control the presence of kelp forests (Filbee-Dexter & Scheibling 2014) and in extreme situations result in complete removal of the kelp vegetation (barren grounds). Such barren grounds have been reported in the Disko area (Hansen & Schlütter 1992), and underwater video surveys in 2013 and 2014 also found such barren grounds in Uummannaq Fjord and in the Upernavik area north of the assessment area (S. Wegeberg, unpubl. observations).

The depth of the photic zone varies considerably along the Greenland west coast due to, for example, local outfall of turbid melt water from the glaciers or due to variation in sea ice cover (Krause-Jensen et al. 2019), and the depth range of the kelp belt increases from north towards south along Greenland's west coast in parallel to the increase in the ice free period (Krause-Jensen et al. 2011). However, despite ice-cover for 77-133 days year^{-1}, the Disko Bay kelps hold a depth-record for this region (north of 50° N). The deepest kelps (deeper than 61 m) were located at offshore sites off Disko Island and the main land, supported by deep rocky substratum, a low density of grazers (sea urchins) as well as clear waters, (Krause-Jensen et al. 2019, Hansen et al. 2013b). Increasing water turbidity (and potentially lowered salinity), as a result of an increase in freshwater runoff due to global warming, could thus impoverish depth penetration and growth conditions in some areas (Krause-Jensen et al. 2019).

Production of kelp in the upper sub-littoral zone (≤20 m) reach values up to 175 g dw year^{-1} per mature kelp individual (Krause-Jensen et al. 2012, Ørberg et al. 2018a). Kelp biomass quantified for southern Greenland and Northeast Greenland (Wegeberg 2007, Wegeberg et al. 2020) document quite similar biomasses across localities reaching 10-15 kg wet weight m^2, which is therefore probably also the case in the assessment area.

A unique sublittoral feature in Disko Fjord, in the assessment area, is the habitat of large loose-lying coralline red algae, rhodoliths, with diameters of up to 13 cm, occurs on a soft and muddy bottom (Düwel & Wegeberg 1992, Thormar 2006). Such unique areas, dominated by rhodoliths, are only reported from a couple of other localities in Greenland; around Nuuk (Schoenrock et al. 2018) and close to Qaqortoq, but these areas are stony habitats with encrusting coralline red algae and rhodoliths intermixed (Wegeberg 2012).

The vegetation and communities in the littoral zone has been investigated along the Greenland west coast from Cape Farewell to Upernavik, including Disko Bay in the assessment area. The results showed that the mean biomasses in the mid littoral zone reached c. 250 g ww in 25 × 25 cm study plots in the assessment area and dropped markedly between southern Disko (69° N) and Uummannaq (71° N) (Thyrring et al. in prep.). This study also showed no significant relationships between community metrics and average air temperature or ice coverage as obtained from local weather stations and satellites, respectively. Although the mean biomass decreased > 50% from south to north, local biomass in excess of 10,000 g ww m^{-2} was found even at the northernmost site, demonstrating the patchiness of this habitat and the effect of small-scale variation in environmental characteristics, e.g. scouring from ice floes (Thyrring et al. in prep.).

The sea ice and the glacier ice from the Jakobshavn Glacier (see Chapter 2.3) may impact the littoral vegetation (Wegeberg & Geertz-Hansen 2020), mainly by mechanical scouring. The sea ice is a complex driver, also on the littoral vegetation (Wegeberg & Geertz-Hansen 2020). The mechanical scouring of floating ice floes prevent especially perennial fucoid species to establish in the littoral, which, however, also depends on the rugosity of the rocky substratum (Ørberg et al. 2018b). However, the littoral vegetation may survive being frozen into an ice foot, as the perennial species from the littoral zone do tolerate freezing (Becker et al. 2009), but provided that the ice foot melts without scouring and hence disrupting the vegetation. The macroalgal vegetation then remains intact as observed in more sheltered localities. In Kobbefjord, close to Nuuk south of the assessment area, the formation of an ice foot during winter was found to constitute a protective shield around the tidal zone, which both reduced ice scour and insulated against low temperatures (Ørberg et al. 2018b).

Climate change will probably affect the littoral macroalgal vegetation both by warming and longer season with open water, and thereby a longer season for growth as well as reduced impact from ice scouring and shading by sea-ice. As the growth rates of *Ascophyllum nodosum* correlated with temperature and annual ice free days (Marbà et al. 2017), an increase in its growth and northern distribution edge can be expected with warming. The study included data from the northernmost site for *A. nodulosum* at the Greenland west coast (69.7°N).

Hence, as concluded by Thyrring et al. (in prep.), climate changes may lead to an overall increase in the intertidal standing stock in north Greenland, but is unlikely to drive dramatic change in the intertidal ecosystem structure in the near future, although increased growth and a northward range expansion of species is a likely scenario as exemplified by *Ascophyllum nodosum* (Marbà et al. 2017). A poleward migration has also been observed for *Fucus vesiculosus* on the Greenland northwest coast (Krause-Jensen et al. in prep.).

3.4 Benthic fauna

Martin E. Blicher (GINR), Nanette Hammeken Arboe (GINR), Diana Krawczyk (GINR) & Jørgen L.S. Hansen (AU)

The benthic habitat has a central role in the marine ecosystem in the Arctic, in terms of elemental cycling, ecosystem function, and biodiversity. Benthic macrophytes are confined to a relatively narrow photic zone extending from the inter-tidal zone to approximately 50 m depth. The biomass and production of perennial kelps can be significant and the large macroalgae create specific habitats with a characteristic associated fauna. The benthic fauna is found at all depths and all types of substrate. Benthic invertebrate communities can be very species rich and overall, they represent the majority of the marine biodiversity. The benthic fauna process a major fraction of the marine primary production by filtering suspended particulate organic matter (e.g. detritus and plankton) directly from the water column or by feeding on it after it has been deposited on the seafloor. Thereby the benthic fauna exert an important link between primary production of plankton algae in the upper illuminated layer of the water column and the higher trophic levels in the ecosystem. Three benthic invertebrate species are exploited commercially in Greenland waters. The scallop (*Chlamys islandica*) and the snow crab (*Chionoecetes opilio*) live directly on the sea floor, whereas the northern shrimp (*Pandalus borealis*) is found closely associated with the bottom. Moreover, there have been attempts to develop commercial exploitation of blue mussels (*Mytilus edulis*), sea urchins (*Strongylocentrotus sp.*) and sea cucumbers (*Cucumaria spp.*).

The benthic fauna community is affected by a multitude of different biological and physical parameters; with depth, temperature, food input, substrate composition, particle load, disturbance level (e.g. ice scouring, trawling) and hydrographical regime being the most prominent (e.g. Gray 2002, Wlodarska-Kowalczuk et al. 2004, Piepenburg 2005). Therefore the benthic community is often extremely heterogeneous on both local and regional scales (Sejr et al. 2010a, Yesson et al. 2016, Blicher & Hammeken Arboe 2017).

3.4.1 General context

Ecology

The different fauna groups in the benthic community undertake many different functions in the marine ecosystem, and the functional composition of the community often reflect specific environmental conditions in an area. The fauna can be grouped according to their feeding mode and the relative dominance of different groups depend on the overall productivity of the system, and on the physical habitat characteristics. Filter feeding fauna (filtrators) are dependent on the concentration and availability of suspended organic matter in water column. The filtrators typically have high biomasses in productive systems and in areas where the bathymetry allows the benthos to have contact with the productive surface mixed layer. Strong currents also favour the biomass dominance of filtrators that benefit from the advective transport of suspended material. In contrast, the group of fauna that feed on organic material deposited on and in the sediment, the deposit feeders, typically dominates in sedimentary basins with weak current, such as in the deep fjords and troughs. In areas with stronger bottom-near currents, emergent lifeforms of both flora and fauna uses the available hard substrate to anchor themselves. Such emergent fauna contribute to the structural complexity of habitats, supporting a rich associated fauna, and may ultimately provide vital ecosystem services such as nursery areas. In a similar way, the faunal diversity of the soft sedimentary bottoms is also related to structural heterogeneity. However, here the structural heterogeneity largely results from the structures in the sediment (e.g. borrow, tubes etc.), whereas the influence of emergent epifauna on the biogenic complexity of the habitat is less significant. On hard substrates, large epifauna can contribute to the structural complexity of habitats and support a rich associated fauna. Considering the commercial importance of living resources connected with the seabed, relatively little is known about benthic ecology in Greenland waters. Common notions are often based on the results of case studies limited in space and time. There have been reports of high standing stocks of macrofauna (>1000 g wet weight m^{-2}) in shallow benthic habitats in Greenland (< 100m), and macrobenthos is considered an important food source for fish, seabirds and mammals (Vibe 1939, Anonymous 1978, Ambrose & Renaud 1995, Sejr et al. 2000, Sejr et al. 2002, Born et al. 2003, Merkel et al. 2007, Sejr et al. 2007, Blicher et al. 2009, Blicher et al. 2011). The productivity of benthic fauna in the Arctic is often linked to food availability (e.g. Grebmeier & McRoy 1989, Ambrose & Renaud 1995, Piepenburg et al. 1997, Blicher et al. 2009) and consequently high production is expected to be found in areas where sea ice cover is minimal and does not control primary production, and at shallow depths where benthic primary production is considerable and pelagic production is transferred most efficiently to the sea floor. Upwelling zones and subsurface discharge from glaciers can also stimulate pelagic primary production and create hot spots for secondary producers, such as benthic fauna. Moreover, it has been suggested that low individual energy requirements at low temperatures contribute to a positive energy budget despite low and/or highly seasonal primary production (Clarke 2003, Blicher et al. 2010).

As opposed to the marine life in the water column, the majority of the benthic invertebrate species are relatively stationary either during their entire life cycle or in their adult life after finishing a planktonic larval stage. Thereby the benthic fauna is very sensitive to natural and anthropogenic impacts, including physical disturbance from bottom trawling, hypoxia, or exposure to oil spills or other hazardous substances.

Species

Many benthic taxonomic studies were conducted in Greenland waters by Danish research expeditions in the late 19th century and the first half of the 20th century, mainly providing qualitative descriptions of species and communities. The Natural History Museum of Denmark (NHM) holds a compilation of the large amounts of historical records (up to 2001) of benthos from Greenland waters down to 1000 m depth. This work was done in an attempt to make a qualitative baseline for the region, but never seem to have reached a larger audience (Tendal & Schiøtte 2003). Recently, in CAFF's *State of the Marine Biodiversity Report* (Jørgensen et al. 2017) it was summarized that the complete data set counts more than 2100 species of benthic invertebrates, with arthropodes, molluscs and polychaetes representing 55% of the species. However, the state of knowledge is strongly limited by sampling effort. There is a significant correlation between the number of sampling stations in each of 18 sub-regions and the number of species registered in these sub-regions. The Disko West Assessment Area has a large number of historical sampling stations and more than 900 species of benthic invertebrates have been identified. This extensive data compilation is a valuable baseline for present and future benthic studies in Greenland. Data are stored at NHM.

More recent surveys in coastal areas in West Greenland have also consistently confirmed that local species richness of soft bottom infauna can be high, with up to >80 species/taxa per 0.1 m^2 grab sample (Sejr et al. 2010a, Sejr et al. 2010b). A dedicated study of macro-infauna in the Disko West area was conducted in 2009, with a main focus on the shallow banks Store Hellefiskebanke and Disko Banke, and described separately in Box 1.

Habitat

The complex topography and hydrography of the assessment area also result in a highly heterogeneous substrate composition. A recent study of the Greenland shelf has documented a mix of seven different main surface substrate categories covering the entire spectrum from soft clay and mud, to sand, gravel and solid rock. A classification model was developed using environmental proxies to make habitat predictions for the West Greenland shelf (200-700 m depth, up to 72° N) (Fig. 4.4.1; Gougeon et al. 2017). The resolution and quality of environmental variables limited predictions to single habitat classes in 3.5x3.5 km grid cells, which are likely to encompass multiple habitats. Still, the model underlines the heterogeneity of the seabed in the assessment area.

This was further underlined in a recent, high-resolution benthic habitat mapping pilot study (MapHab) conducted in central Disko Bay (see Figure 8 for location), utilizing multi-beam survey with collection of physical ground-truthing (Krawczyk et al. 2019). The multi-beam-derived data provided information on water depth and seafloor topography (bathymetry data) and allowed differentiating seafloor materials, such as rugosity and sediment grain size (backscatter data). Physical ground-truthing is needed to calibrate and validate the interpretation of multi-beam data and imagery from a towed video sled and a bottom-triggered drop camera together with physical grab samples to characterize substrate types and habitat-forming benthic taxa (Figure 19).

Multi-beam and ground-truthing data served as seafloor descriptors and were combined into benthic habitat classes describing physical sedimentary environment, as well benthic communities on a fine, meter scale (Figure 20).

The hitherto approach to benthos sampling has generally not reflected this heterogeneity in the physical habitat. Until recently, most of the benthos information available from Greenland consisted of macro-infauna collected with scientific grabs, typically sampling 0.1 m^2 of soft seabed. Consequently, there has been little information about benthos communities with an affinity to hard and mixed seabed substrates (epifauna), and about large benthic organisms (megafauna) typically occurring in relatively low densities. These components contribute to a complex habitat structure and may ultimately support ecosystem services by creating habitats and nursery grounds for a diverse range of associated fauna, including fish and shellfish.

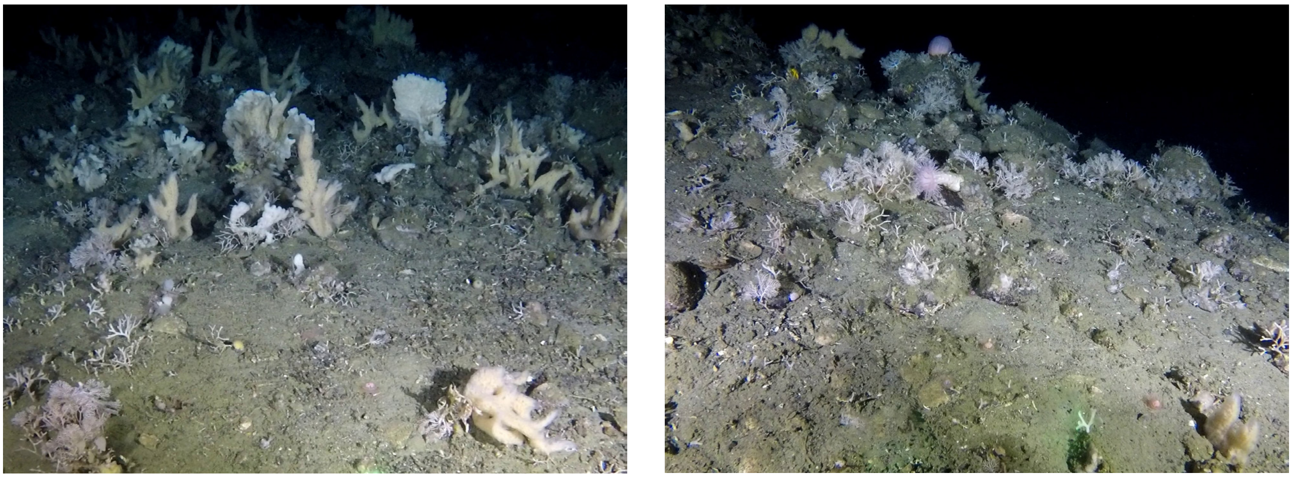
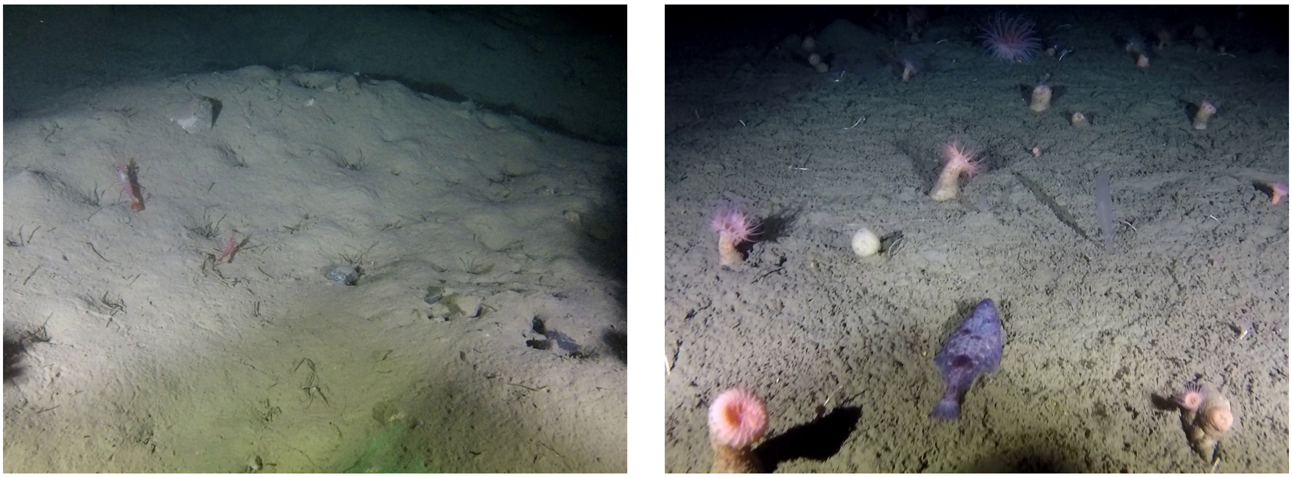


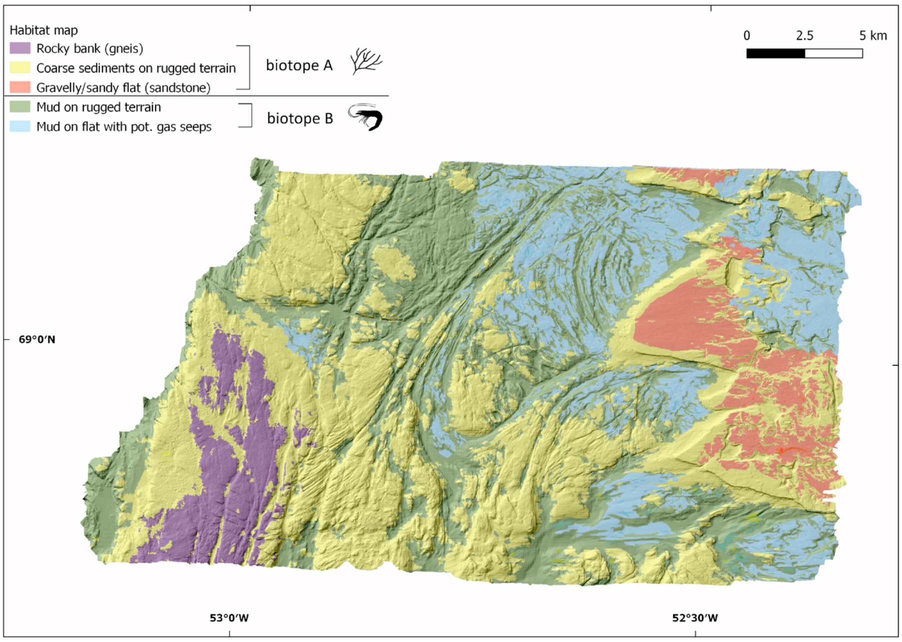
Figure 19. Example stills of habitats and taxa encountered during video surveys in central Disko Bay in the MapHab pilot area (see Figures 8 and 20). Top: Pristine coarse and rugged seabed dominated by erect calcified bryozoans and sponges, and a mix of associated species. Mid: Gravelly sand/mud with sea anemones, ascidians, sponges and calcified bryozoans. Bottom left: muddy seabed with signs of trawling activity, dominated by commercially fished prawns *Pandalus borealis*. Bottom right: Pristine muddy seabed dominated by large sea anemones (attached to subsurface hard substrate) with Greenland halibut. Each image represents an area of several square meters.



Such an example was described recently in a quantitative analysis of seabed imagery providing Greenland's first description of a soft coral garden habitat and other communities. The coral garden and observed densities were considered in relation to the VME[4] guidelines (FAO 2008) and wider literature. The study proposed a 486 km^2 area spanning ~60 km of continental slope as a VME-candidate. The area can be described as the area with depths of 300-600 m between 64°50′ N and 64°22′ N on the western edge of the Toqqusaq Bank (Long et al. 2020), which is south of the assessment area.

4 Vulnerable Marine Ecosystem (VME); a term which is used to identify deep sea areas or habitats vulnerable to especially botton trawling, based on its uniqueness, functional significance, fragility, recovery potential and structural complexity (FAO 2008).

Figure 20. High-resolution (10 x 10 m) benthic habitat map showing distribution of five physical habitats (see legend) and associated biotopes in a pilot study area in central Disko Bay (location indicated with black rectangle in Figure 8).



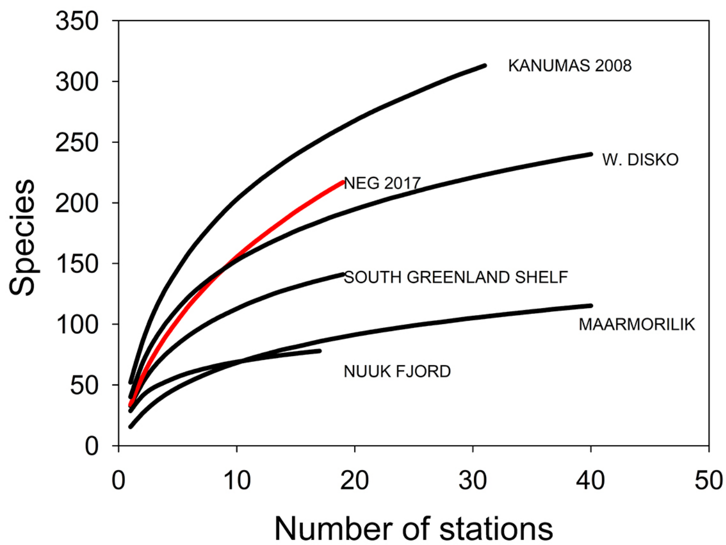
Also, the first living sample of the reef-forming coral, *Desmophyllum pertusum*, was accidentally caught with hydrographic equipment, and later photo documented in situ at c. 1000 m depth on the continental slope in South Greenland (60.36° N, 48.45° W) (Kenchington et al. 2017). The area is designated as a VME-candidate. On the Canadian side of the Davis Strait a protectien area has been designated based on the prescence VME indicator species (Link). See also Fuller et al. (2008).

3.4.2 Recent studies and current monitoring of benthic fauna in the assessment area

The infauna community

The spatial distribution of infauna diversity at a larger scale (i.e. beta and gamma diversity) is poorly described for West Greenland benthic habitats due to the few data available. However, species accumulation plots for the recent West Greenland sampling surveys show an overall pattern with more flat and saturated curves in fjord systems as compared to steep curves in open shelf areas (Figure 21). The shape of the curve reflects how much the diversity (the community composition) change when increasing the sampled area, and is related to the heterogeneity of the habitat and the connectivity of the benthic populations to areas outside the sampled area. The curve shape also gives an indication of

Figure 21. Species accumulation curves representing six different infauna surveys in Greenland waters. Reproduced from Hansen et al. (2019a).



how well-described the biodiversity is in the area, and for the West Greenland Waters, it is clear that the open shelf areas, including the Disko West, are the areas with the poorest understanding of the infauna biodiversity.

The epifauna community

As outlined above, the knowledge of benthos communities in the assessment area is affected by the fact that most historical samples have been collected at sites with soft sediment due to the technical difficulties of quantitative sampling on hard or mixed substrates. Consequently, our knowledge about benthic communities associated with such heterogeneous habitats has been limited. A recent drop camera survey on the West Greenland shelf documented significant differences in epibenthic taxon composition and diversity between soft and hard substrate. Not surprisingly, hard substrates were dominated by sessile attached groups, such as Hydrozoa, Anthozoa, Bryozoa and Porifera, while epibenthos on soft substrates were less diverse and dominated by mobile Malacostraca (pandalid shrimps) and Polychaeta (Yesson et al. 2015). Results also showed that communities associated with hard or mixed substrates are more vulnerable than soft bottom communities towards physical disturbance, such as bottom trawling, with significantly longer recovery times of 10-20 years after disturbance (Yesson et al. 2016). This is regarded a rather conservative estimate as the taxa and communities regarded most vulnerable to physical disturbance (e.g. coral and sponge gardens) were poorly represented in the dataset due to methodological limitations.

However, these results contributed to a realisation that large-scale monitoring of benthos communities in Greenland was crucial for knowledge-based spatial management and assessment of the potential combined influence of climate changes, commercial activities on the marine ecosystem and other ecosystem services.

Therefore, in 2015, the Greenland Institute of Natural Resources (GINR) launched a program intended for long-term and large-scale monitoring of benthic invertebrate fauna. A "trawl bycatch-program" on national fisheries assessment surveys in Greenland waters was implemented as a minimum standard, collecting information about focal components of the benthic community on the continental shelf and slope, covering depths from *c.* 50 to 1500 meters. In West Greenland, fishery surveys are conducted annually from 59° 30′ N up to 72° 30′ N (Blicher & Hammeken Arboe 2017, Jørgensen et al. 2017). The bycatch of benthic invertebrates in assessment trawl hauls are analysed and identified to the highest possible taxonomic resolution by an international team of benthos taxonomists. Despite the low catch-efficiency of commercial-type demersal trawls and its geographical restriction to the fisheries survey areas, the method has proven effective for documenting large-scale distributions of benthic mega-epifauna (Jørgensen et al. 2014, Blicher & Hammeken Arboe 2017), and it enables the initial detection of potential VME's, valuable ecosystem components or areas subject to dramatic changes (e.g. biodiversity hot spots, coral or sponge gardens, nursery grounds). The detection of such potential focus areas can be followed up by more targeted benthos sampling (e.g. photo/video, beam trawl, grab, multibeam acoustics), see for example Figure 22. A towed video sled and a scientific beam trawl have been used to document benthic communities in more detail, both as a supplement to the general monitoring in West Greenland, and in relation to specific questions and projects (Figure 23). One such project is an ongoing collaboration between GINR and the Institute of Zoology at Zoological Society of London (ZSL), which focuses on the potential impact of deep-sea trawling for Greenland halibut, on the benthos community in West Greenland. The study is motivated by an increasing focus on sustainability of

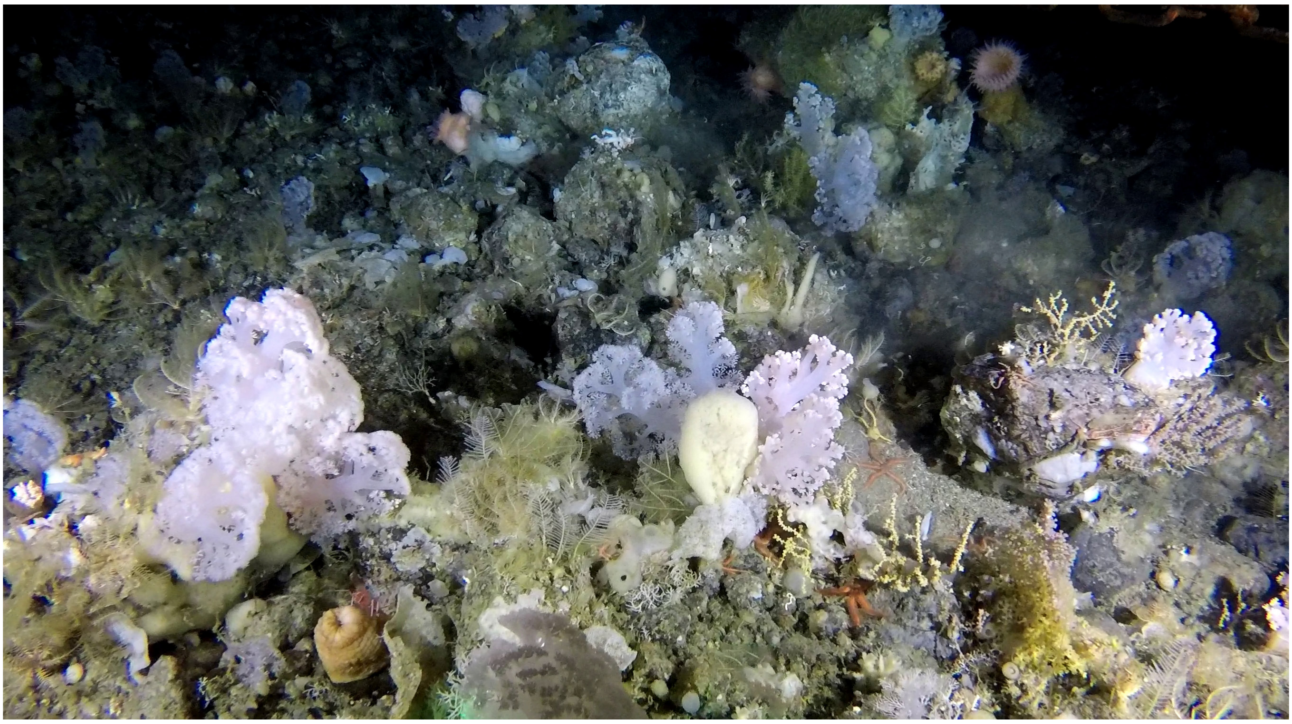


Figure 22. Example still showing the structural complexity of the soft coral garden habitat on rocky ground at a depth of 585 m, on the continental slope off Toqqusaq Bank, south of the Disko West Assessment Area. Nephtheidae, Crinoidae, gorgonian corals, Porifera, Actinaria, Hydrozoa and calcified Bryozoa are present with a rich associated fauna.

fisheries. Several fisheries in Greenland have been, or are currently being, evaluated according to the sustainability principles defined by the Marine Stewardship Council (Link). Data from video imagery and trawl bycatch samples will be used to separate the effects of environmental drivers and trawling in the survey areas for Greenland halibut. Results will be presented in late 2020 in a PhD thesis by Stephen Long.

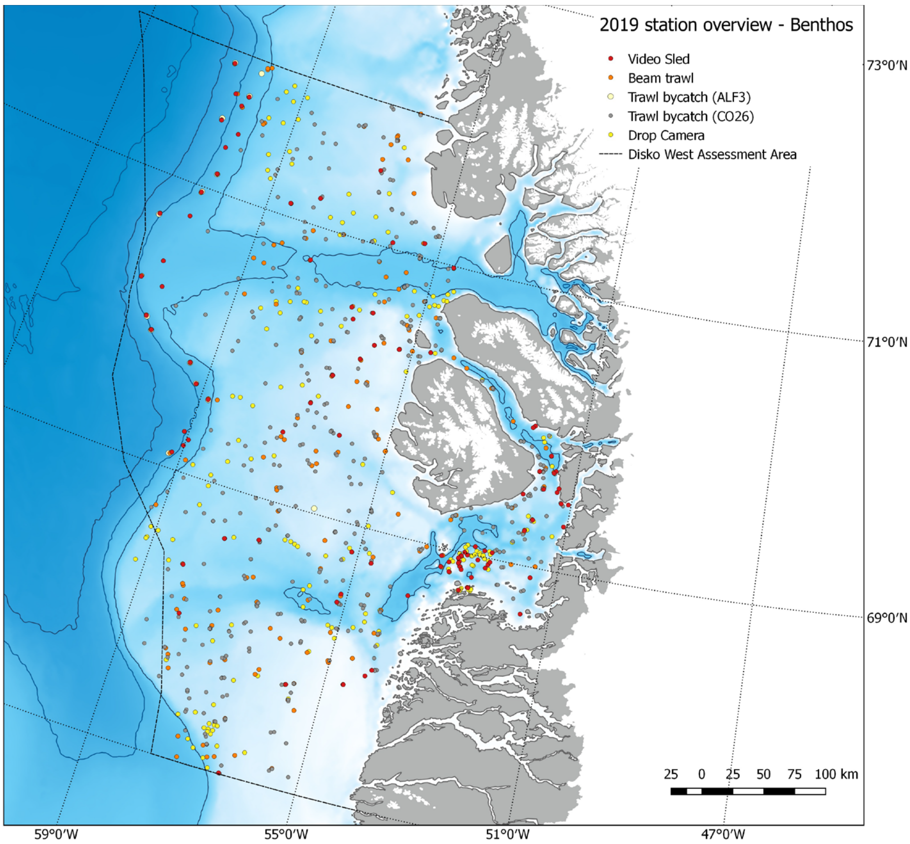


Figure 23. Overview of benthos sampling stations in the Disko West Assessment Area in GINR's Benthos monitoring program in the period 2015-19. The standard sampling program includes identification of benthic invertebrate bycatch in fisheries assessment trawls. Additional sampling is conducted with beam trawl, a bottom-triggered drop camera and a towed video sled.

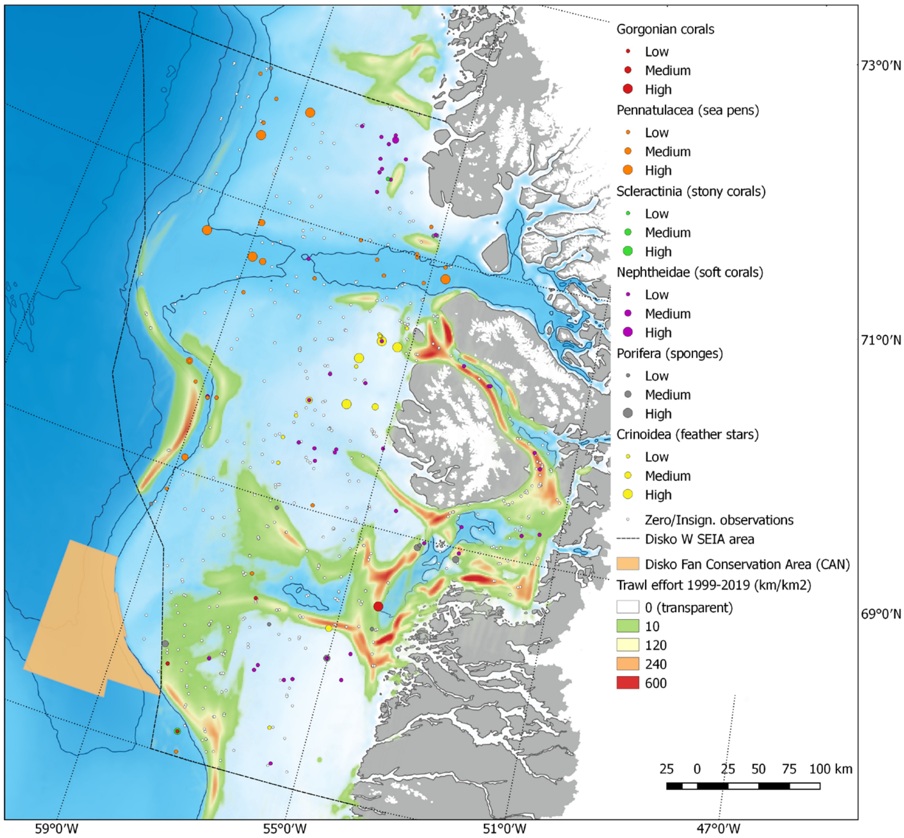


Figure 24. Bubble diagram showing relative densities of corals, sponges (Porifera) and feather stars in the Disko West Assessment Area, determined from bycatch in fisheries assessment survey trawl hauls and beam trawl. The taxa are relevant in the context of Vulnerable Marine Ecosystems. The size of bubbles indicates the relative density of a taxon but are not directly comparable between taxa. Trawl effort indicates the accumulated line density of commercial bottom trawling in the period 1999–2019. The Disko Fan Conservation Area in the Canadian EEZ is indicated with an orange polygon.

By 2019, a total of more than 800 benthos invertebrate species/taxa have been registered within the Disko West assessment area in GINR's sampling program, at depths ranging from 50 to 1300 m. A wide range of different main communities are observed, both in terms of species and functional traits composition. An exhaustive description of all the available data is out of scope for this report. And the relevance of potential analyses will always depend on the questions being asked. But, two specific fauna groups that seem particularly relevant in this context are cold-water corals and large sponges. Many species of these groups are considered indicators of VME's (Buhl-Mortensen et al. 2019). Corals and sponges are widespread in large parts of the north Atlantic. In high abundances they create unique habitats inhabited by a rich associated fauna (Mortensen & Buhl-Mortensen 2004, Bryan & Metaxas 2006). While much effort has been put into identifying and mapping potential VME's in Canadian, Icelandic and Norwegian waters (Edinger et al. 2007, Kenchington et al. 2011, Buhl-Mortensen et al. 2019), data on the distribution of corals, sponges and other VME indicator taxa have been scarce for West Greenland until the implementation of GINR's benthos monitoring program. Figure 24 is intended to give a preliminary overview, up to 2019, of observations of four main groups of corals (gorgonians, Scleractinia, Pennatulacea, Nephtheidae), large-sized sponges (Porifera) and feather stars (Crinoidea) caught in trawl hauls in the assessment area.

Data based on trawl bycatch provide relative densities of the benthos species caught, due to the assumed low catchability, and as such, data is regarded indicative. But the extensive spatial coverage of the sampling program makes it possible to point out localities or areas with higher concentrations of focus taxa, or other special features. Firstly, large occurrences of sponges (glass- and demosponges) and gorgonians seem quite scattered. Also, the absence of black corals (Anthipatharia) in our samples suggest that they are rare in the assessment area. But there are VME indicator taxa that occur consistently over larger areas. This is for example the case for soft corals (Nephtheidae) in an area west of Sigguup Nunaa (Svartenhuk Peninsula) in the 200 m depth

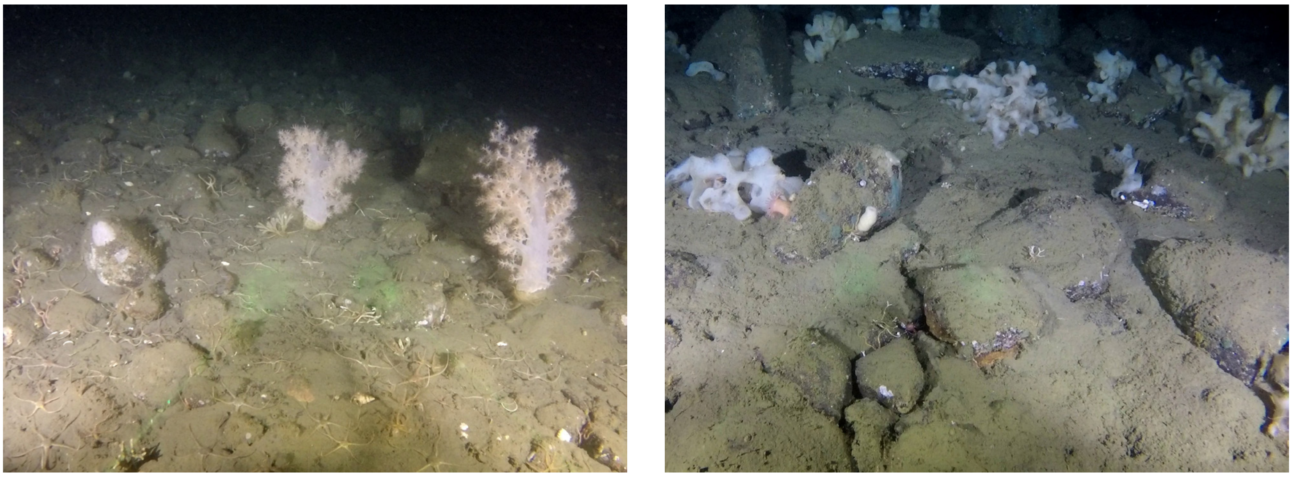
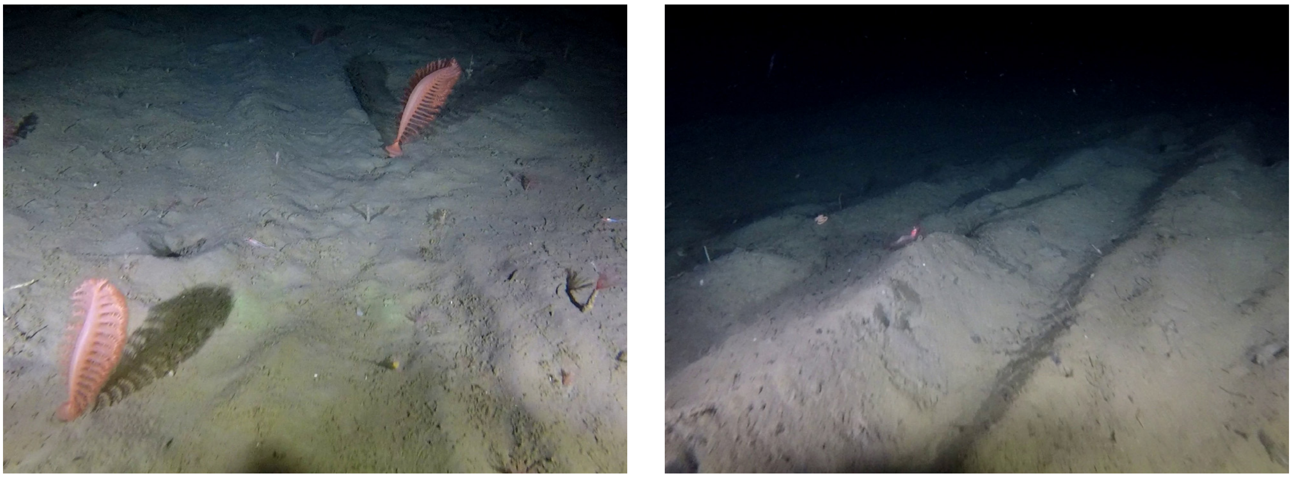


Figure 25. Example stills of taxa and habitats encountered during video surveys in the offshore part of the Disko West Assessment Area with reference to Figure 23. Top left: Soft corals (Nephtheidae indet.) and brittlestars, *Ophiura sarsii*, on stony substrate with thin layer of mud. Top right: Field of glass sponges, *Asconema foliatum* on mixed rocky ground. Mid left: Rocky habitat with dominance of feather stars (Crinoidea), *Heliometra glacialis*, and brittlestars, mainly *Ophiopholis aculeata*. Bottom left: Sea pens, *Pennatula grandis*, on homogenous mud substrate. Bottom right: Scars after trawling for Greenland halibut at c. 1000 m depth.



range at around 71° 30′ N. The single video haul available from the area shows a homogenous stony seabed with high densities of brittlestars (Ophiuroidea) and abundant soft corals (Figure 25 top). Similarly, a rocky area west of Qeqertarsuaq (Disko Island) around 71° N at 100-200 m depth is inhabited by dense concentrations of feather stars, Crinoidea (*Heliometra glacialis*) (Figure 25 mid). In the group, Crinoidea, only the stalked sea lilies are normally considered VME indicators. However, feather stars share many of the same characteristics, and are included here due to their unusual abundance in what seem to be relatively a restricted geographical area. Sea pens, Pennatulacea, mainly represented by *Anthoptilum grandiflorum, Pennatula (Ptiella) grandis, Umbellula encrinus*, have a clear affinity to muddy substrate and occur at depths >300 m in troughs and on the continental slope, particularly in the northern part of the assessment area (Figure 25 bottom).

An area with '*Significant concentrations of large gorgonian corals, including large tracts of globally unique, high-density bamboo corals*' in the Canadian EEZ, have led to the designation of the 7,485 km^2 large Disko Fan Conservation Area (Figure 24; Link). The area is situated close to the Greenlandic EEZ at depths >500 m. However, based on the sparse data available at the time of writing this report, there is no evidence that this benthic community extends into the Disko West assessment area.

The current geographical coverage of GINR's standard monitoring program correspond to the areas included in fisheries assessments in Greenland. Therefore, an obvious limitation of the program is the bias towards more trawl impacted areas. Un-trawled areas that sustain more pristine habitats are generally under-represented. Therefore, data are also generally scarce from the shallow banks. Such areas will need to be surveyed through targeted ship campaigns.

See also Box 2 describing the results of a benthic survey on Store Hellefiskebanke in 2009.

3.4.3 Data storage

GINR's benthos monitoring program is linked to the existing fisheries survey capacities. Therefore, all benthos data are stored in a benthos extension to the survey database (Microsoft Access) for fish and shrimps maintained by the Department for Fish and Shellfish at GINR. This also includes sampling station metadata (e.g. gear type, start-end positions, sampling area, bottom temperature, bottom depth, wire length, speed-over-ground). Data are quality-checked and secured at GINR. Specific information can be extracted and presented to authorities and stakeholders on request.

3.5 Sea ice Ecology

Dorte Søgaard Schrøder (GINR)

In the Arctic region the sea ice cover doubles its size from summer to winter with a total sea ice area ranging from 4.7 – 7.7 million km^2 to 14.3 – 16.3 million km^2, respectively (median values 1981-2010; Lund-Hansen et al. 2020). Combining the total sea ice extent at the Arctic region and the Southern Ocean, the maximum sea ice extent covers about 10% of the world´s oceans, representing one of the largest biomes on earth. Sea ice is a highly dynamic and extreme environment with large vertical variations in light conditions, temperature, salinity and nutrient availability. Organisms living inside the brine channels and at the bottom of the sea ice are called sea ice or sympagic fauna, which includes viruses (Bowman et al. 2013), bacteria, algae, ciliates, heterotrophic flagellates, amphipods and copepods (Lund-Hansen et al. 2020).

Information on sea ice algal productivity in the assessment area is limited. In other Arctic areas the sea ice primary production varies between 0.2 and 463.0 mg C m^{-2} d^{-1} (Arrigo 2017), which is low compared to the estimated pelagic primary production in West Greenland of 185- 1370 mg C m^{-2} d^{-1} (Jensen et al. 1999a, Juul-Pedersen et al. 2015, Meire et al. 2015). Even though sea ice primary productivity only account for 1 to 57% of the pelagic primary production in the Arctic Ocean, it is still of great importance for the higher trophic levels in the Arctic food chain at times of the year where the pelagic and benthic productions are low, with ice algae being the main carbon source (Lund-Hansen et al. 2020). This is illustrated in a study of fatty acids of the under-ice

Box 2. Benthic invertebrate fauna in the Disko West area with focus on Store Hellefiskebanke

Jørgen L.S. Hansen, Mikael Sejr, Alf B. Josefson, Paul Batty, Morten Hjorth & Søren Rysgaard

Present 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 (Figure 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.

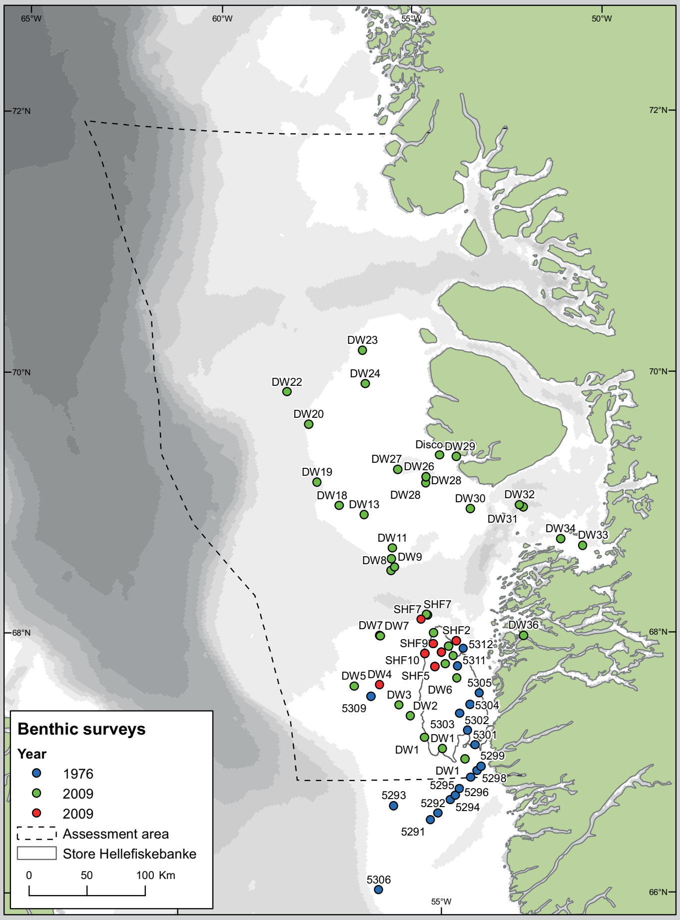


Figure 1. Stations sampled during the 2009 survey qualitatively and quantitatively (red and green symbols). Previous sampling (1976) is marked with blue symbols.

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 (Figure 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 (Figure 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.

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.

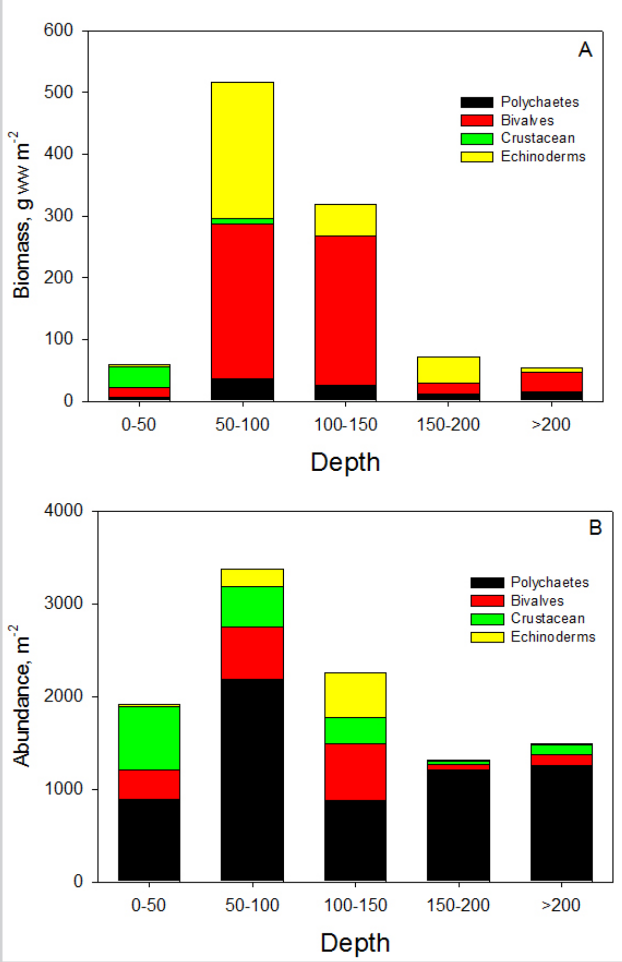


Figure 3. A) Distribution of benthic biomasses among major taxa in 50 m water depth intervals; B) Distribution of corresponding taxa in terms of abundance.

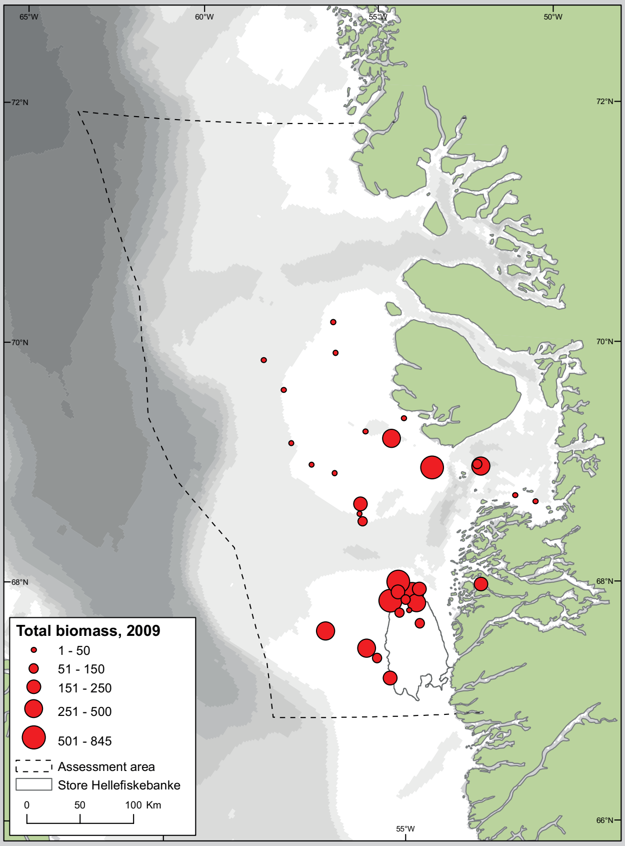


Figure 4. Distribution of benthic macrofauna biomass in the Disko West area May 2009.

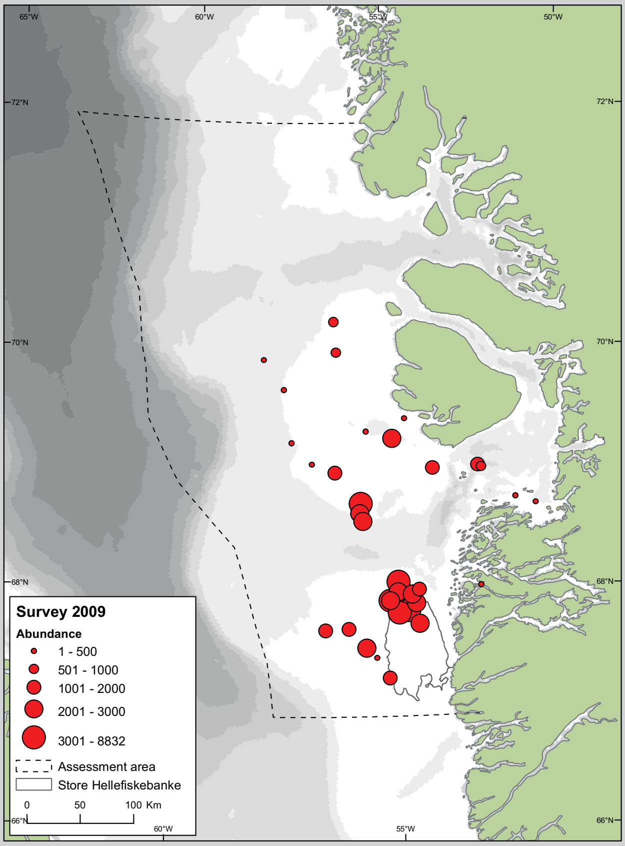


Figure 5. Abundance m^{-2} of benthic macrofauna in the Disko West area in May 2009.

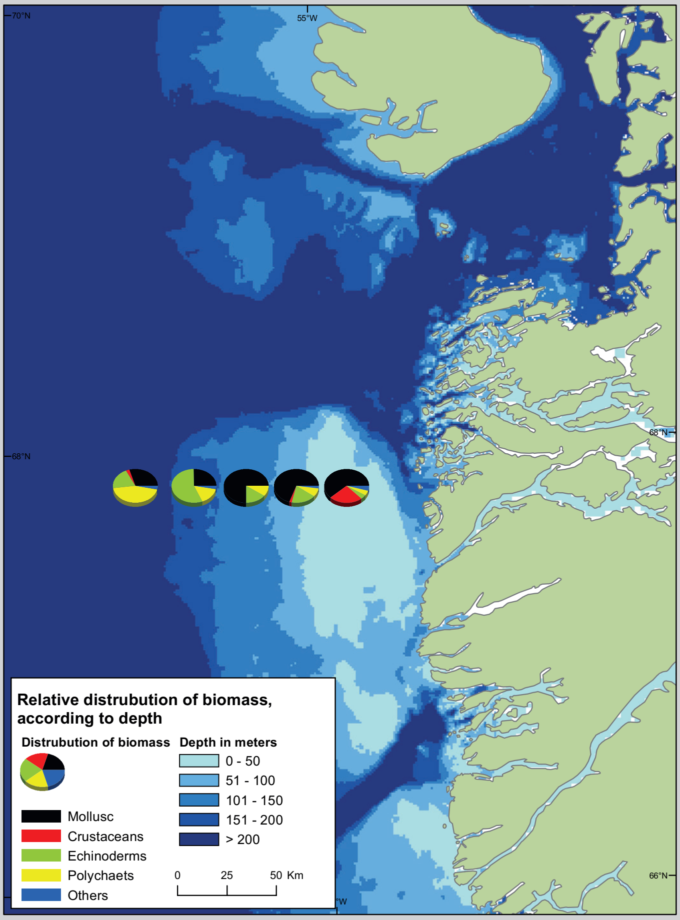


Figure 6. Distribution of benthic macrofauna communities during the survey in May 2009 in terms of biomass in different depth intervals <50 m, 50-100 m, 100-150 m, 150-200 m and depth > 200 m.

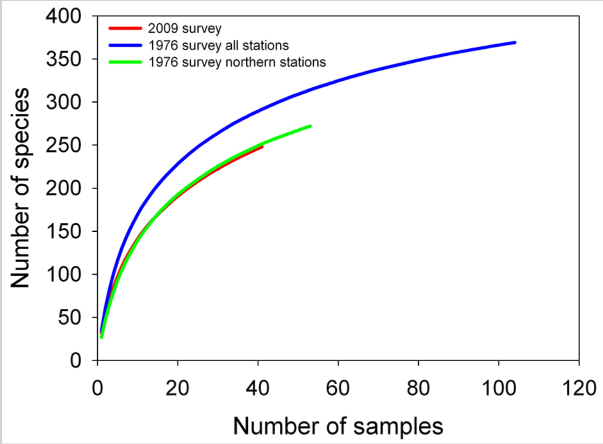


Figure 7. Randomised species accumulation curves showing cumulated number of species vs. number of Van Veen samples on the Store Hellefiskebanke in 1976 (blue line) and 2009 (red line). The green line shows the distribution of species at the stations in the northern part of the 1976 survey.

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; Figure 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 (Figure 3).

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} (Figure 4.4.1.4). 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 taken 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.

Bathymetry, and in particular depth can be seen as a major factor for the distribution of the macrofauna communities in the Disko West area (Figure 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 historical 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 (Figure 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, Figure 8) it is expected to find 369 species of four major taxa. One more sample would add 1 more 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.

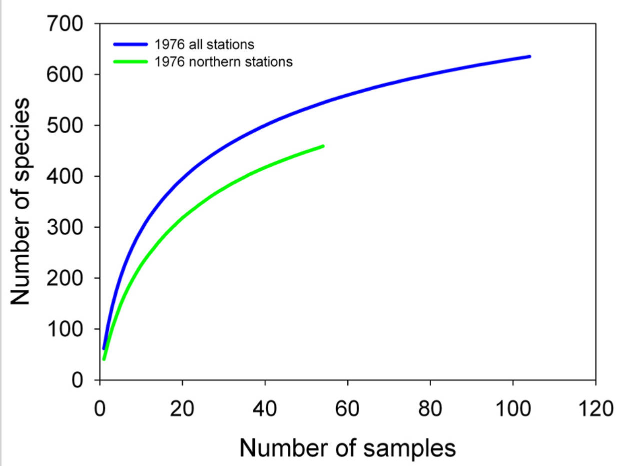


Figure 8. Distribution of species richness on the Store Hellefiskebanke in 1976 (data represents average number of species per 0.1 m^2 (Van Veen samples).

As found elsewhere the benthic ecosystem in the aphotic zone in the Disko West area 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.

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 (Figure 7 and 8), these numbers may only represents a fraction of the total diversity of the invertebrate fauna. During a previous investigation carried out at the Store Hellefiskebanke in 1976 about 700 species were documented in about 150 samples. The differences in community composition between individual samples were high and even higher among stations.

The distribution of polychaetes species among stations, for example, showed markedly differences in the communities although the stations were gathered 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 straight forward this suggests that the "real number" of species in the area could well be considerably higher maybe exceeding 1000.

Potentially there are several new species to science among the found 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 should probably 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 Store Hellefiskebanke (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 3).

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 easy accessible. Large aggregations of king eiders are seen in the area during winter (Box 4) 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 baseline and effect studies performed 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 recommended to construct a reference collection based on this and other investigations for quality assurance of future investigations 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.

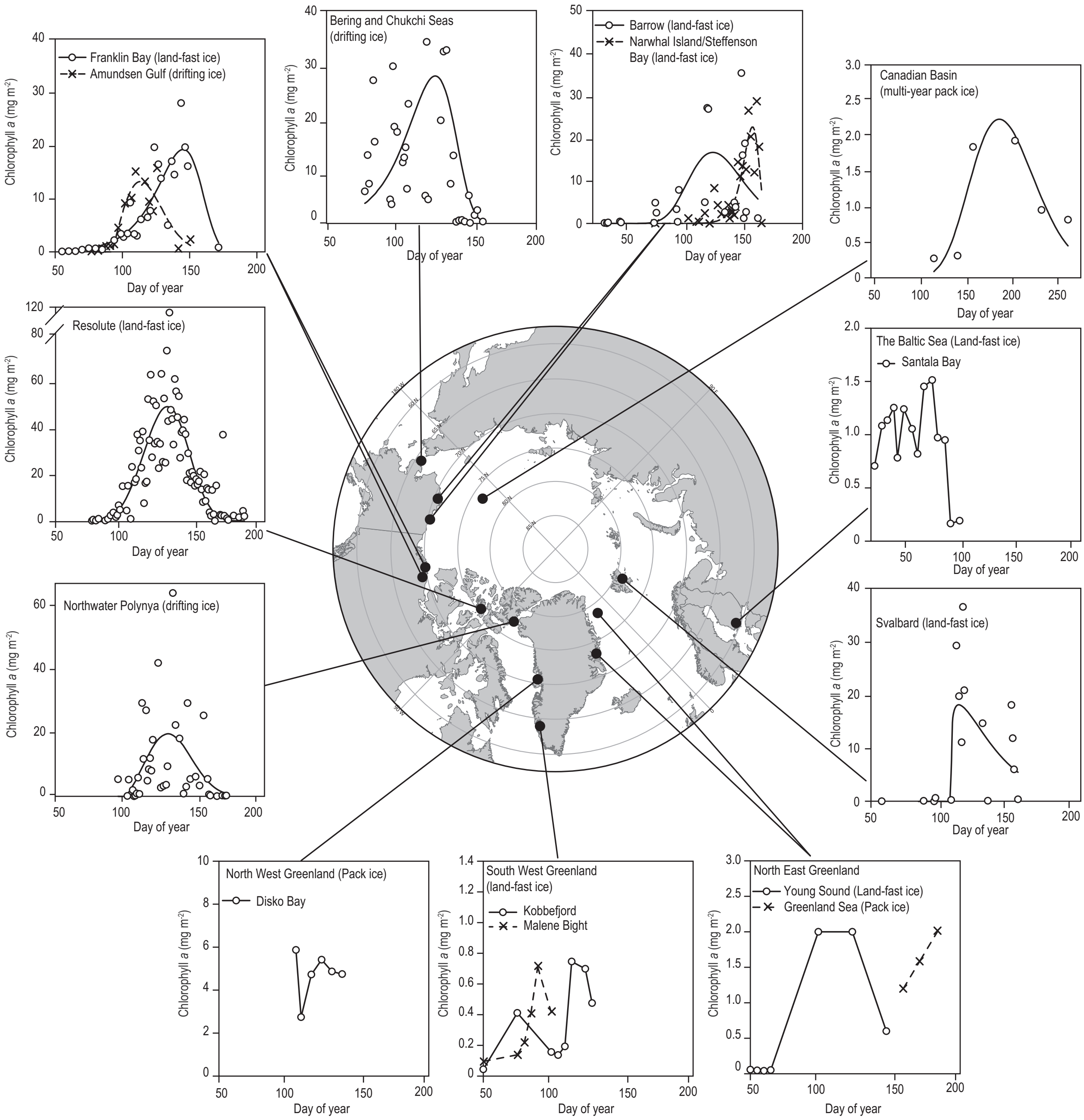
Techniques for a more precise positioning of soft bottoms sampling in relation to small-scale properties of bottom surface morphology such as iceberg scours etc. will lead to a better understanding of small-scale habitat heterogeneity and thereby opening the possibility of developing better BACI-designed (**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 or sandeels.

fauna species including copepods, ice-associated amphipods, pelagic amphipods and pteropods from the central Arctic Ocean. It is shown that the species thrived on the carbon synthesised by ice algae and also that polar cod is strongly dependent on the occurrence of sea ice algae, as between 34 to 65% of the carbon uptake by polar cod is derived from sea ice algae (Brown et al. 2017, Kohlbach et al. 2018). As for the highest level in the Arctic food chain, the polar bear, a study showed that 72 to 100% of the polar bear diet is derived through the food chain from sea ice algae (Brown et al. 2018), which emphasizes the importance of sea ice algae for all trophic levels in the Arctic.

Figure 26. Seasonal development of Chl *a* concentrations in sea ice in different regions of the Arctic (modified from Lund-Hansen et al. 2020). One of the studies was carried out in Disko Bay within the assessment area and two just south of the assessment area.

Strong patchiness of the sea ice algae is commonly reported (Figure 26), caused by the heterogeneity of the ice as well as varying snow cover affecting light conditions (e.g. Tedesco et al. 2019). Søgaard et al. (2010) found, in their study in West Greenland (two site within the assessment area and one site just north of) that the patchiness of algal biomass was strongly controlled by the snow cover thickness and the light availability within the ice. Algal biomass from sea ice in Greenland coastal areas range from 0.04 to 6.0 mg chl. *a* m^{-2},



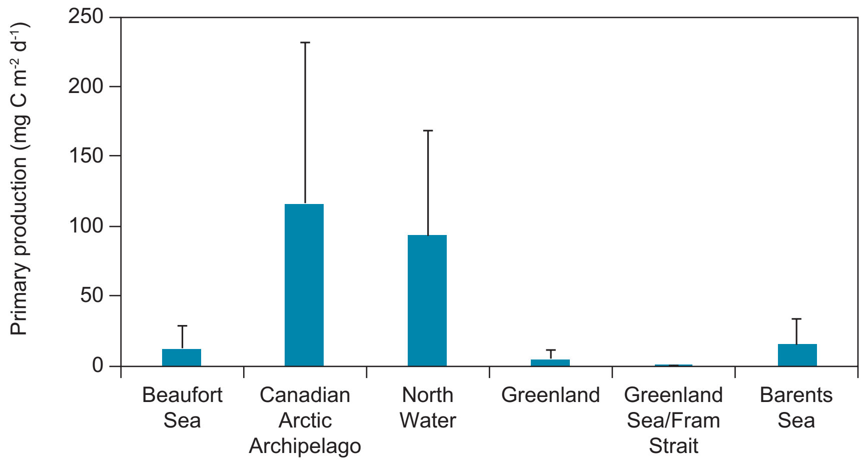


Figure 27. Sea ice algae primary production average with standard deviation at sites in the Arctic Region. Compiled from Barber et al. (2015), Leu et al. (2015) and Arrigo (2017). Modified from Lund-Hansen et al. (2020).

which is similar to values measured in sea ice in the central Arctic Ocean and the Baltic Sea (Figure 26). However, Greenland biomass values are extremely low compared to values recorded from Arctic sea ice in general, which range between 30-40 mg chl. *a* m^{-2} in Svalbard and up to 120 mg chl. *a* m^{-2} near Resolute in the Canadian Archipelago (Figure 27). Areas with low sea ice algal biomass as the Greenland coastal areas are generally also areas with low sea ice primary production rates (Lund-Hansen et al. 2020).

Sea ice primary productivity rates of 0.1 to 21 mg C m^{-2} d^{-1} are recorded for various areas around Greenland, which corresponds to < 1% of the pelagic production (Rysgaard et al. 2001, Rysgaard & Glud 2007, Mikkelsen et al. 2008, Søgaard et al. 2010, Søgaard et al. 2013, Lund-Hansen et al. 2018) (Figure 27). The ice algal production in the northern part of the Barents Sea is reported to be 13.7 mg C m^{-2} d^{-1}, which corresponds to 16-22% of the total annual primary production (Quillfeldt et al. 2009). In the ice-covered Arctic Ocean the ice algae were found to contribute on average 57% of the entire primary production (Gosselin et al. 1997).

There is further a high spatial variability in species composition of Arctic sea ice algae communities (e.g. Van Leeuwe et al. 2018). In Baffin Bay, Irwin (1990) found dominance of a centric diatom, *Cosinodiscus* sp., which accounted for 63% of the total number of cells in ice floes at the Labrador Shelf, while Michel et al. (2002) found that pennate diatoms completely dominated (85% in first-year ice) in the North Water Polynya. Somewhat conflicting results have been reported for the colonial, centric diatom species, *Melosira arctica* (Table 2). This diatom is found to be either very dominant or rare/absent (Gutt 1995b); e.g. it dominated the ice algal biomass in the Barents and Greenland Seas, but was not reported from the Beaufort Sea, Baffin Bay or in Kobbefjord, SW Greenland (Horner & Schrader 1982, Irwin 1990, Michel et al. 2002, Mikkelsen et al. 2008).

There have been an increasing number of under-ice blooms of pelagic phytoplankton (Arrigo et al. 2014) but to which degree or whether the blooms were initiated by sea ice algae is still uncertain. Mikkelsen et al. (2008) tested if the ice algae acted as primers initiating the spring bloom of phytoplankton by

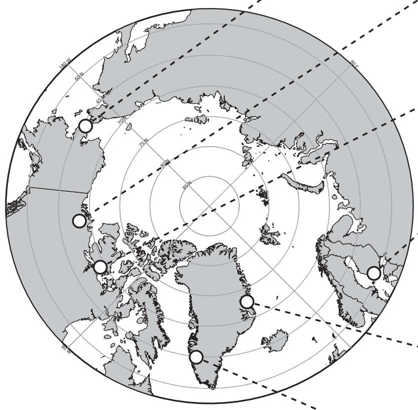
Table 2. Observations of *Melosira arctica* connected to either first-year or multiyear ice.

Source	Area	First-year ice	Multiyear ice
Gosselin et al. 1997	Arctic Ocean	X	
Gutt 1995	NE Greenland	X	
Quillfeldt et al. 2009	Barents Sea		X
Lund-Hansen et al. 2015	Arctic Ocean	X	X

algal seeding, but had 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. In addition, Booth (1984) found that species composition in the sea ice differed significantly from that of the phytoplankton in Davis Strait.

Both algal production and bacterial production influence the overall productivity of the Arctic marine ecosystem. Bacteria are the most abundant heterotrophs in sea ice (Deming & Collins 2017).They contribute typically with less than 10% of the total sea ice productivity of carbon during spring and summer, but can account for most of the total winter productivity (Deming 2010) (Figure 28). Few combined measurements of bacterial and algal productivity exit in the assessment area, making it difficult to assess the spatial and temporal impact of these processes (Figure 28). In general, the annual succession follows the same pattern with a winter stage characterized by a net heterotrophic activity and remineralisation of nutrients by sea ice bacteria. The autotrophic activity exceeds the heterotrophic activity once the light levels has passed a critical level (> 0.17 µmol photons m^{-2} d^{-1}; Hancke et al. 2018), resulting in nutrient depletion. In the late part of the sea ice season the algae become nutrient limited and a post bacteria bloom is often observed.

A synthesis on Arctic and Antarctic studies of sympagic biota showed significant patterns in microalgal community structures with autotrophic flagellates that characterize ice bottom surface communities, while interior communities consist of mixed microalgal populations, and pennate diatoms dominate bottom communities (Van Leeuwe et al. 2018). Sea ice algae contribute to the biomass of the sea ice communities with 43%, bacteria with 31%, heterotrophic flagellates with 20% and meiofauna with 4% in the Greenland Sea (Gradinger et al. 1999). Diatoms are the main primary producers, and contribute with up to 60% of total algal biomass. *Melosira arctica*, together with the pennate



Chukchi Seas (land-fast ice)

Study	Bacterial production (µg C L^{-1} d^{-1})	Primary production (µg C L^{-1} d^{-1})
Baer et al. (2015)	0.33 ± 0.50	15.90 ± 36.50

Canadian Arctic (land-fast ice)

Study	Bacterial production (µg C L^{-1} d^{-1})	Primary production (µg C L^{-1} d^{-1})
Smith and Clement (1990)	1.65 ± 0.70	–

Central Canadian Arctic (land-fast ice)

Study	Bacterial production (µg C L^{-1} d^{-1})	Primary production (µg C L^{-1} d^{-1})
Nguyen and Maranger(2011)	10.25 ± 6.50	–

The Baltic Sea (land-fast ice)

Study	Bacterial production (µg C L^{-1} d^{-1})	Primary production (µg C L^{-1} d^{-1})
Kaartokallio et al. (2008)	4.08 ± 2.50	–
Kuosa et al. (2006)	5.24 ± 3.30	78.50 ± 36.50
Mock et al. (1997)	5.60 ± 1.40	–

North East Greenland

Study	Bacterial production (µg C L^{-1} d^{-1})	Primary production (µg C L^{-1} d^{-1})
Søgaard et al. (2019)	1.95 ± 1.60	0.07 ± 0.09

South West Greenland (land-fast ice)

Study	Bacterial production (µg C L^{-1} d^{-1})	Primary production (µg C L^{-1} d^{-1})
Søgaard et al. (2010)	0.28 ± 0.15	0.30 ± 0.10
Søgaard et al. (2013)	1.80 ± 1.60	3.40 ± 5.80
Kaartokallio et al. (2013)	8.70 ± 12.20	–

Figure 28. Sea ice bacterial and algal productivity compiled for different Arctic locations (Modified from Lund-Hansen et al. 2020). The studies in West Greenland was carried out just south of the assessment area.

diatom, *Nitzshia frigida*, tend to be the dominant diatom species off Northeast Greenland/Barents Sea (Gutt 1995b, Gosselin et al. 1997, Quillfeldt et al. 2009), and when the ice melts, it is supposed that the diatom sinks to the bottom and thereby may constitute a relatively large input of organic material to the pelagic grazers and benthic communities (Gutt 1995b, Michel et al. 2002). However, flagellated algal cells were also found to be of significance (Gradinger et al. 1999, Van Leeuwe et al. 2018), and they were primarily cryptophytes and dinoflagellates (Ikävalko & Gradinger 1997), the latter were almost all heterotrophic in the North Water Polynya in northern Baffin Bay (Michel et al. 2002).

A synthesis on the distribution of meiofauna on a local to a pan-Arctic scale showed similar species composition and abundances on a scale of meters, while higher variability was observed on a scale of kilometres and even more so on a regional scale (Bluhm et al. 2018). Still, the same phyla were found across the Arctic with abundances dominated by taxa having resting stages or tolerance to extreme conditions (e.g. nematodes and rotifers). They also found that meroplankton (organisms with temporary planktonic life stages, which often occur near the seabed) was only observed in locations experiencing nearshore and landfast sea ice. Light availability, ice thickness and distance from land was found to be significant predictor variables for community composition in the sea ice at different scales (Bluhm et al. 2018).

The ice fauna was dominated by ciliates, nematodes, flatworms and crustaceans in the Greenland and Barents Seas (Gradinger et al. 1999, Arendt et al. 2009). Gradinger et al. (1999) calculated a potential ingestion rate of the meiofauna, which levelled the estimated annual sea ice primary production, and therefore they presumed that grazing could control biomass accumulation. However, Rysgaard et al. (2001) considered that the low ice algal production in Young Sound in Northeast Greenland did not seem to be caused by high grazing pressure, since the biomass of grazers was not exceptionally high in the location. In addition, Michel et al. (2002) concluded that very little ice algal production was channelled through the meio- and microfauna within the ice in the North Water Polynya due to suboptimal prey size for predators.

3.5.1 Important areas for sea ice communities

It is not possible to designate especially important or critical areas for sea ice fauna and flora; the information is too scanty and the ice-associated ecosystem is too variable and dynamic. It should be noted that the sea ice habitat is rapidly declining (Wang & Overland 2009). Based on sea ice data from 1950 to 2014 from Young Sound in Northeast Greenland sea ice breaks up 0.15 d yr^{-1} earlier (Middelbo et al. 2018). With younger and thinner sea ice, coupled with an earlier onset of snow melt and increased melt pond formation the Arctic marine ecosystems will be altered on different trophic levels. A biogeochemical model study for ice algae with sea ice drivers for different climate future scenarios showed distinct latitudinal patterns (Tedesco et al. 2019). Thus, snow cover thinning may have the biggest impact on algal blooms below 66° N, and thereby shifting of the ice seasons toward more favourable light conditions may increase ice algal production even above 74° N, while only small changes may be observed in the 66° N to 74° N band. However, another model showed that an ice-free Arctic Ocean at latitude >85° N will not add significantly to overall Arctic Ocean pelagic primary production due to the strong stratification of the water column (Lund-Hansen et al. 2020).

3.6 Fish and shellfish

AnnDorte Burmeister (GINR), Anja Retzel (GINR), Adriana Nogueira (GINR), Rasmus Nygaard (GINR), Helle T. Christensen (GINR), Søren Post (GINR) & Teunis Jansen (GINR)

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 1995a, Munk et al. 2003, Pedersen 2005, and references therein, Simonsen et al. 2006, Bergstrøm & 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 is probably a result of both higher temperatures, south to north directed currents and due to more knowledge on occurrence and distribution gained in relation to intensive fishing and other fishery research.

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 3) 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 Chapter 5.3). 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).

Table 3. 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, de-mersal 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

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 Chapter 5.3) but also important for the marine ecosystem in general.

3.6.1 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 for Greenland halibut (Smidt 1969, Stenberg et al. 2016), 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 at 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 unpl. data). Young halibut, i.e. one and to some extend two year old fish feed on zooplankton while older fish feed on shrimps, fish and squids at the sea bed 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).

Atlantic cod (*Gadus morhu*a)
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 was fished intensively until the offshore stock crashed. Today, Atlantic cod is fished inshore and landings in the assessment area increased to historic heights of nearly 6000 t in 2016/2017, but has since declined (ICES 2019a). In recent years an increasing number of juvenile Atlantic cod (age 1-2 years) have been registered on Store Hellefiskebanke between 66° and 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 5.4 on climate change).

Another cod species common in the assessment area, is Greenland cod (*Gadus oqac*). 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).

Quantitative spatial dynamics of capelin in West Greenland are understudied. Documentation and understanding of the seasonal and ontogenetic migrations as well as stock sizes are therefore poor/missing. Some capelin are in the fjords while others migrate out of the fjord. When in the fjords, 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). A large proportion of the spawning stock dies after spawning, especially males, suggesting that the stock should be considered as one-time spawners (Huse 1998b, Friis-Rødel & Kanneworff 2002b).

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 1998a, Friis-Rødel & Kanneworff 2002a).

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 amphipods (*Themisto* spp.) (Hedeholm 2010), depending on size. Capelin is, as it has a high lipid content, also a high quality prey for various predators such as cod, harp seals, whales and many seabirds (Friis-Rødel & Kanneworff 2002a, 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 which 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.

Recent studies indicate that the lumpsuckers spawning in West Greenland are separated into more than one stock (Mayoral et al. 2016).

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 as an 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 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 (for more details see Box 3).

Box 3. Abundance of sandeel (*Ammodytes dubius*) in the Store Hellefiskebanke area

Jørgen L.S. Hansen & Morten Hjorth

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 (Figure 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 (Figure 1). The distribution of sandeels correlates with the distribution of sandy sediments (Figure 2) and almost all specimens were found on the Store Hellefiskebanke (Figure 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 (Figure 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.

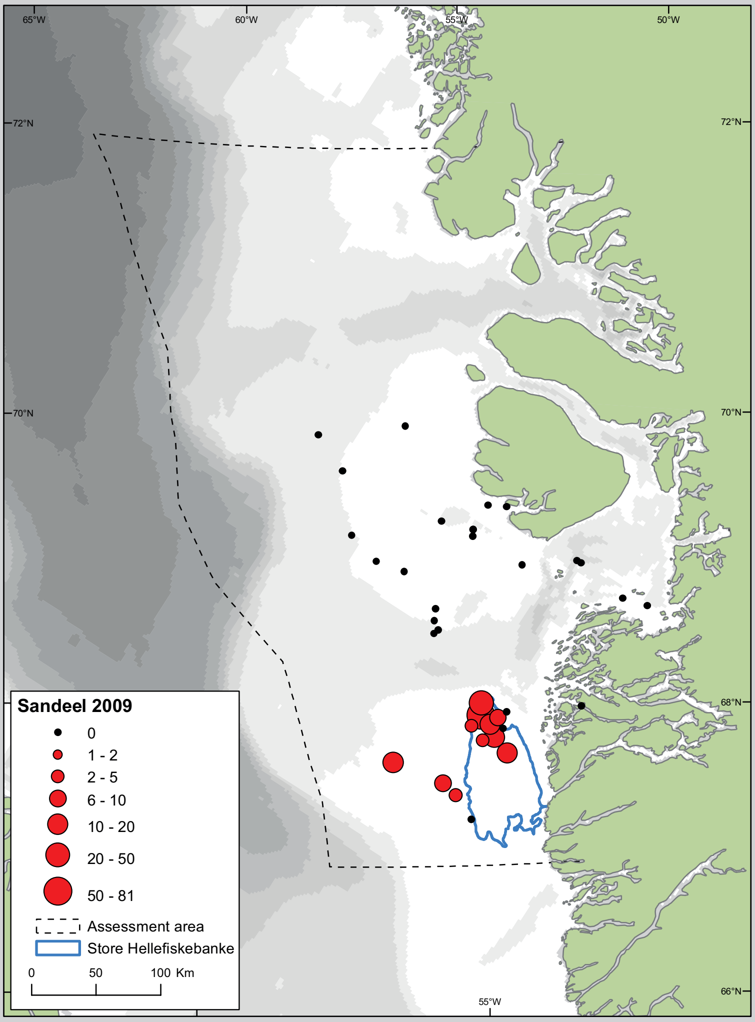


Figure 1. Distribution of sandeel in May 2009.

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 15000 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

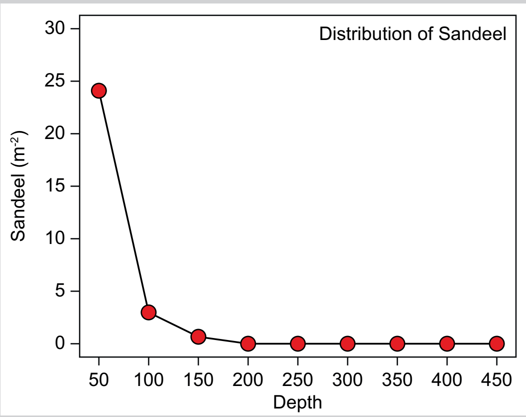


Figure 2. Distribution of sandeel versus depth in the Disko West area in May 2009.

in the 2-year class (Figure 4) whereas Andersen (1985) found up to 20 year old individuals. The ratio between 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.

A catastrophic pollution event would not only affect the part of the population buried in the sediment. A greater part of the population inhabiting areas such as Store Hellefiskebanke could be lost in case larger parts of the benthic habitat are damaged due to oil pollution.

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.

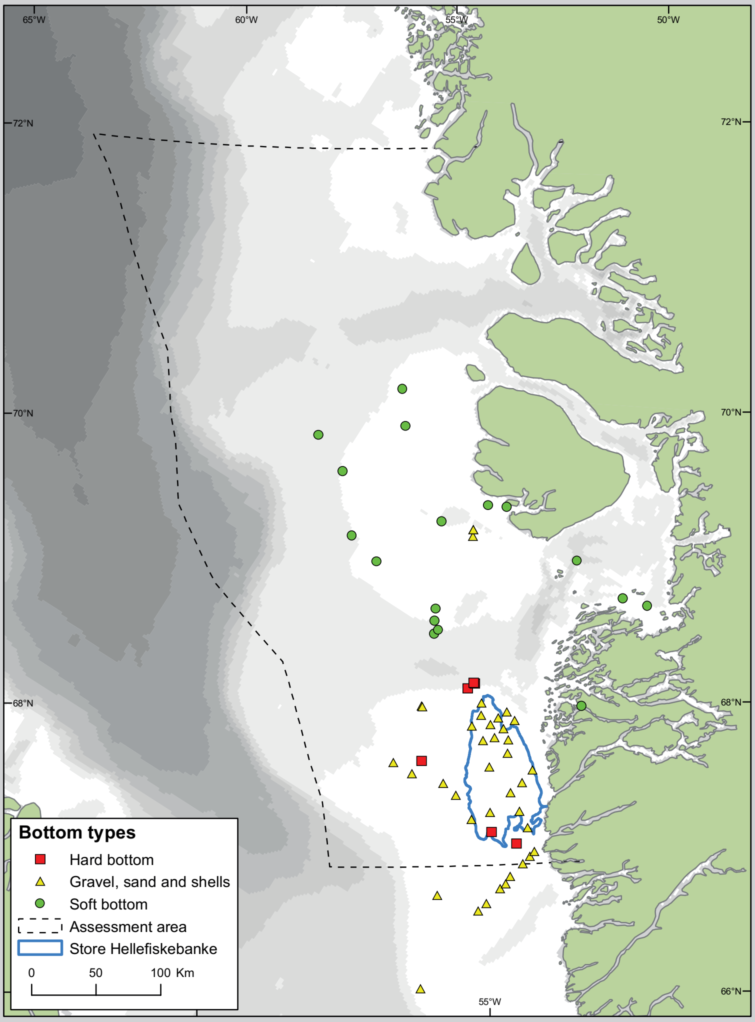


Figure 3. Distribution of sediment types: Hard bottom (red), bottoms with shells, gravel, stones and sand (yellow) and soft clay and mud (green).

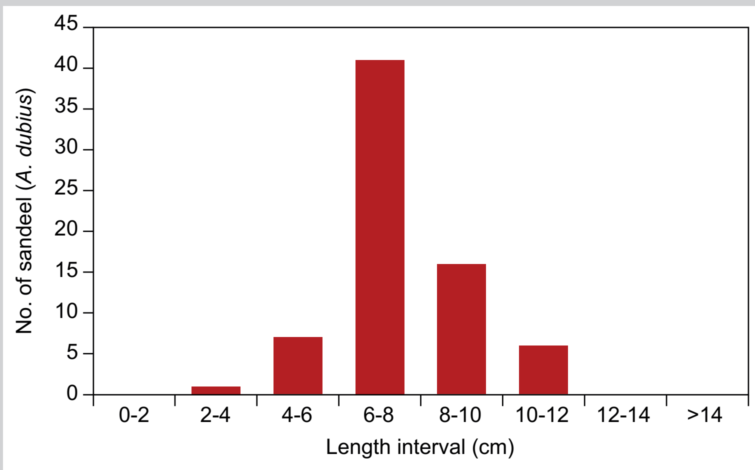


Figure 4. Frequency distribution of body length of the captured sandeels in the Disko West studies 2009.

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 (LeBlanc et al. 2019). 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 winter (November to March) and the eggs float and assemble under the ice (Hop & Gjøsæter 2013, Nahrgang et al. 2016). The larvae hatch over a long period from late winter to summer when the ice melts (Bouchard & Fortier 2008, 2011, Bouchard et al. 2016).

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

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 for narwhals in the northern wintering ground and during summer.

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). Bottom trawl surveys reveal increasing abundance and biomass of polar cod from the Sisimiut area and northwards including the Disko bay (GINR, unpublished).

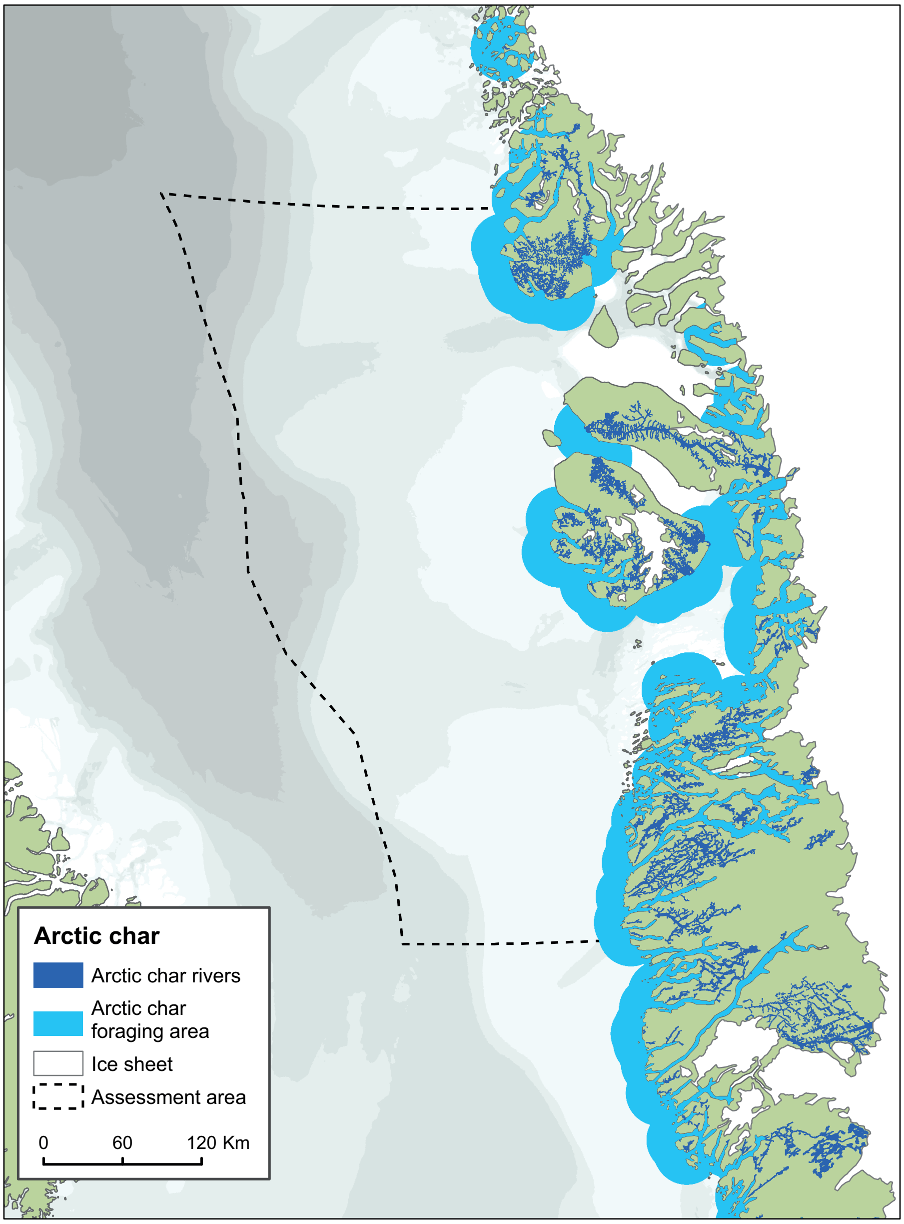
Arctic char (*Salvelinus alpinus*)
Arctic char is the most northern ranging freshwater fish and has a circumpolar distribution. It is widespread in Greenland including the most northern areas (Muus 1990) and also widespread in the assessment area (Figure 29).

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. Anadromous char mature at a size of 35-40 cm (Muus 1990), corresponding to an age of 5-7 years. Migratory Arctic char 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

Figure 29. Map of rivers with arctic char (blue) and their presumed habitat in coastal waters when staying in marine areas (pale blue). From Christensen et al. (2015)



an age of 3 to 6 years depending on growth conditions (Rigét & 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 and Alaska showed that char populations from different rivers mix largely at sea (Nielsen 1961, Furness 1975).

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 also 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. (Horsted 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 (Horsted 1978).

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).

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 is believed to be distributed along the entire coast of West Greenland (Storm & Pedersen 2003) and females carrying eggs 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 598 Kt. Since then the biomass has declined to a low level in 2014 mainly owing to a decrease in the biomass in the offshore areas. Since the biomass of northern shrimp in West Greenland waters has increased and was estimated to 334 Kt in 2019 (Burmeister & Rigét 2019a, b).

Since 1988 the majority 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 past two decades the distribution area for northern shrimp has moved northwards and the main biomass (70% to 90%) has been concentrated north of 67° N (including Disko Bay) (Burmeister & Rigét 2019b)

From 1999 the biomass in Disko Bay has been averaging 24% of the total biomass in West Greenland waters, but accounted for almost 50% in 2012 and 2014. The mean density of northern shrimp in Disko Bay is significantly higher than in the offshore areas. In 2019 only 13% of the total shrimp biomass in West Greenland waters was found in the Disko Bay (Burmeister & Rigét 2019b).

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° and 74° N in both offshore and inshore (fjords) waters (Burmeister 2002). It predominantly 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 with separate sexes. 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 occurring in the assessment area has an unfavourable conservation status due to years of high fishing pressure.

3.7 Seabirds

David Boertmann (AU), Flemming Merkel (GINR), Anders Mosbech (AU) & Kasper L. Johansen (AU)

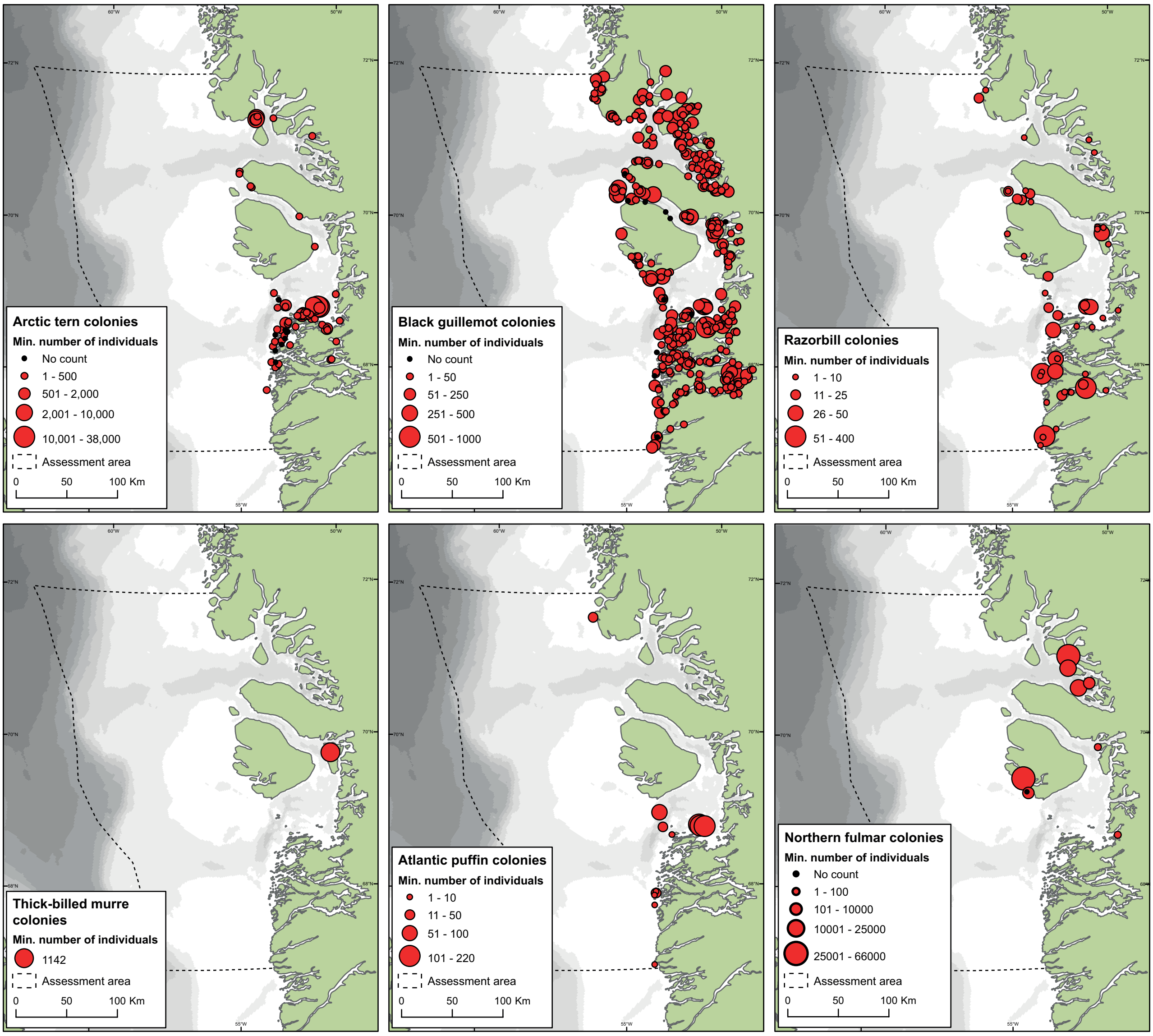
3.7.1 Biology

Seabirds constitute an important component in the marine ecosystem of the Disko West assessment area. Many species consume fish, particularly schooling species such as capelin, sandeel, and polar cod. Some species live on or supplement their fish diet with crustaceans (copepods, krill, amphipods) and squid, 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 wintering king eiders (*Somateria spectabilis*) was for example estimated to hold up to 30,000 birds, which may represent as much as 3% of the total population wintering in Greenland. Other examples are the large breeding colonies of which the largest hold up to 50,000 breeding pairs of e.g. northern fulmar (*Fulmarus glacialis*). An overview of the seabird species occurring in the assessment area is given in Table 4.

Table 4. Overview of selected seabird species occurring in the Disko West assessment area. b = breeding, (b) = breeding inland, 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	Feeding strategy	Occurrence		Distribution	Red-list status in Greenland	Importance of study area to population
Fulmar*	surface and shallow diver	b/s/w	year round	c & o	Least concern (LC)	High
Great cormorant*	diver and feed in water column	b/s/w	year round	c	Least concern (LC)	High
Brent goose	grazing on salt marshes	mi	spring and autumn	c	Vulnerable (VU)	Medium
Mallard	surface	w/(b)	winter	c	Least concern (LC)	Medium
Common eider*	diver to seabed	b/s/m/w	year round	c	Least concern (LC)	High
King eider	diver to seabed	m	Aug.-Sept.	c	Least concern (LC)	High
		w	October-May	c & shallow banks		
Long-tailed duck	diver to seabed	b/m/w	year round, in winter only southern part	c	Least concern (LC)	Medium
Red-breasted merganser	diver and feed in water column	b/m/w	year round, in winter only southern part	c	Least concern (LC)	Medium
Harlequin duck	diver to seabed	m/w	July-May	c (rocky shores)	Least concern (LC)	Medium
Red-necked phalarope	surface	mi/(b)	spring and autumn	o	Least concern (LC)	Low
Grey phalarope	surface	mi/b	spring and autumn	c & o	Least concern (LC)	Low
Arctic skua	surface	b	summer	c	Least concern (LC)	Low
Black-legged kittiwake*	surface	b/s	year round, few in winter	c & o	Vulnerable (VU)	High
Glaucous gull*	surface	b/s/w	year round	c & o	Least concern (LC)	Medium
Iceland gull*	surface	b/s/w	year round	c & o	Least concern (LC)	Medium
Great black-backed gull*	surface	b/s/w	year round	c & o	Least concern (LC)	Medium
Sabine's gull	surface	b	very localised	c	Near threat-ened (NT)	Low
		mi	August and May/ June	o		
Ross' gull	surface	b	very localised	c	Vulnerable (VU)	Low
Ivory gull	surface	w/mi	November - May	o	Vulnerable (VU)	Medium
Arctic tern*	diver and feed in water column	b	May - September	c	Near threat-ened (NT)	High
Thick-billed murre*	diver and feed in water column	b/s/w	year-round	c & o	Vulnerable (VU)	High
Razorbill*	diver and feed in water column	b/w	year-round	c & o	Least concern (LC)	High
Atlantic puffin*	diver and feed in water column	b/w	year-round	c & o	Vulnerable (VU)	High
Black guillemot*	diver and feed in water column and in kelp forest	b/w	summer	c	Least concern (LC)	High
			winter	c & o		
Little auk*	diver and feed in water column	b	May - August very few	c & o	Least concern (LC)	High
		w	September - May	o		
White-tailed eagle	surface	b/w	year round	c, in southern part only	Vulnerable (VU)	Low

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 30). The colonies vary in size, from a few pairs to 50,000, and in species composition, from a single up to 10 different species. The breeding seabirds utilise the waters near the breeding site; thick-billed murres from the local colony at Ritenbenk in Disko Bay foraged up 20 km away from the col-



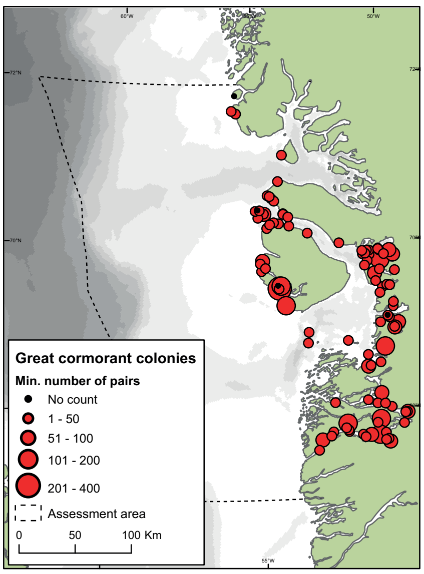


Figure 30-1. Distribution and size of breeding colonies of the most common seabirds breeding in the assessment area.

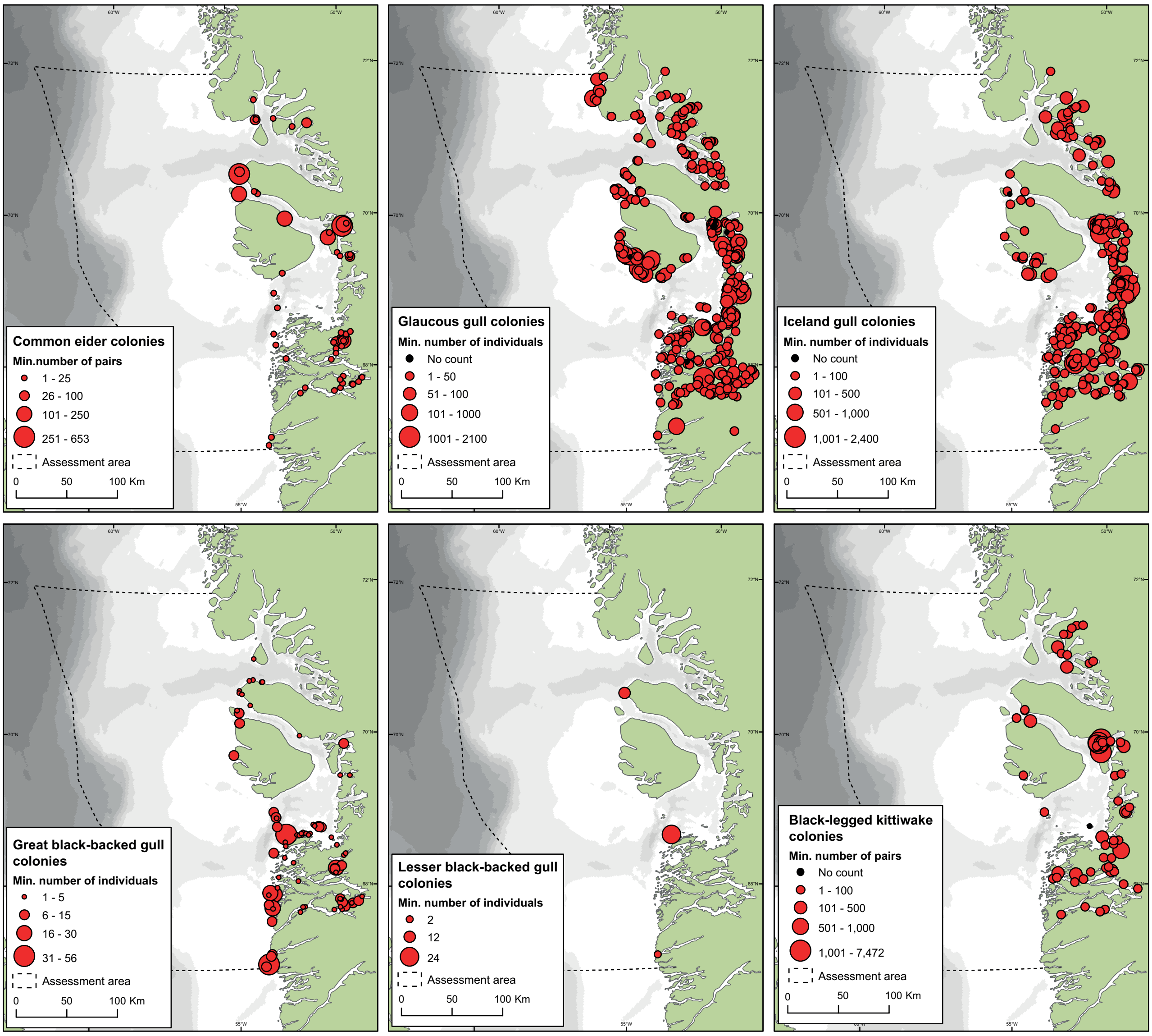


Figure 30-2. Distribution and size of breeding colonies of the most common seabirds breeding in the assessment area.

ony (Merkel et al. 2016) while fulmars from colonies outside the assessment area may fly more than 100 km to find their food and thick-billed murres (*Uria lomvia*) from colonies in Avanersuaq also moved up to 100 km to feed (Falk et al. 2000, Frederiksen et al. 2017a). Black guillemot (*Cepphus grylle*) on the other hand mainly forage in the immediate surrounding to the colony.

At-sea distribution

In the following there will be referred to maps showing the at-sea distribution of the most important seabird species in the four seasons of the year. At-sea distribution patterns during these season have been mapped based on systematic ship and aerial survey data collected between 1988 and 2017 by DCE/GINR and by Marine Mammal and Seabird Observers (MMSO) on-board seismic vessels (Figures 34–40). In total, 55 ship surveys and 7 aerial surveys were included in the analysis and their coverage is shown in Figure 34, and it is clear that the number of surveys on which the average bird densities are based varies markedly between seasons and areas.

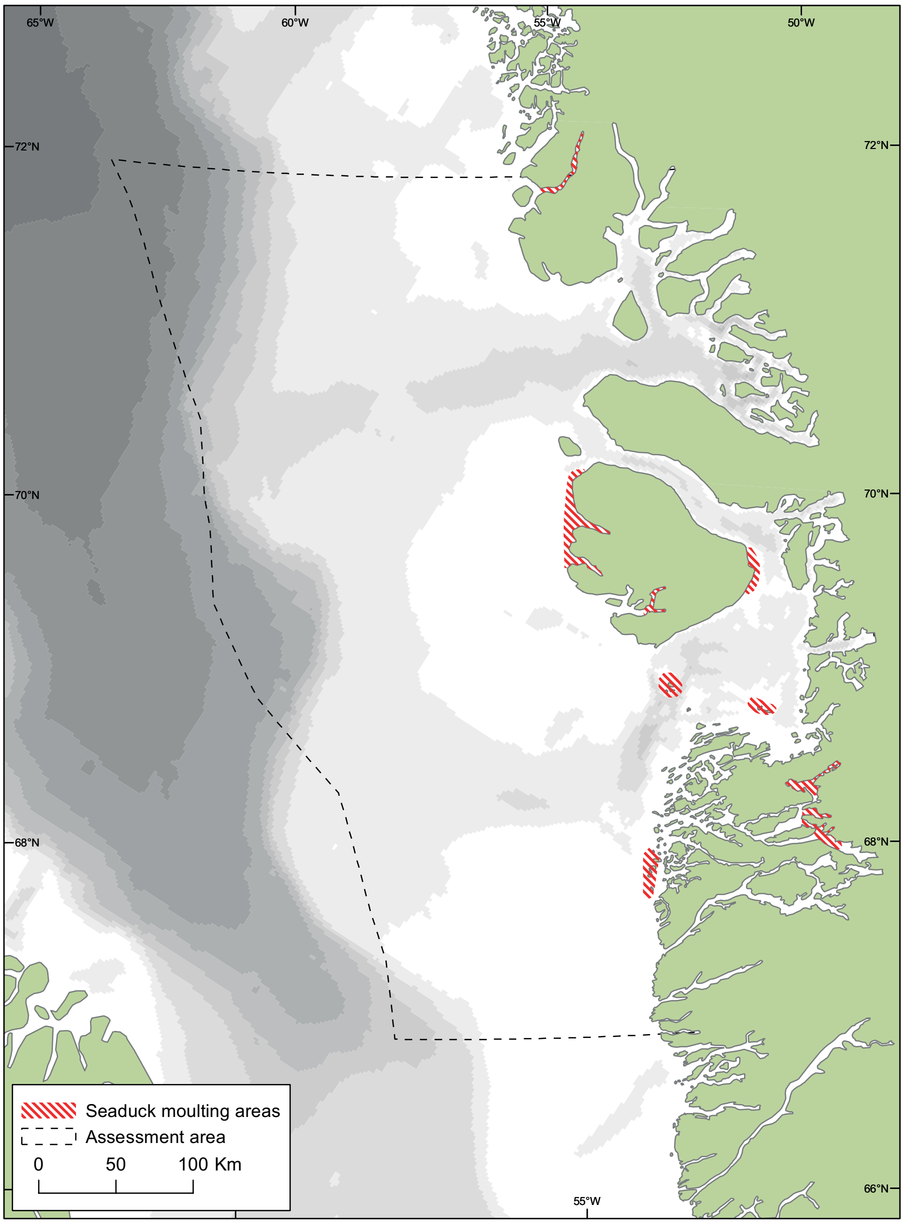


Figure 31. Important areas for moulting sea ducks. King eiders are the most numerous and also common eiders, harlequin ducks and red-breasted merganser are among the moulting ducks. The moulting period is July to September. (Map based on Mosbech & Boertmann (1999) and Boertmann & Mosbech (2001, 2002).

3.7.2 Breeding seabirds

Sixteen species of seabirds breed in the assessment area (Boertmann et al. 1996). The most widespread is the black guillemot, breeding along almost all rocky coasts. Northern fulmar is found in immense numbers in a few breeding colonies in Disko Bay and Uummannaq Fjord. Great cormorant (*Phalacrocorax carbo*) breeds in small colonies on the coasts of both fjords and more exposed sites scattered throughout the assessment area. There is only a single colony of thick-billed murre in the region (Box 5). Numbers here are declining, primarily due to unsustainable harvest (Merkel et al. 2016). Although spring hunting was banned in 2001, the decline continues. Since 2017, there is again a limited hunt in spring north of the assessment area. 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 a significant positive impact on the breeding population of common eiders (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 in Disko Bay, and another large colony is

Box 4. King Eider satellite tracking

Anders Mosbech, Flemming Merkel & Christian 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. 2006). 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 (Figure 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 (Figure 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: 227,000 – 709,000) staging in the shallow parts of Store Hellefiskebanke (Figure 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) and based on aerial survey in April 2017 an abundance of amazing 1,107,318 king eiders (95% confidence interval: 506,120–2,422,653) for Store Hellefiskebanke was estimated (Merkel et al. 2019). 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.

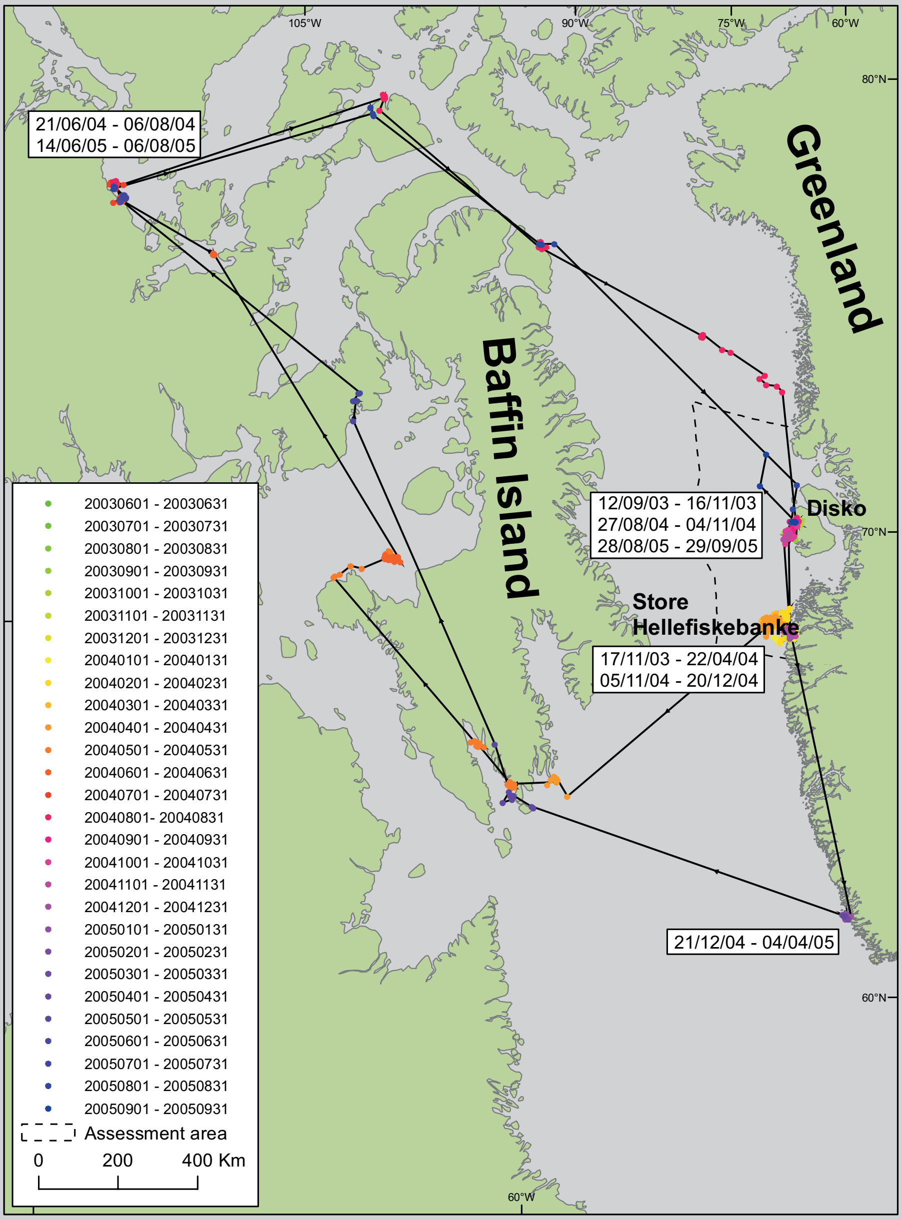


Figure 1. A single king eider tracked with satellite transmitter (No. e41195) from the moulting area at Disko Island in September 2003 and the following two years through two full migration cycles to the breeding grounds in Arctic Canada. Two sites in the assessment areas were of particular importance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

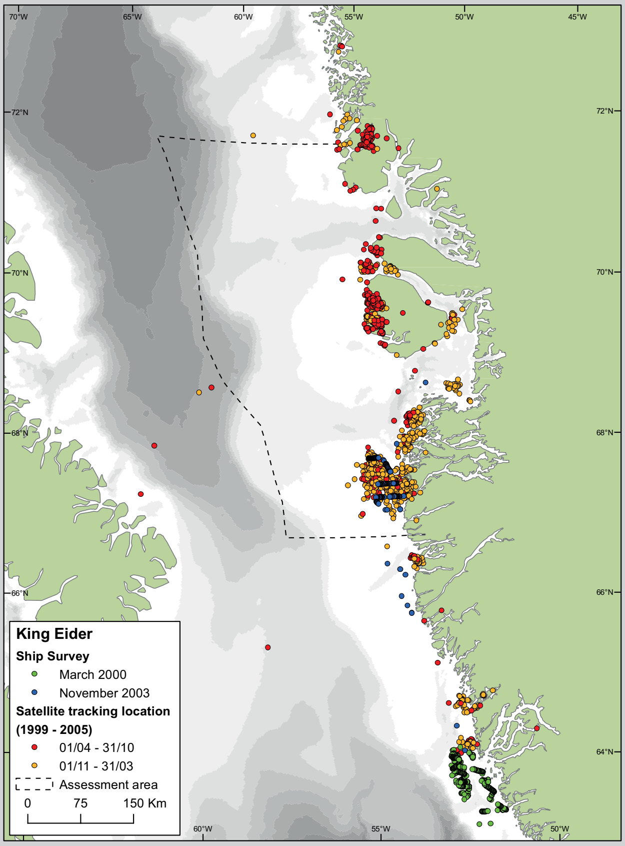


Figure 2. King eider satellite tracking locations from year round tracking of birds implanted at moulting localities in Umiarfik and the fjords at the west coast of Disko and at a breeding locality in Arctic Canada (outside the map). The scattered dots in the central Baffin Bay and on Baffin Island are 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). 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 during daylight, even in midwinter, with only a few hours of twilight (Figure 4) (Mosbech et al. 2006), indicating the importance of these few hours for foraging (Systad et al. 2000). 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.

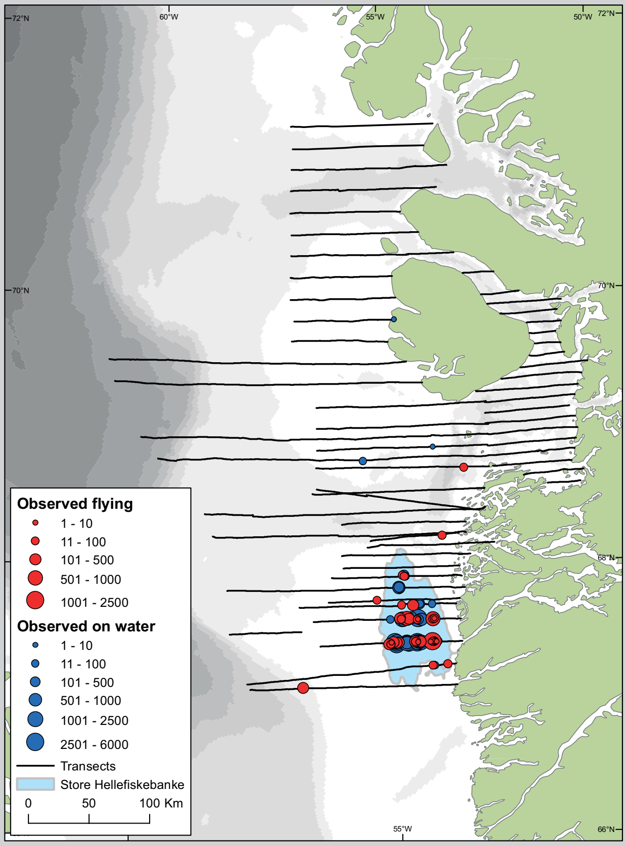


Figure 3. Distribution of king eiders (n = 57100) observed on aerial transects in April and May 2006. Their estimated abundance is based on the blue area corresponding to the 50 m isobath of Store Hellefiskebanke, see text for further information.

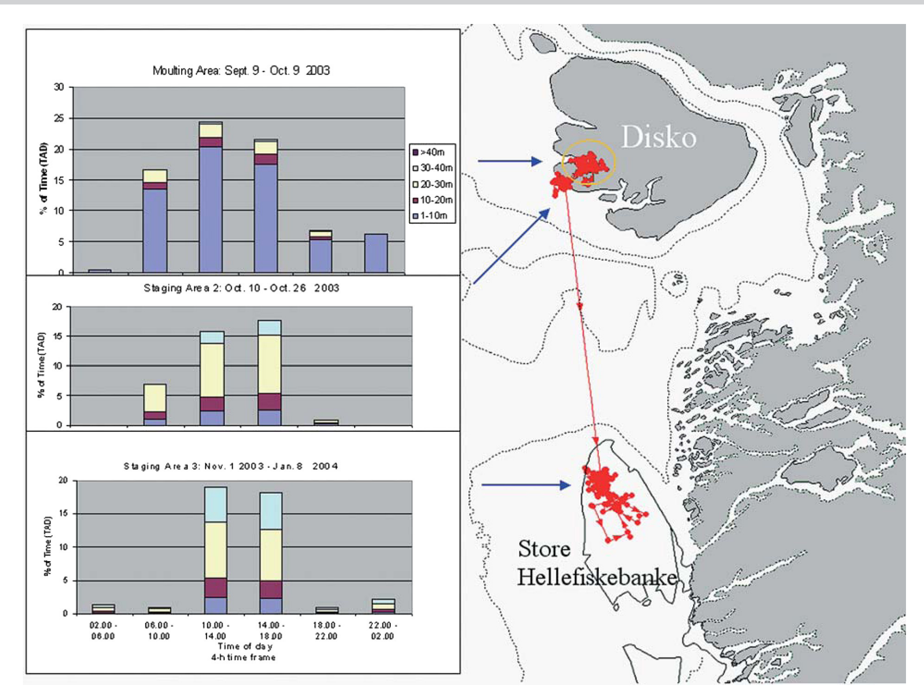


Figure 4. Satellite tracked locations and track-line for a female king eider using three distinct staging areas from 7 September to 8 January and diurnal diving behaviour in these three areas. The columns show the time spent in different depth intervals (Time At Depth, TAD) as percentage of the time 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).

Box 5 Thick-billed murre studies at the Innaq (Ritenbenk) colony in Disko Bay

Anders Mosbech, Flemming Merkel & Kasper L. Johansen

The thick-billed murre colony at Innaq (Ritenbenk) is the last remaining thick-billed murre colony in Disko Bay. It has been declining for at least 40 years from about 5,500 to only about 1150 birds in 2017, and if the declines continue, the colony will likely go extinct within this decade. 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 (Merkel et al. 2016). 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 was reduced with the new legislation in 2001 (Merkel & Christensen 2008). However, oil exploration in the Disko West Area was a new challenge to the thick-billed murre population and made 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.

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 (Figure 1 and 2).

Later in August and September most tracked murres occurred dispersed in SE Baffin Bay (Figure 3). While most birds thus moult their flight feathers in Baffin Bay, two of the birds migrated SW towards Labrador and Newfoundland (Figure 4). It is concluded that a large part of the population migrate north of Disko Island 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.

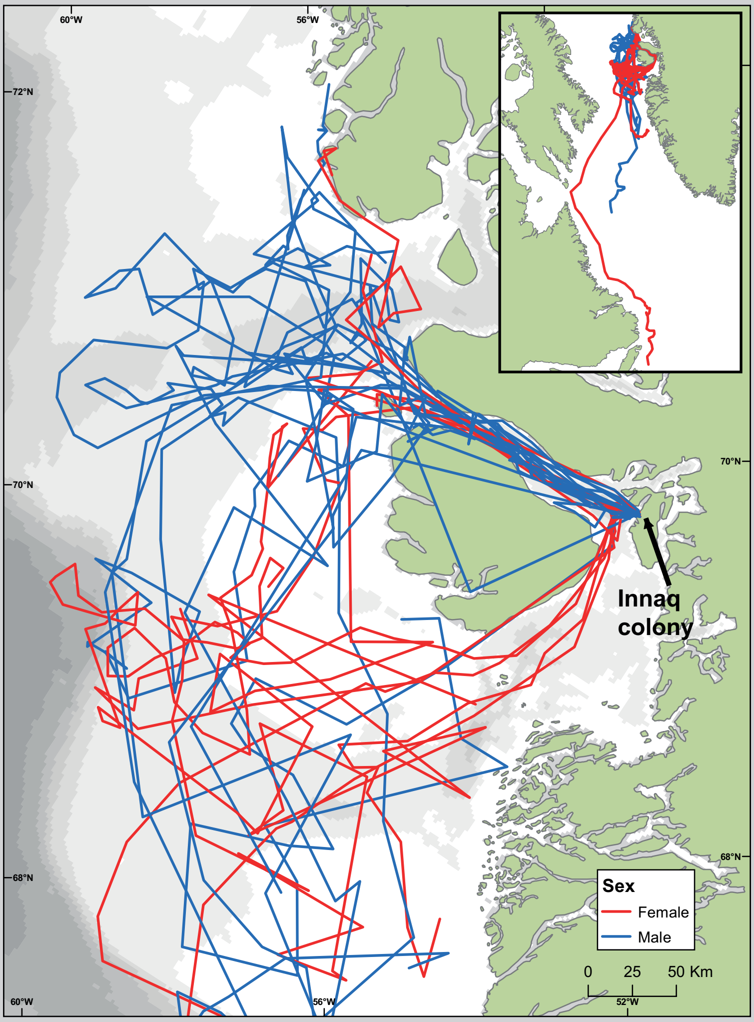


Figure 1. Tracking routes of 27 thick-billed murres from the Innaq colony in 2005 and 2006. Blue lines = males, red lines = females.

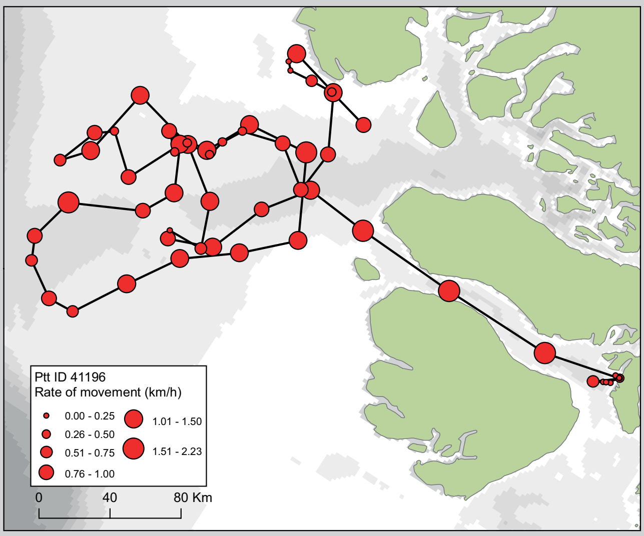


Figure 2. The route tracked for a male thick-billed murre using a subcutaneous satellite transmitter. The male took up parental care on the breeding ledge and later left the ledge with the chick and started swimming migration. Average rate of movement is calculated between the best quality locations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

Foraging behaviour, feeding conditions and population development

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 (Figure 5), whereas chick feeding frequencies were observed directly. Capelin was an important food item in 2006 (Figure 6), feeding trips were relatively short (Figure 7), and the proportion of time birds spent diving was relatively low (<10 %) (Figure 8). The overall impression was that food availability was sufficient in 2006 and 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. This is supported by studies on breeding success from 2011 to 2017, which show that breeding success is high at Innaq and comparable to the breeding success at the Kippaku colony further north (Merkel et. al. in prep). Most likely both hunting pressure (Mosbech et al. 2009, Merkel et al. 2016) and climate change in the wintering areas (Descamp et al. 2017, Frederiksen et al. 2016) contribute to the decline of the Innaq population, which may go extinct within this decade if conditions remain unchanged (Figure 9).

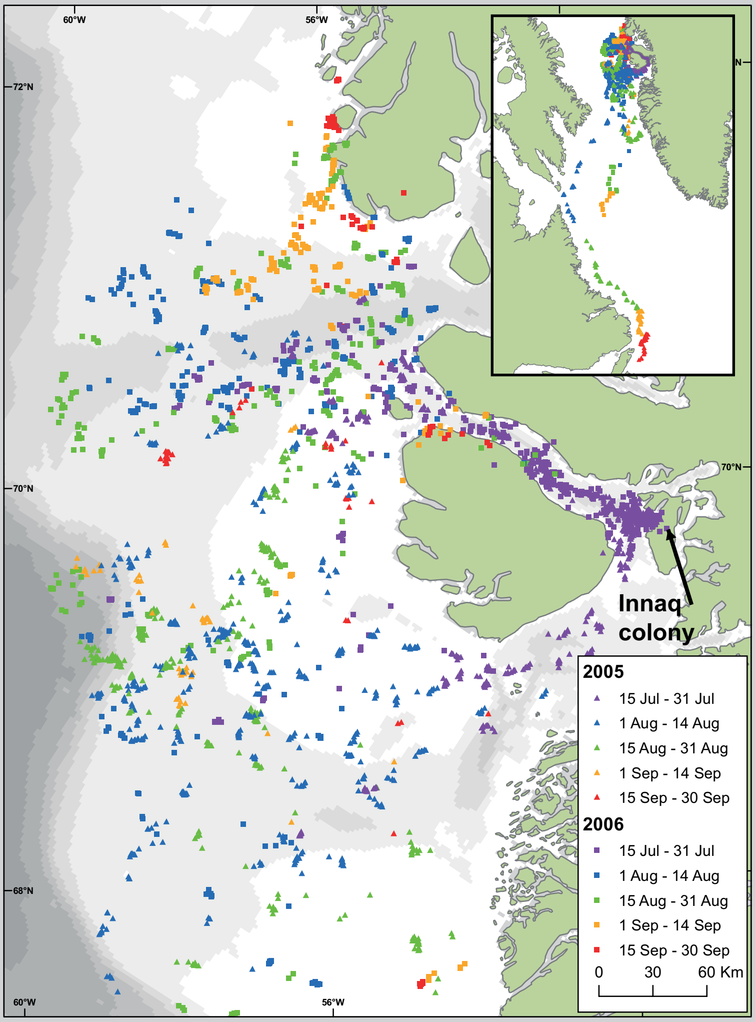


Figure 3. Temporal and spatial distribution of locations from 27 thick-billed murres tracked from the Innaq colony.

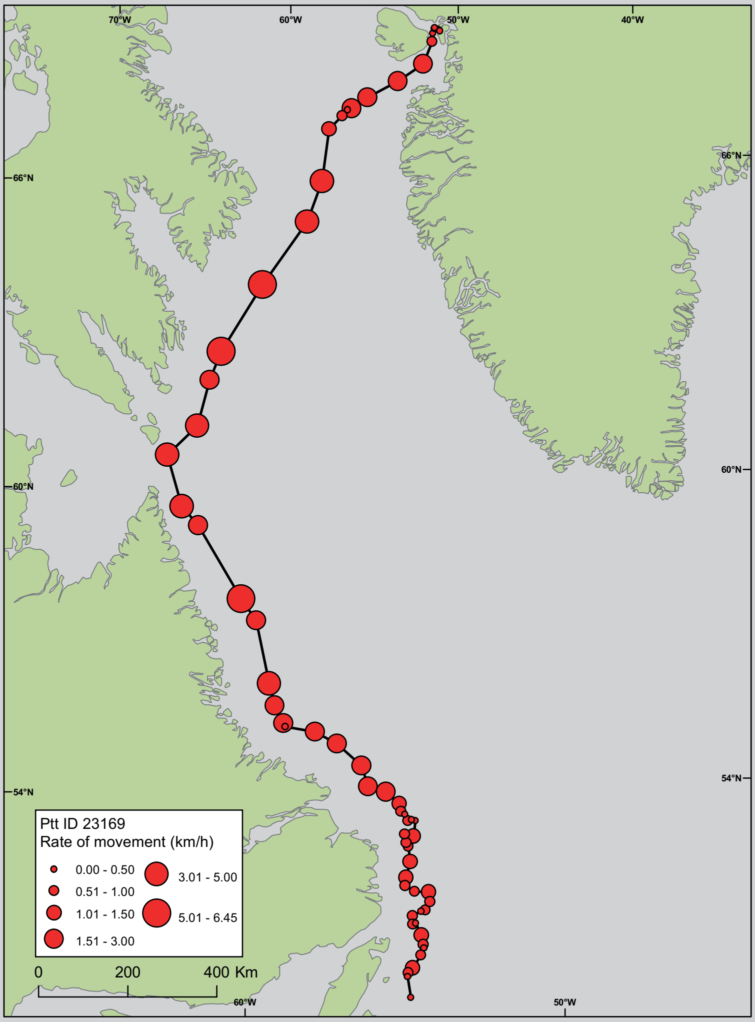


Figure 4. The route of a female thick-billed murre (#4137507) tracked from Innaq and arriving in northern Newfoundland in the first half of August 2005. The average rate of movement was calculated between the best quality locations in consecutive transmission periods ('best pick' locations). At the coast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

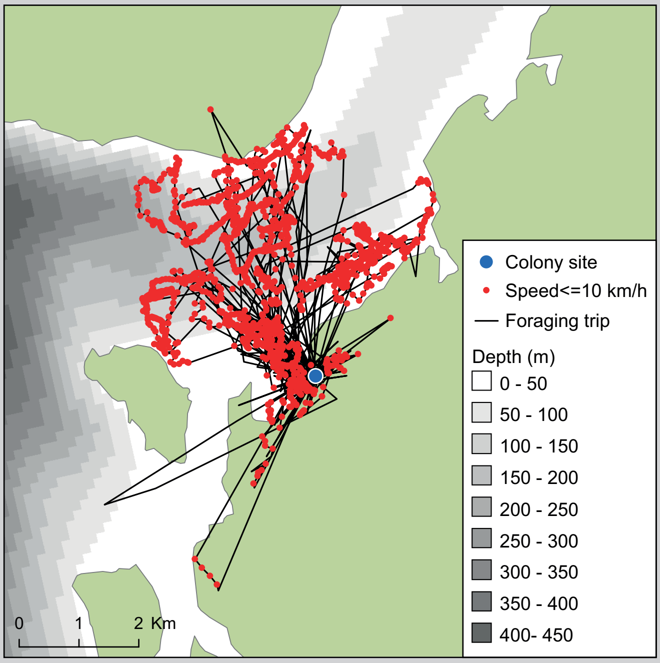


Figure 7. In 2011-12, nine thick-billed murres from the Innaq colony were GPS-tracked during chick-rearing, resulting in the mapping of 112 foraging trips. All birds foraged exclusively within a distance of 5 km from the colony site, mainly targeting the entrance of Sanfannguaq bay NNW of the colony site.

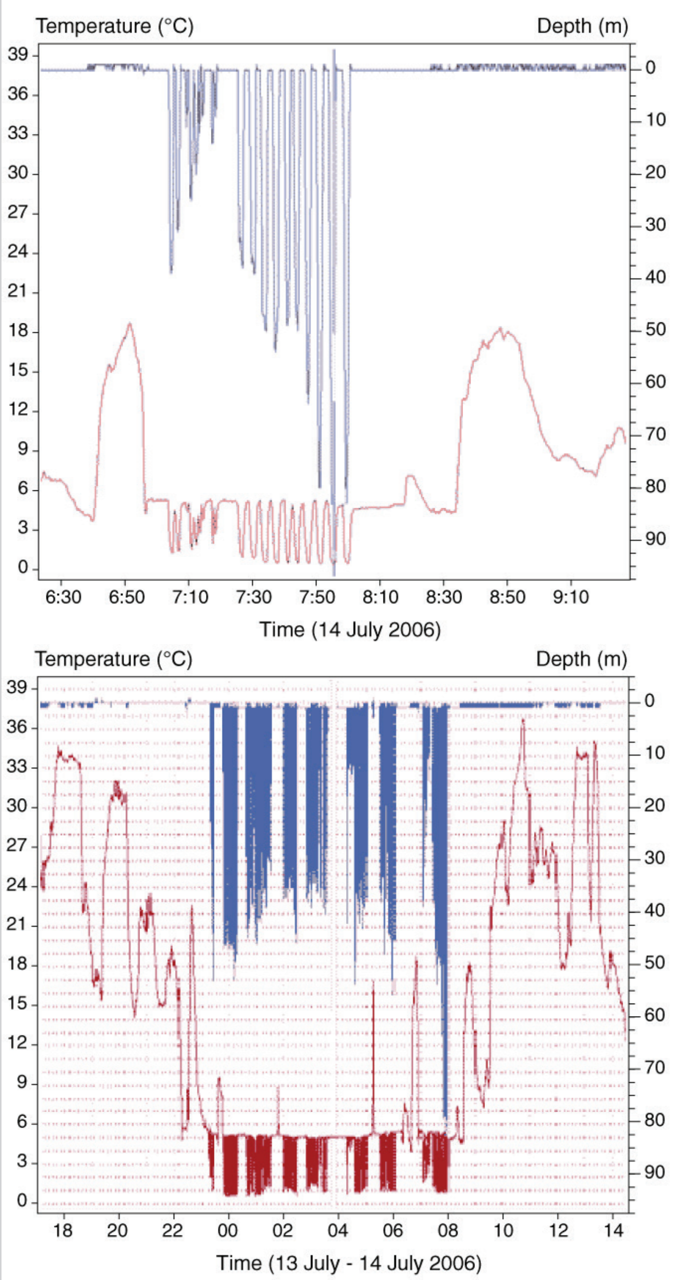


Figure 8. Upper/ Diving behaviour recorded with Time-Depth Recorder (TDR) for a thick-billed murre on a foraging trip the night between 13 and 14 July 2006. Between 11 PM and 8 AM the murre made 9 feeding bouts. Most dives (blue) went to about 40 m, but in the last feeding bout dives exceeded 80 m depth. 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. Lower/ Enlargement of the last feeding bout in upper panel.

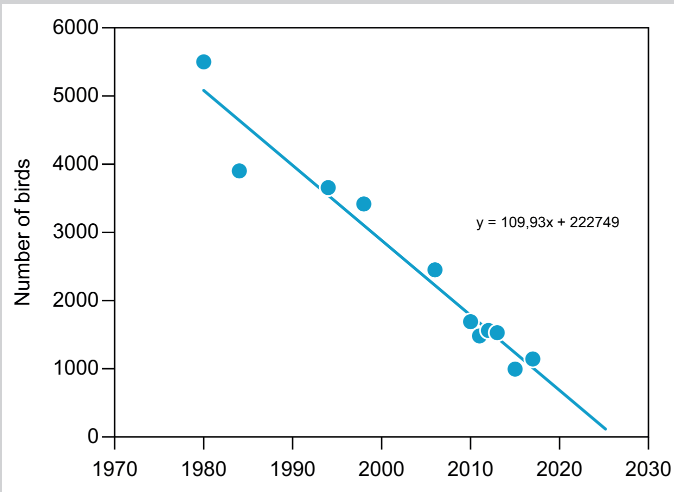


Figure 9. The population development in the Innaq colony since 1980. Number of birds are given as direct counts or raw counts on photos. Most counts have been corrected for diurnal attendance. A linear trend-line has been inserted, and if the linear decline continues it is evident that the colony will go extinct within this decade (data from Mosbech et. al. 2009, Merkel et al. 2016, Merkel unpublished).

found on Schades Øer in Uummannaq Fjord (Egevang & Boertmann 2003, 2012, Egevang et al. 2005). Scarcer breeding species include Atlantic puffin (*Fratercula arctica*) and little auk (*Alle alle*). Ross's gull (*Rhodostethia rosea*) and Sabine's gull (*Xema sabinii*) are very rare breeding birds both occurring in a single site in the assessment area (Egevang & Boertmann 2008, 2012). Figure 30 show the distribution of breeding colonies of a number of the common species in the assessment area.

3.7.3 Non-breeding seabirds in summer

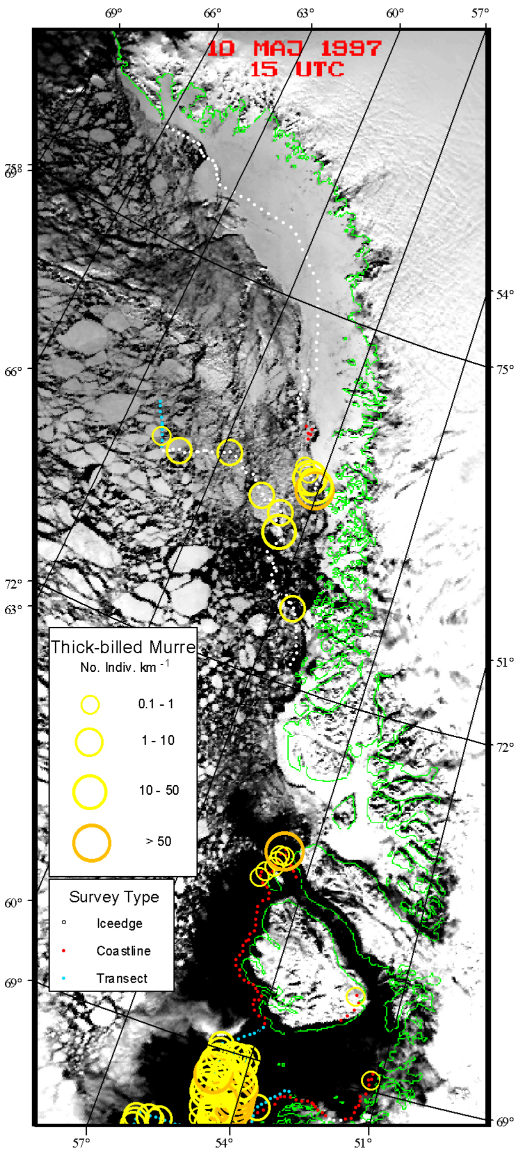


Figure 32. Distribution of thick-billed murres in May 1987, based on airborne surveys. Results are superimposed on a synoptic image of the ice distribution. A large concentration of birds is seen in the mouth of Disko Bay (DCE unpublished).

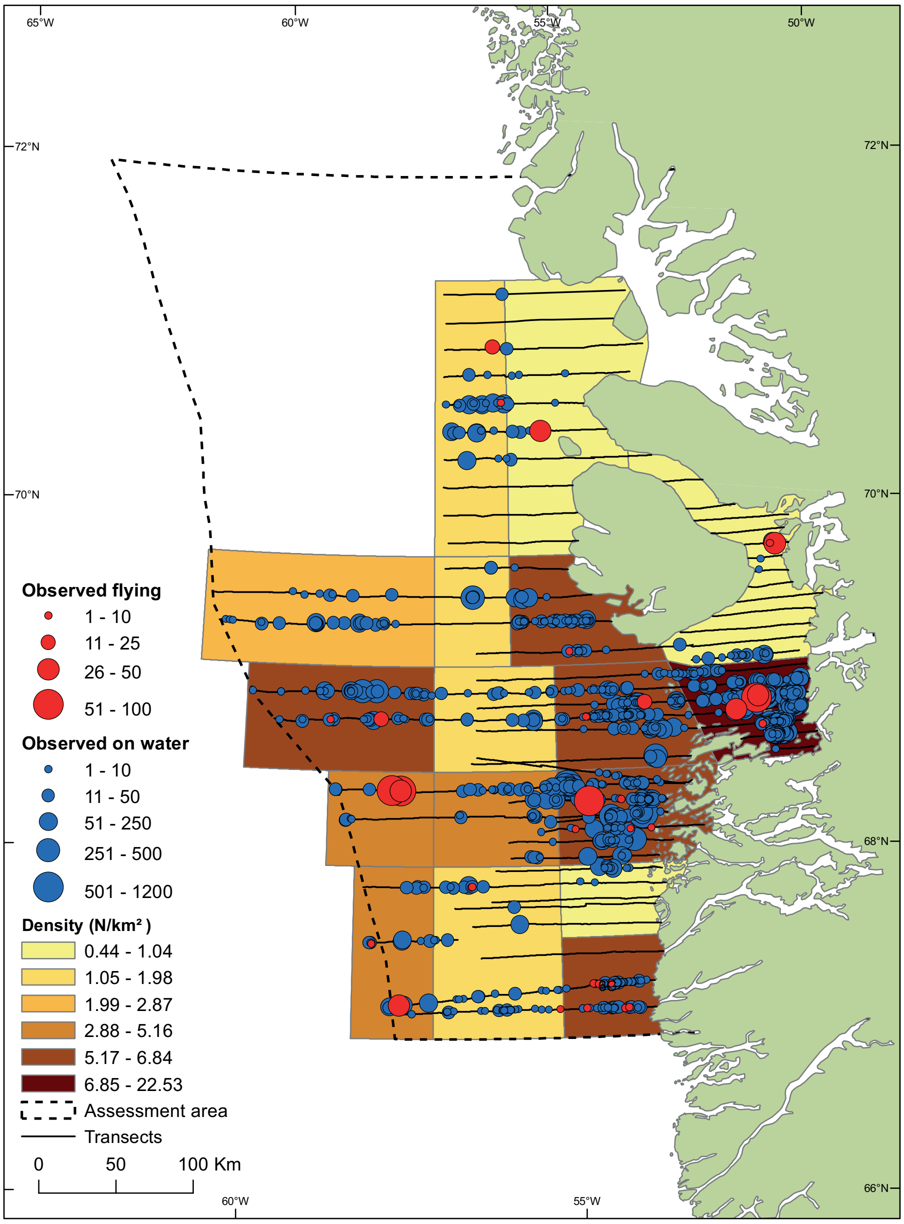
Numerous non-breeding seabirds also utilise the waters of the assessment in summer. These comprise non-breeding individuals from breeding populations all over the North Atlantic – mainly black-legged kittiwakes and northern fulmars (Lyngs 2003). The maps showing summer at-sea distribution of these species (Figures 34–40) to large extend may show the distribution of such birds.

The thick-billed murres occurring along the southwest border of the assessment area in summer (Figure 39b) are probably also non-breeding birds –alternatively breeding birds from colonies on Baffin Island in Canada. The little auks appearing here in summer (Figure 40b) may also be non-breeders.

Great shearwaters (*Ardenna gravis*) breeding in the southern hemisphere occasionally also occur offshore in the region.

Another non-breeding seabird segment utilises the region in summer. Seaducks (mainly males) arrive from breeding sites in Canada and inland Greenland and assemble to moult in remote bays and fjords (Figure 31). King eiders are numerous in the fjords of Disko Island and further north, 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 and the rare and threatened ivory gull (*Pagophila eburnea*) (Boertmann 1994).

Figure 33. 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 resided 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).



3.7.4 Migration periods, autumn and spring

During autumn large numbers of seabirds move through the assessment area on their way to wintering quarters further south. Some are under way to wintering sites outside Greenland waters – e.g. little auks and thick-billed murres from the Thule area (Frederiksen et al. 2017b, Mosbech et al. 2017), but many stay throughout the winter, mainly south of the assessment area (Boertmann et al. 2006).

The autumn 2009 survey described in Box 1 included also seabird surveying, and especially little auks were found in deep waters off the shelf and mainly west of the assessment area in accordance with the results of tracked birds from the breeding sites in Thule (Mosbech et al. 2017) and also reflected in the seabirds-at-sea data which are to some degree based on the same data (Figure 40c). Thick-billed murres were numerous and distributed patchily on the shelf (inside the assessment area) at sites where also high densities of small polar cod were found in depths accessible to the murres, see also Figure 39c. These birds may derive from the breeding colonies in Upernavik District as birds tracked from there moved through the assessment area, while breeding birds from Thule moved further west on the Canadian side of Baffin Bay

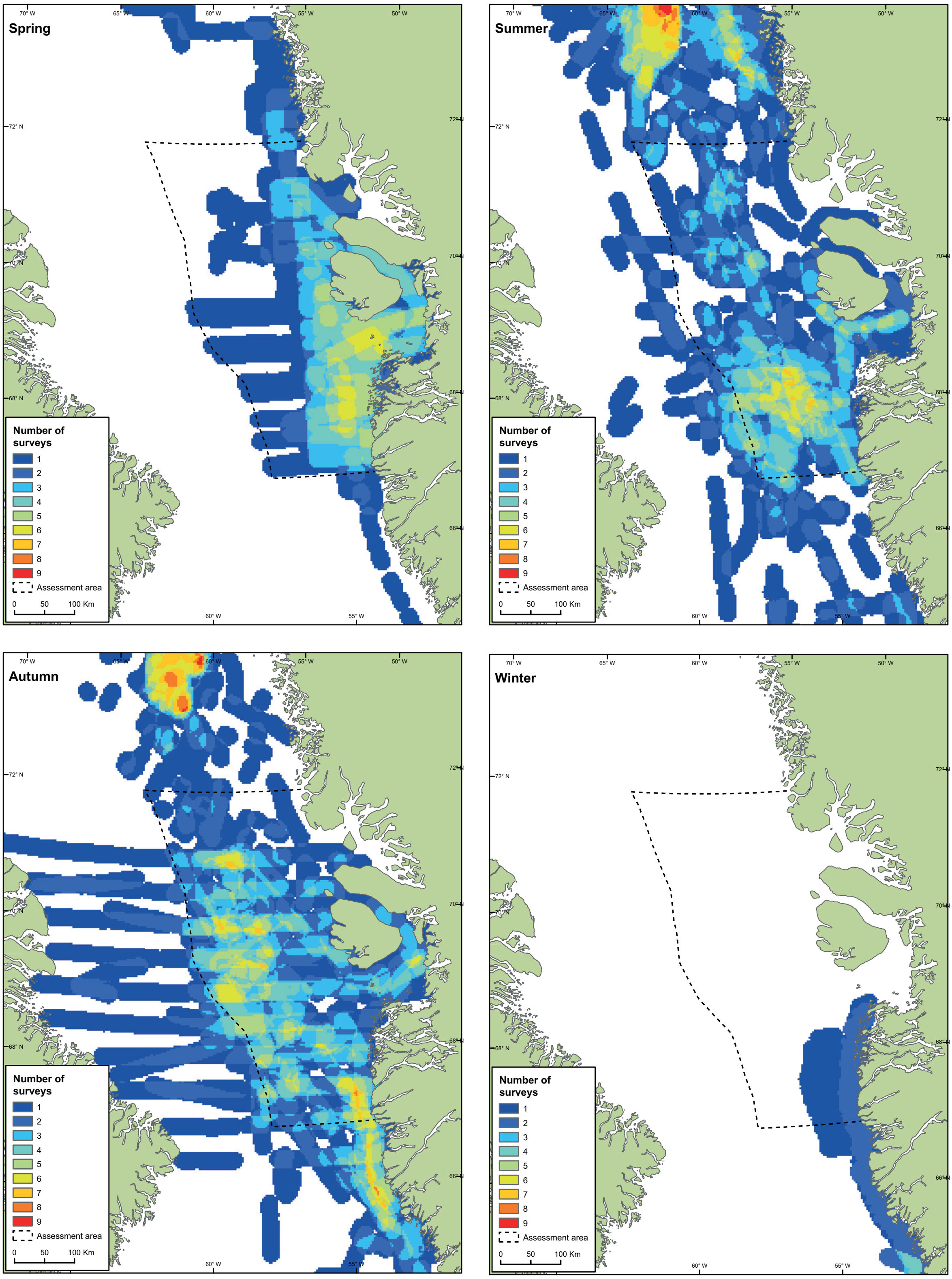


Figure 34a-d. The number of systematic ship or aerial surveys on which the average at-sea seabird densities in figures 35–40 are based during spring (Apr.–May), summer (Jun.–Aug.), autumn (Sep.–Dec.) and winter (Jan.–Mar.). Areas with no survey activity are shown as white. The maps do not necessarily include all surveys conducted in the area assessment, only those available in DCE/GINR survey databases for West Greenland at the time of analysis (May 2020), corresponding to 55 ship surveys and 7 aerial surveys conducted between 1998 and 2017. Seabird densities were calculated as follows: The survey transects were split into 3 km segments, and at the center point of each segment, a density was calculated based on the number of birds observed along the segment, the segment length, and an effective search width estimated by means of distance sampling methods (Buckland et al. 2001). For each survey, season and species, the segment densities were then interpolated to a raster grid with 3x3 km cells covering West Greenland waters, using inverse distance weighted interpolation (power 2, radius 15 km). Densities were interpolated only to cells within 15 km of the original survey transects. Then, for each species and season, an average density surface (birds/km^2) was calculated across the raster grids, and the result was finally subjected to a slight spatial smoothing (value of each 3×3 km cell represents the mean value of all cells within a 9 km radius).

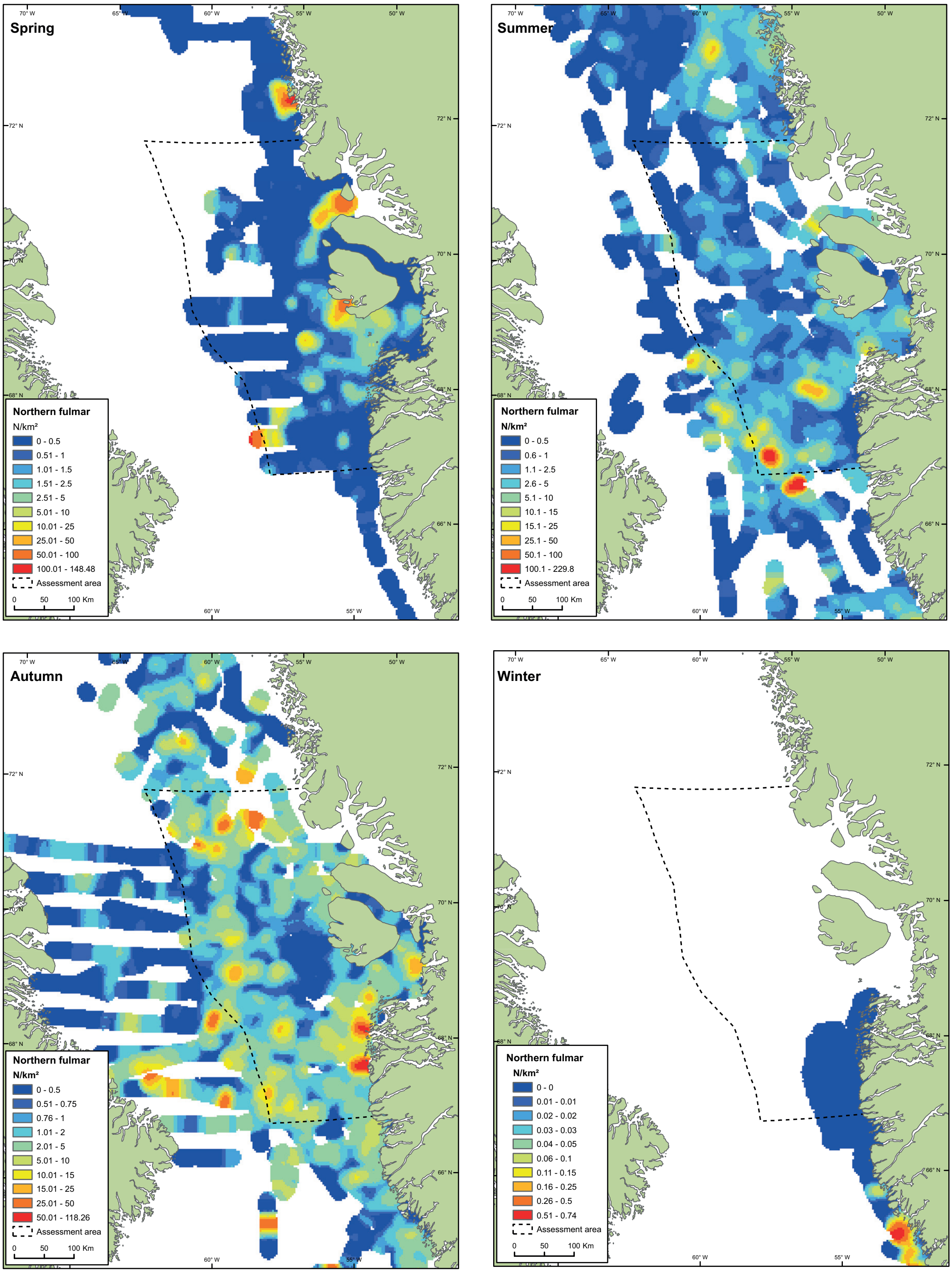


Figure 35a-d. At-sea distribution of northern fulmar in the assessment area during spring (Apr.–May), summer (Jun.–Aug.), autumn (Sep.–Dec.) and winter (Jan.–Mar.) based on ship and aerial survey data collected between 1988 and 2017. Note that survey coverage and density scale varies between seasons.

(Frederiksen et al. 2017b). Stomach analysis of both little auks and thick-billed murres sampled in deep off-shelf waters indicated that especially the hyperiid amphipod *Themisto* was an important prey (see Box 1).

Another study in 2005 focused on the post-breeding migration of thick-billed murres from the breeding colony in Disko Bay. The three-week old chicks

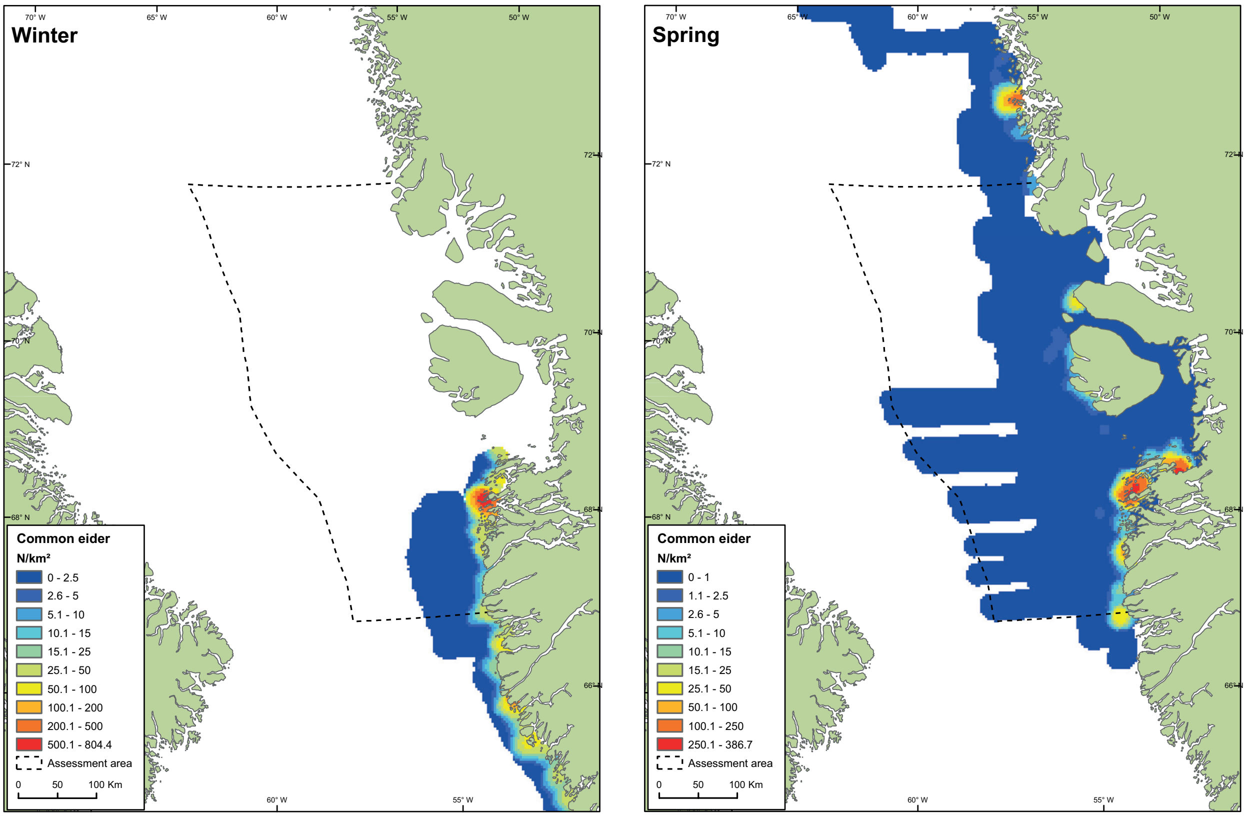


Figure 36a-b. At-sea distribution of common eider in the assessment area during spring and winter based only on aerial surveys (due to the evasive behaviour of this species during ship surveys). In the map for winter, total count surveys in fjords from Merkel et al. (2002) and Merkel et al. (2019) are exceptionally included in the analysis.

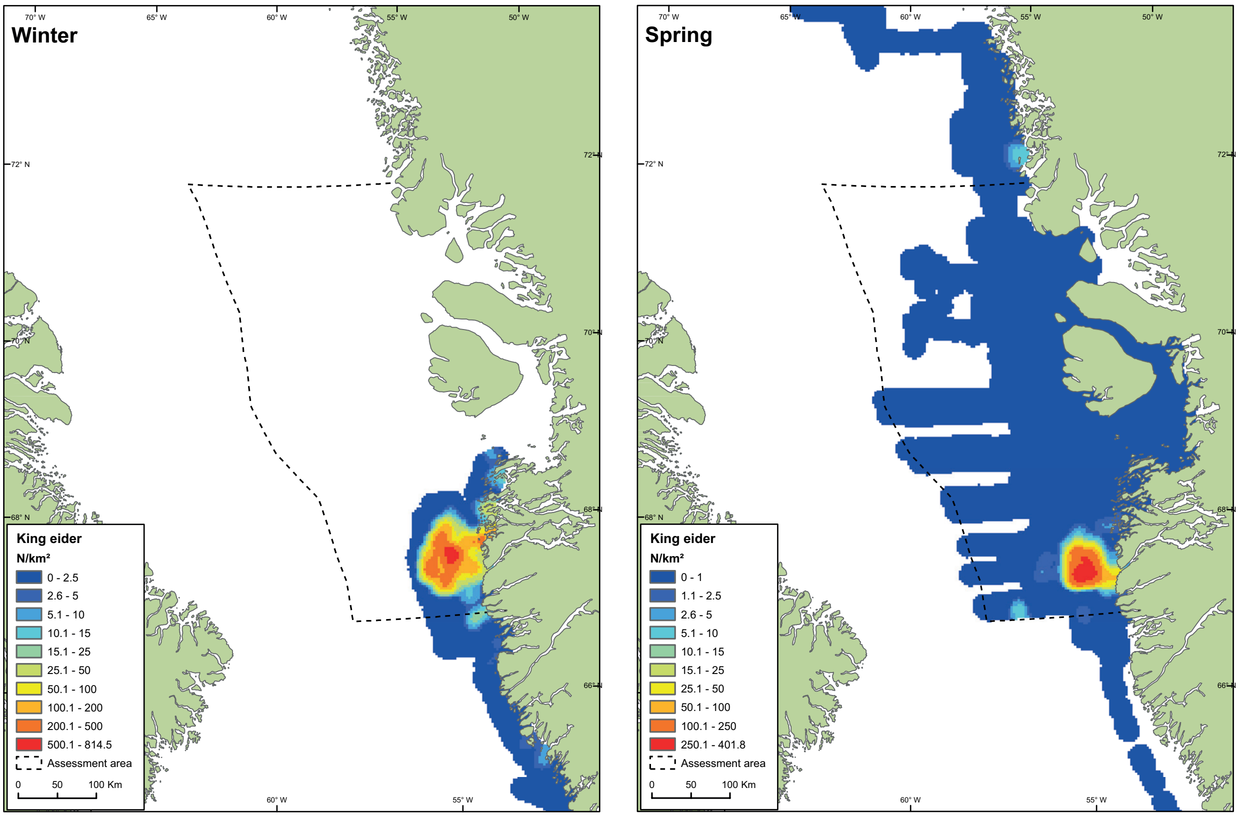


Figure 37a-b. At-sea distribution of king eider in the assessment area during spring and winter based only on aerial surveys (due to the evasive behaviour of this species during ship surveys). In the map for winter, total count surveys in fjords from Merkel et al. (2002) and Merkel et al. (2019) are exceptionally included in the analysis.

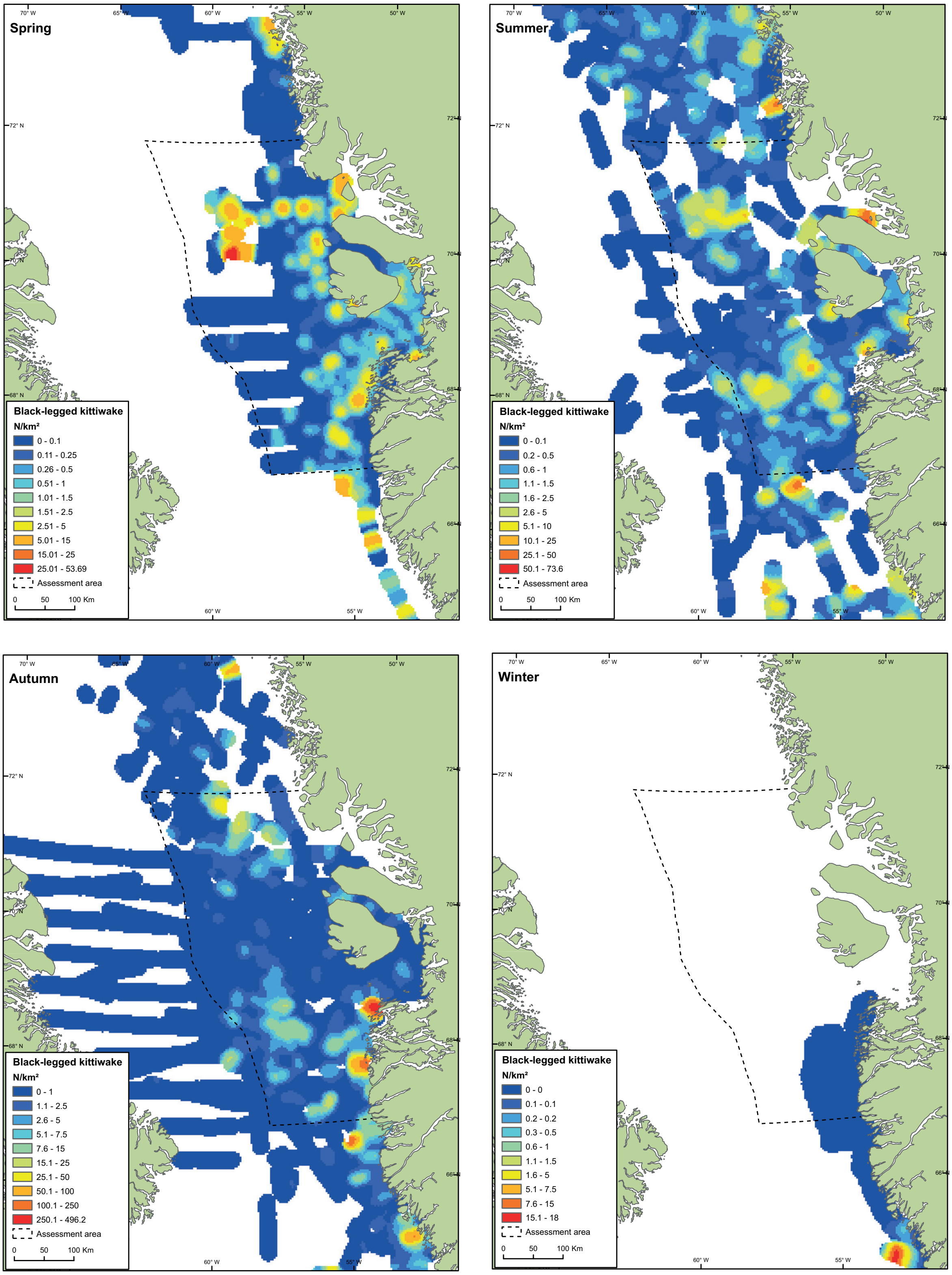
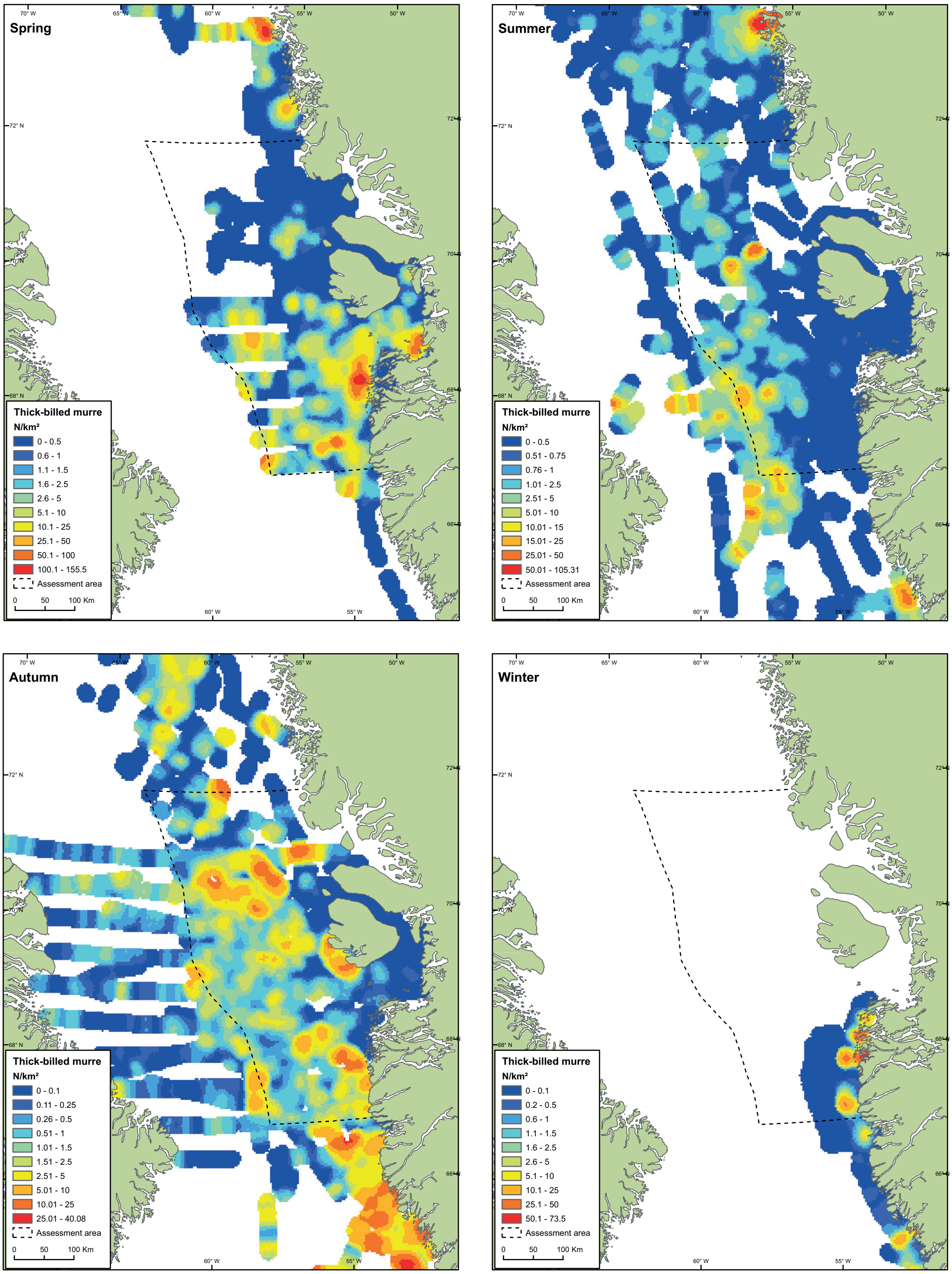


Figure 38a-d. At-sea distribution of black-legged kittiwake in the assessment area during spring (Apr.–May), summer (Jun.–Aug.), autumn (Sep.–Dec.) and winter (Jan.–Mar.) based on ship and aerial survey data collected between 1988 and 2017. Note that survey coverage and density scale varies between seasons.

leave the colony and initiate a swimming migration together with the male parent bird which then moult the 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). The birds moved both to the south of Disko island and to the north through Vaigat, and dispersed in the waters west of Disko (Box 5).



39a-d. At-sea distribution of thick-billed murre in the assessment area during spring (Apr.–May), summer (Jun.–Aug.), autumn (Sep.–Dec.) and winter (Jan.–Mar.) based on ship and aerial survey data collected between 1988 and 2017. Note that survey coverage and density scale varies between seasons.

Northern fulmar occur numerous and widespread in the assessment area in autumn, with local concentrations, probably related to feeding areas (Figure 35c). Black-legged kittiwake is another numerous species in autumn, although not as widespread as the fulmar (Figure 38c).

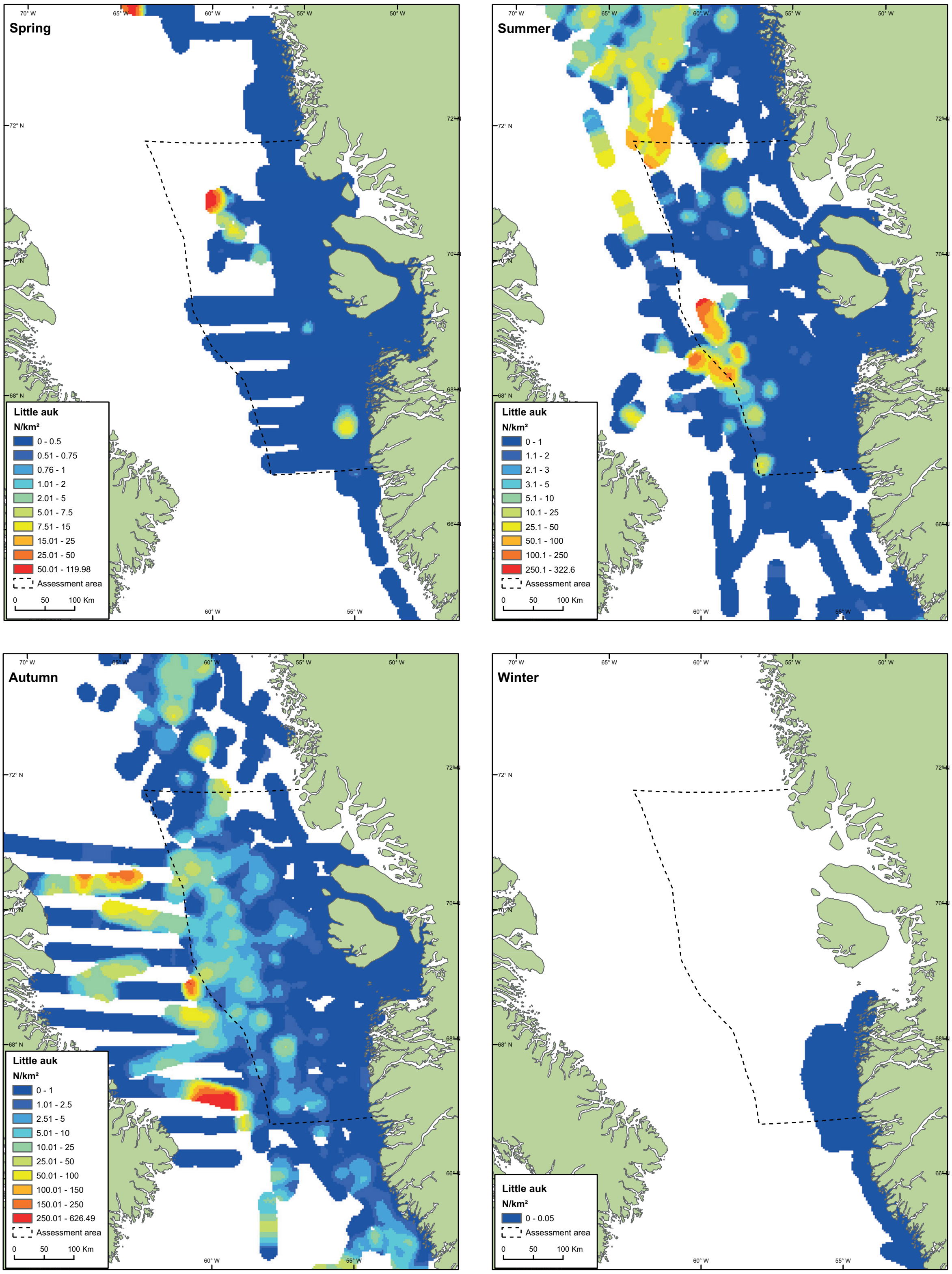


Figure 40a-d. At-sea distribution of little auk in the assessment area during spring (Apr.–May), summer (Jun.–Aug.), autumn (Sep.–Dec.) and winter (Jan.–Mar.) based on ship and aerial survey data collected between 1988 and 2017. Note that survey coverage and density scale varies between seasons.

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 (Figures 32, 33), although the murres were much more widespread in the area and many were found even in dense drift ice near the Canadian border (Figure 33). In total about 400,000 thick-billed murres were estimated to be present in the assessment area during the survey (Figure 33). See also Figure 39a which include the 2006-data mentioned above.

Also in spring common eiders are numerous along the coasts of the assessment area and concentrations occur in the same area as in winter and also in the Disko Bay (Figure 36a).

Figure 37a show that the wintering king eiders also use the Store Hellefiskebanke area in the spring.

Other species like northern fulmar and black-legged kittiwake may also occur in concentrations in the assessment area in spring, but probably in unpredictable areas determined by the occurrence of available food (Figure 35a and 38a).

3.7.5 Winter

The information on wintering seabirds in the assessment area are primarily the result of two surveys in late winter in 1999 and 2017 which covered entire southwest Greenland (Merkel et al. 2002, 2019) supplemented with other information (see Boertmann et al. 2004 and Box 1). The coverage of the two surveys in the assessment area is shown in Figure 34.

The knowledge of the habitat use of the wintering seabirds and the factors governing their distribution is generally poor. Despite these 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).

The most numerous species wintering in the assessment area are common eider, king eider (see below), thick-billed murre and the large gull species (glaucous gull (*Larus hyperboreus*), Iceland gull (*L. glaucoides*) and great black-backed gull (*L. marinus*)).

Among these, the king eider is the most important because of the very high numbers occurring very localised on Store Hellefiskebanke (Figure 37b). These are birds from breeding grounds in Arctic Canada, and a very high part of the population are assembled in the assessment area in winter. A number of studies of this seaduck species have been conducted (Box 4). In 2017, the winter population concentrated on Store Hellefiskebanke was surveyed from aircraft, and the population was estimated to number 1,078,000 (95% CI: 472,600–2,462,300) birds (Merkel et al. 2019). This seems to be higher than earlier estimates. However, survey conditions are difficult and confidence intervals are large, so the trend is only indicative. On the basis of observations from marine mammal surveys in March 1981, 1982, 1991 and 1993, Mosbech & Johnson (1999) estimated about 300,000 king eiders wintering in the area in March (maximum year estimate 437,000). On the basis of a ship-based survey in November 2003, Mosbech et al. (2007) estimated about 750,000 king eiders (75% CI: 529,000–1,083,000) and Frederiksen et al. (2008) estimated about 400,000 birds (75% CI: 227,000–709,000) from an aerial survey in late April/ early May.

While the king eiders primarily winter on the shallow offshore Store Hellefiskebanke, many other species winter in the open water parts of the coastal zone, where especially the area near Kangaaatsiaq is very important (Merkel et al. 2019). There 137,875 (95% CI: 116 511–174 578) common eiders were estimated in 2017, together with high numbers of other wintering seabirds particularly gulls, mallards and great cormorants (Merkel et al. 2019). The area is clearly marked on the map in Figure 36b.

Thick-billed murres were observed in very different numbers during the two winter surveys. They were numerous in 1999 (Figure 39d) and almost absent in 2017 (Merkel et al. 2002, 2019).

Black guillemots winter dispersed in the drift ice, and relatively high concentrations were found in the drift ice north of 67° N in both winter survey years (Merkel et al. 2002, 2019).

Kittiwakes were not observed in the assessment area during the two winter surveys (Figure 38d), and an analysis of tracked birds from colonies all over the North Atlantic indicate that very few black-legged kittiwakes may occur there (Frederiksen et al. 2012). This is also the case for the Norwegian SEATRACK-data (Link), although colonies from Greenland and Canada is not included in the dataset.

Several other species occur in the assessment area in winter, such as long-tailed duck, red-breasted merganser, northern fulmar and little auk. However, generally in relatively low numbers and for example no little auks nor northern fulmars were observed during the two winter surveys (Figure 35d and 40d).

3.7.6 Other birds

Although not seabirds, geese should also be mentioned in this context, because they often utilise saltmarshes for feeding within the assessment area. These saltmarshes are very low-lying and occasionally become inundated at high water levels. Particularly brent geese (*Branta bernicla*) on migration between breeding sites in Arctic Canada and wintering grounds in northwest Europe utilise these salt marshes during stopovers in autumn (Boertmann et al. 1997, Egevang & Boertmann 2001a).

3.7.7 Sensitivity

It is well known that seabirds are particularly sensitive to oil spills on the sea surface, both to the direct effects of contact with oil and to sublethal effects of ingestion (Schreiber & Burger 2002). They are also sensitive to disturbance from the different activities related to oil and gas exploration and exploitation. These topics are discussed further in Chapter 6.

3.8 Marine mammals

Marine mammals are another important element of the ecosystem in the Disko West assessment area. Besides polar bear and walrus, at least 14 species of whales and five species of seals occur in the area (Table 5).

Some of the marine mammals listed in Table 5 have been studied more intensively during the past years within the assessment area thus allowing a more detailed description. This apply to polar bear, walrus and narwhal.

3.8.1 Polar bear (*Ursus maritimus*)

Biology: The general biology of polar bears is well-described (see Wiig et al. 2015 and others). Polar bears occur at low densities throughout the circumpo-

Table 5. 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/ spring	Drift ice and ice edges	Relatively common and mainly when ice is present	Hunting regulated	Vulnerable (VU)	High	+
Walrus	Dec-May	Polynyas, MIZ, shallow water	Locally common on Store Hellefiskebanke and west of Disko Island	Hunting regulated	Vulnerable (VU)	High	+
Hooded seal	Jun-Oct	Mainly deep waters	Common and widespread	Hunting unregulated	Vulnerable (VU)	Medium	
Bearded seal	Whole year	Waters with ice	Widespread and abundant	Hunting unregulated	Least Concern (LC)	Medium	+
Harp seal	Jun-Feb	Whole area	Numerous and widespread	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 visitor	Hunting regulated	Near Threatened (NT)	High	+
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)	Endangered (EN)	Low	
Blue whale	Summer	Edge of banks	Few, and in southern part	Protected (1966)	Vulnerable (VU)	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	Rather abundant mainly in southern part	Hunting regulated	Least Concern (LC)	Low	
Pilot whale	Summer (Jun-Oct)	Deep waters	Occasional in southern part	Hunting unregulated	Least Concern (LC)	Low	
White-beaked dolphin	Summer	Shelf waters	Occasional in southern part	Hunting unregulated	Least Concern (LC)	Low	
Killer whale	all year, sporadical	Ubiquitous	Rare visitor	Hunting unregulated	Data Deficient (DD)	Low	
White whale	Winter (Nov-May)	Banks	Abundant winter visitor	Hunting regulated	Vulnerable (VU)	High	+
Narwhal	Winter	Winter: edge of banks, deep waters. Summer: Fjords coastal waters	Abundant winter visitor	Hunting regulated	Neart threatened	High	+
Sperm whale	Summer	Deep waters	Unknown	Protected (1985)	Vulnerable (VU)	Low	
Bottlenose whale	Summer	Deep waters	Unknown	Protected (1985)	Data Deficient (DD)	Low	
Harbour porpoise	Summer (Apr-Nov)	Coastal and deep waters	Common	Hunting unregulated	Least Concern (LC)	Low	

lar Arctic. They are more abundant in shallower, ice-covered waters associated with the continental shelf where currents or upwellings increase biological productivity, such as western Greenland and off Baffin Island. In the summer open water season, polar bears may be found on land on Baffin Island or West Greenland in higher densities. Pregnant females enter dens in snow drifts or slopes on land in NW Greenland or Baffin Island as early as September/October (Escajeda et al. 2018). Females give birth inside the den, usually in late December to early January and emerge in March.

Distribution and abundance: Information from satellite telemetry based on satellite-collared bears moving between Baffin Island (Canada) and West Greenland confirm the prior conclusion (Taylor et al. 2001) that polar bears have a wide range within Baffin Bay and that bears from the Canadian sector of Baffin Bay occur in West Greenland (Laidre et al. 2018a, b, Laidre et al. 2020). Polar bears utilize all the previous license blocks in the entire Disko West area, though use is linked to the presence of annual sea ice in Baffin Bay.

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 these two subpopulations which are also referred to as the Baffin Bay and Davis Strait subpopulations (Taylor et al. 2001). Recent studies using satellite telemetry between 2009–2015 show 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). 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 (Taylor et al. 2001).

A genetic mark recapture of the Baffin Bay subpopulation was conducted in 2012–13 and the mean estimate of total abundance was 2,826 (95% CI: 2059–3593) polar bears. This estimate was similar to the estimate reported by Taylor et al. (2005), however estimates of abundance for the 1990s and 2010s were not directly comparable due to changes in sampling design and environmental conditions (SWG 2016).

A physical mark-recapture study of the Davis Strait subpopulation completed in 2007 estimated the size of the population to be 2142 (95 % CI: 1811–2534) (Peacock et al. 2013). The subpopulation was assessed as stable. Recovery of a few polar bears in Central West Greenland that were tagged in the Davis Strait area indicates that polar bears from the Davis Strait subpopulation occasionally occur in the Disko West assessment area.

Critical and important areas: In general, the Disko West area is critical to the Baffin Bay subpopulation from roughly January through late June when sea ice is present. Denning does not take place within the Disko West region, though bears do den in West Greenland further north on the coast around Melville Bay (Escajeda et al. 2018). 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 6. Additional results with data from other studies are reported in Laidre et al. (2018a, b) and Laidre et al. (2020).

Conservation status: Based on current and projected declines in sea ice, the polar bear is listed as 'Vulnerable' (VU) on the IUCN red list of threatened species (Wiig et al. 2015) and the Greenland red list. It is listed as 'Threatened' under the US Endangered Species Act (USFWS 2008) and of 'Special Concern' in Canada (COSEWIC 2019).

Sensitivity: The primary threat to polar bears is sea ice loss from anthropogenic climate warming see further in Chapter 5.4. Their sensitivity to oil and gas activities are described in Chapter 6.

Box 6. The April 2009 to April 2010 study of polar bear movements and habitat use in Northwest Greenland

Erik W. Born (GINR), Kristin Laidre (GINR), Rune Dietz (AU) & Øystein Wiig (NHMO)

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 assessment 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 (Figure 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.

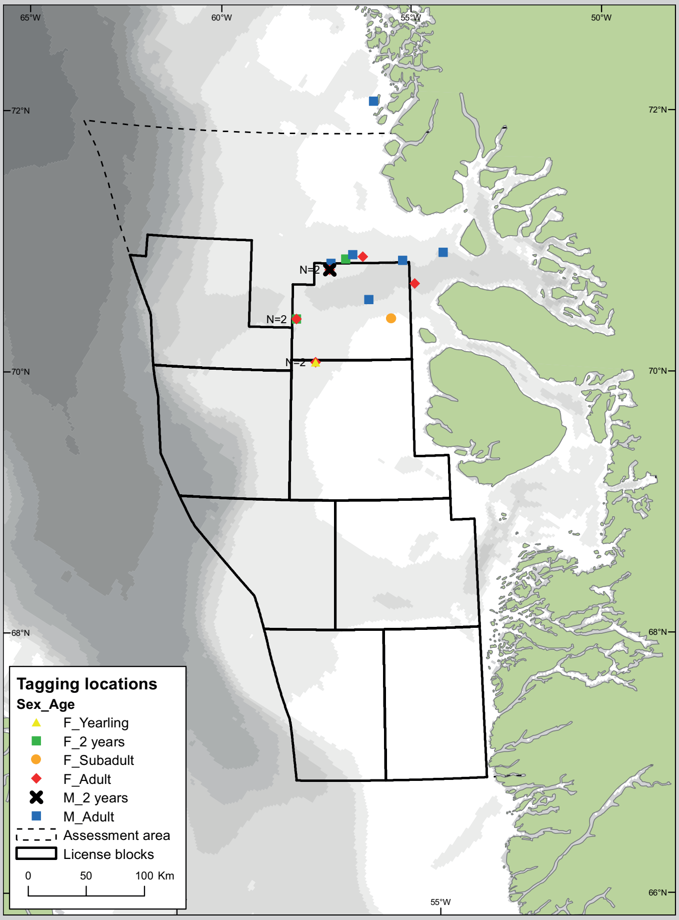


Figure 1. Disko West assessment area with borders of license blocks and locations where 16 polar bears were tagged during April 2009. Fifteen of these bears were fitted with satellite transmitters. F = females, M = males.

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	°N	Min	°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	trans-mitting
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	trans-mitting
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	trans mitting
D7288	F	2 years	23.04.2009	71	2	56	45	2	74782	SPOT5	6/20/2009	59

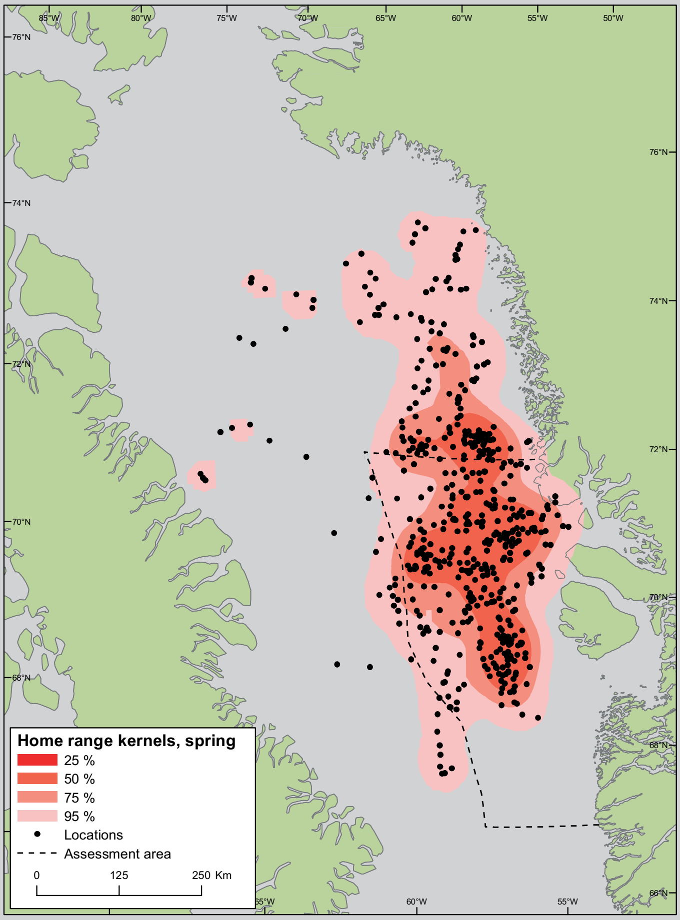


Figure 2. Home range of 16 tracked polar bears in spring (April-May) 2009. Home range calculated as kernel polygons, which show the fraction in % of the locations they include.

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.

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 (Figure 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 (Figure 2).

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

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.

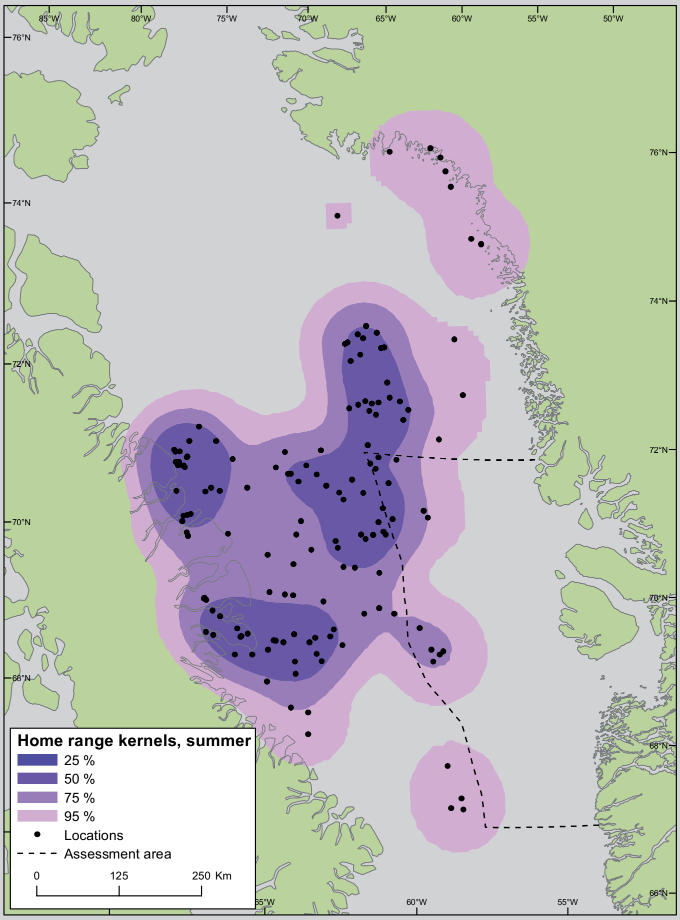
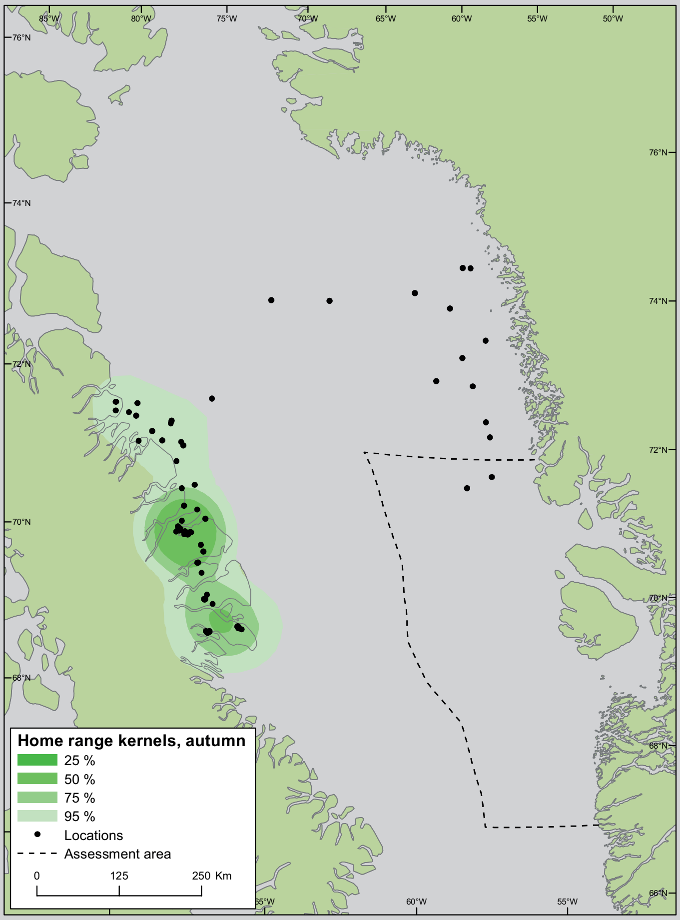


Figure 4. Home range of 5 tracked polar bears (1 male, 4 females) in autumn (Sept.-Dec.) 2009. Home range calculated as kernel polygons, which show the fraction in % of the locations they include.



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 (Figure 4).

In *winter* 2010 (January-March), when the annual sea-ice had formed, three adult polar bears (D7283, D7285, D7287) departed from the land on eastern Baffin Island where they had spent the open water season and moved offshore. Two of these bears moved from Baffin Island during late January 2010, whereas D7283 which had been in a maternity den on Baffin Island moved onto the sea-ice sometime around 31 March 2010. Polar bears typically show fidelity to den and spring feeding areas (Wiig 1995). This tendency was confirmed by bear D7283 and bear D7285 which moved towards the West Greenland coast where they occurred in the shear zone between land fast ice and the offshore Baffin Bay pack ice between ca. 72° and ca. 76° N. D7283 was shot in Upernavik on 13 February 2010. Bear D7287 used the northern Baffin Bay in late winter (Figure 5). However, the two other adult female polar bears (D7283; D7287) were on the ice in the west side of Baffin Bay as of April 2010 (Figure 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 (Figure 5). The total combined winter home range was approximately 310,400 km^2.

Adult males and sub-adults of both sexes had shorter tracking durations due to ear tag attachments and all except bear D7286 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 (Figure 6).

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

All polar bears that were instrumented in April 2009 chose to follow the receding ice and 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).

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.

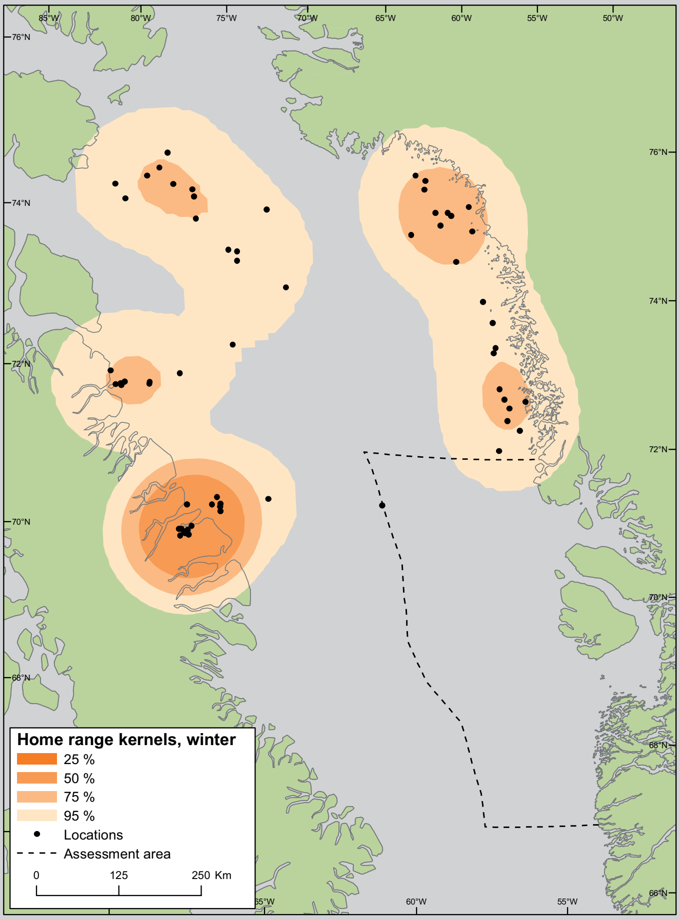
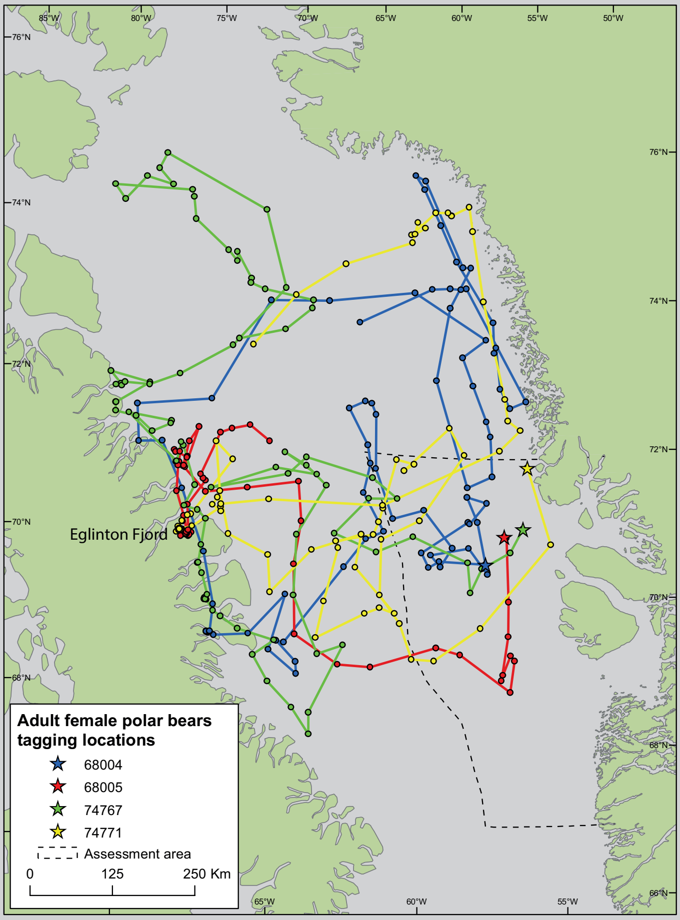


Figure 6. Tagging locations and movements of four female polar bears in 2009 and 2010.



Time spend on the West Greenland side

None of the 15 bears that were instrumented during April 2009 chose to spend the summer in West Greenland. Dates on which bears moved west of 60° W longitude varied within the months of May and June (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 this longitude threshold however many remained in the vicinity (between 60° and 63° W) for several more weeks until the sea-ice had disappeared in central and western Baffin Bay.

Maternity denning sites

During the one year study period two maternal denning sites used by two different female bears were identified along the Baffin Island coast (Figure 6). Both dens were on land and located in 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.

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	°N	°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

3.8.2 Walrus (*Odobenus rosmarus*)

Erik W. Born (GINR)

Biology: Generally, walruses have an affinity to shallow water areas with suitable benthic food and they winter in areas without solid ice, i.e. where there is not 100% sea ice cover (Born et al. 1995 and references therein). On their wintering grounds in the assessment area, walruses prefer relatively dense pack ice (ice coverage: 50–60% or higher) in waters less than 100 m deep, which primarily is found between 66° 30′ N and 70° 30′ N and between the coast and 56° W (Born et al. 1994b, 1995, Dietz et al. 2014).

Information from experienced walrus hunters who were interviewed in 2010 (Born et al. 2017) confirmed that walruses in West Greenland mainly consume bivalve molluscs (including *Mya truncata* and *Hiatella arctica)*, which is in accordance with information in Born *et al.* (1994). Other walrus food items like Icelandic scallop (*Chlamys islandica*), bottom dwelling worms, fish (sandeel, *Ammodytes* spp.) and seals were also reported by the hunters. Samples of stomach contents collected in 2004 from walruses that were shot at Store Hellefiskebanke also showed that walruses feed on *Mya* in this area (Born et al. 2017). Born (2005) estimated that at their present abundance there is amble food at the foraging banks for walruses wintering in West Greenland.

Subadults and females with young generally occur closer to the coast than adult males and in areas with less dense ice and shallower water (Born et al. 1994b, 2017, Dietz et al. 2014). Although larger congregations numbering one to two hundred individuals have in the past been reported in the assessment area (i.e. off Attu–Nassuttoq at ca. 67° 30′ N and west of Disko island at ca. 69° 45′ N; Born et al. 1994b), most walruses observed during more recent aerial surveys were either single or in pairs, and rarely groups of 3–8 walruses have been observed (Born et al. 1994b, Heide-Jørgensen et al. 2014).

During April–May the walruses progressively move farther offshore as the sea ice melts and the edge of the Baffin Bay pack ice (the West Ice) retreats westward towards Baffin Island (Born et al. 2017).

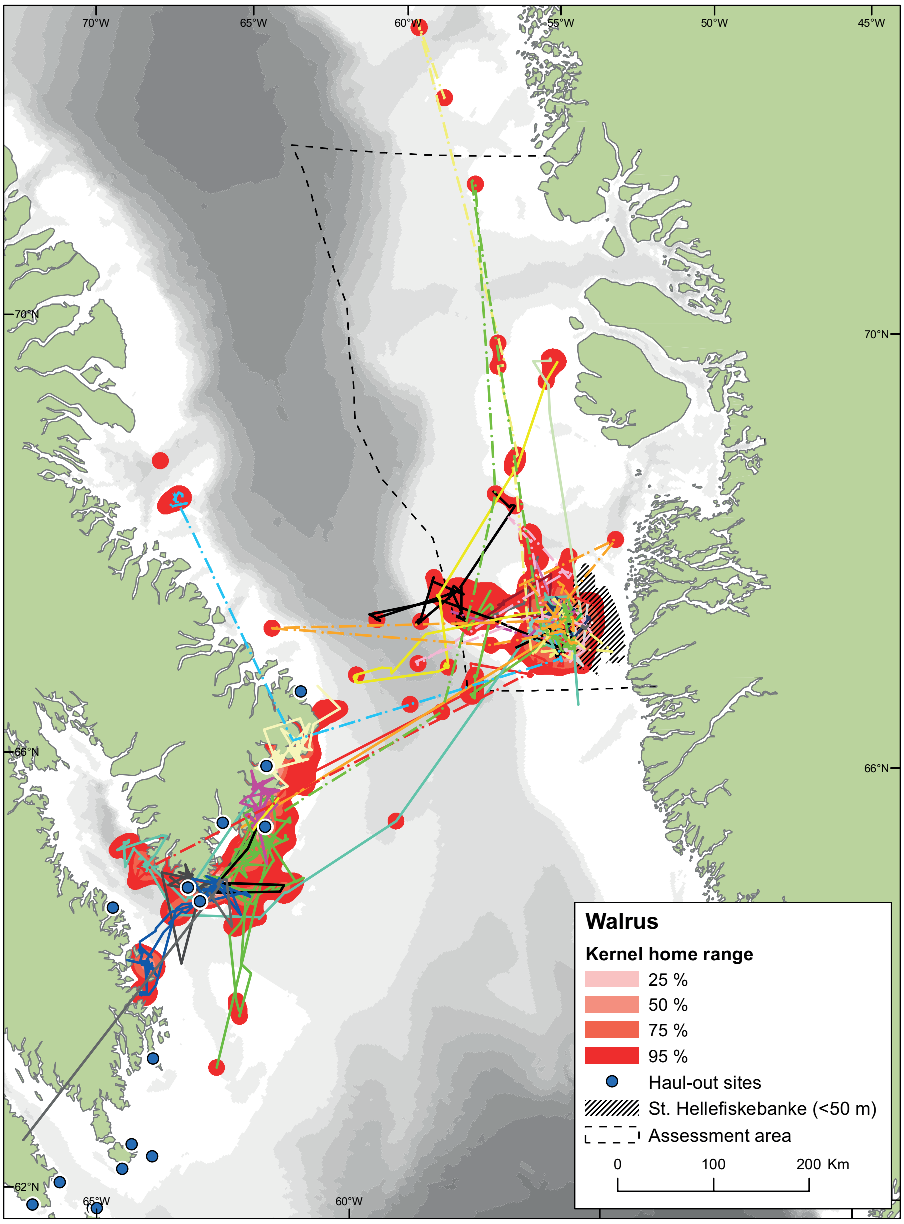
However, the satellite tacked individuals and aerial surveys indicate that during spring the walruses show a great site fidelity to the area irrespective of the density of the sea ice cover suggesting that the main motivation for walruses to occur on Store Hellefiskebanke is access to food rather than access to suitable haul-out possibilities on the sea ice (Dietz et al. 2014, NAMMCO 2018).

During the mating season (January–April; Born 2003 and references therein) male walruses engage in ritualized visual and acoustical display underwater (Fay et al. 1984, Sjare & Stirling 1996, Sjare et al. 2003). Recordings of displaying adult males in April at Store Hellefiskebanke confirm that walruses mate in the assessment area (Born et al. 1994b).

Observations of newborn walruses on the West Greenland wintering grounds are rare (Born et al. 1994b, 2017) which likely reflects that the walruses leave the area before the peak birth period which is late May–early July (Born 2001, Born et al. 2017).

Walruses move between summer and winter habitats. Satellite telemetry during spring of 2005–2008 showed that the majority of walruses that winter in the assessment area move west to summer at southeastern Baffin Island (Figure 41) (Dietz et al. 2014). I also showed that the westward migration took

Figure 41. Track lines and kernel home range polygons from 31 walruses instrumented with satellite transmitters at Store Hellefiskebanke during March-April 2005-2008 and at Southeast Baffin Island during August-September 2008 (Dietz et al. 2014). The home ranges are defined by 95, 75, 50 and 25% of the received positions. Store Hellefiskebanke is an important winter habitat.



place between 7 April and 25 May, with the routes across Davis Strait being quite similar among years and at the shallowest and narrowest part (approx. 400 km) of the strait. Walruses re-appear in the Store Hellefiskebanke area sometime in December–January (Born et al. 2017). The period between May and late fall is spent along the coast of eastern Baffin Island, where walruses that have wintered in West Greenland mix with walruses that have wintered at Baffin Island (*Ibid.*). The timing of the spring dispersal and migration towards Baffin Island seems, to some extent, to be inked to the retreat of the eastern edge of the West Ice (Dietz et al. 2014).

Distribution and abundance: The walruses occurring in the assessment area belongs to the West Greenland-Southeast Baffin Island (WG-SBI) population (#4 in Figure 42), which is genetically deviates from the two other populations in Davis Strait-Baffin Bay region (Cronin et al. 1994, Andersen et al. 1998, Andersen & Born 2000, Born et al. 2001, Andersen et al. 2009b, 2009c, 2014). The satellite trackings (2005–2008) mentioned above also support that walruses in West Greenland and at southeastern Baffin Island belong to the same subpopulation (Dietz et al. 2014), and it seems plausible that the majority of the West Greenland-Southeast Baffin Island subpopulation of walruses winter at the West Greenland banks.

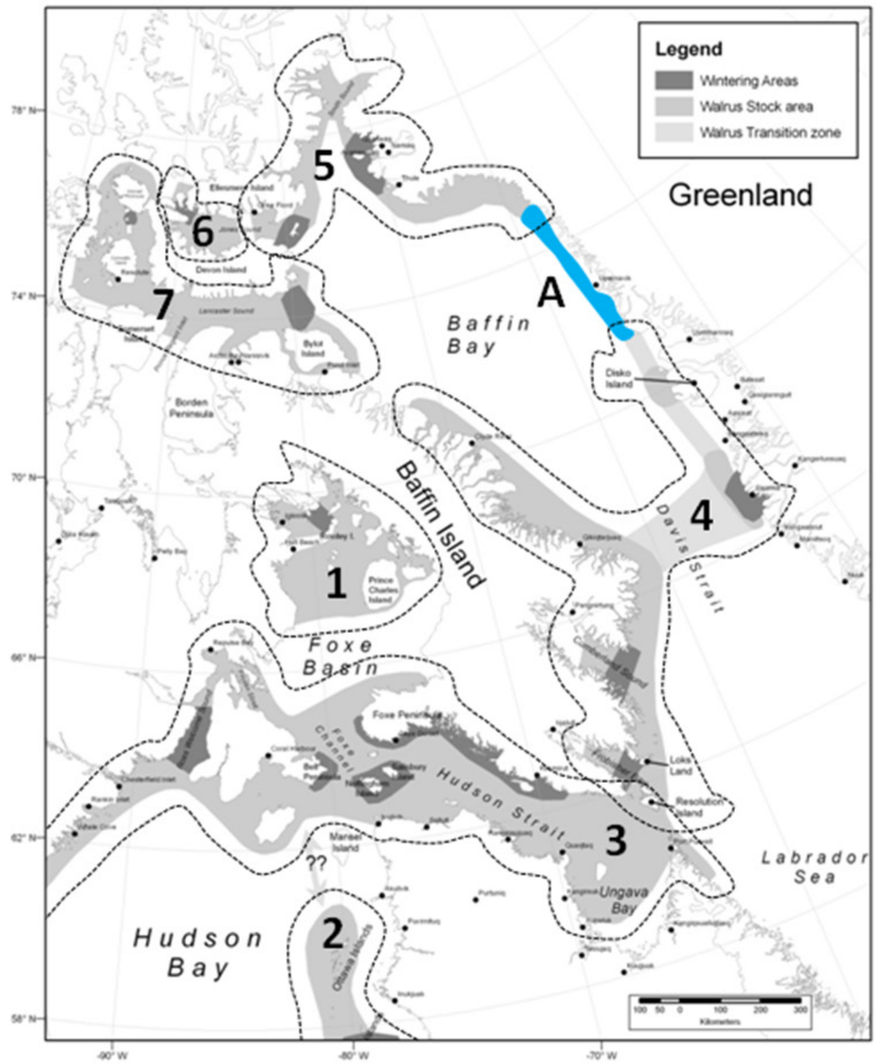


Figure 42. Distribution of seven subpopulations of Atlantic walrus in the western Atlantic Arctic (Born unpublished). The map is based on NAMMCO (2006), Stewart (2008) and courtesy of R.E.A. Stewart (DFO, Canada, unpublished). Legend: (1) Foxe Basin, (2) South and East Hudson Bay, (3) N. Hudson Bay-Hudson Strait-N. Labrador-SE Baffin Island, (4) Central West Greenland-Eastern Baffin Island, (5) North Water/N. Baffin Bay, (6) W. Jones sound, and (7) Penny Strait-Lancaster Sound. A show where transient walruses (blue) occur at low density along the coast of NW Greenland.

Several systematic aerial surveys conducted during 1981–2012 (Born et al. 1994b, Mosbech et al. 2006, Heide-Jørgensen et al. 2014), as well as interviews with experienced walrus hunters in 2010 (Born et al. 2017) showed that walruses in West Greenland are mainly concentrated in two areas during winter: (1) the shallow banks between approx. 66° 30′ N and approx. 68° 15′ N (i.e. at Lille and Store Hellefiskebanke), and (2) the banks along the western coast of Qeqertarsuaq/Disko Island between approx. 69° 15′ N and approx. 70° 30′ N. However, a limited number of walruses also occur in the Uummannaq-Upernavik areas. Here they may occur in small polynyas at the tip of the Nuussuaq and Sigguk Nunaa/Svartenhuk peninsulas in the Uummannaq area. They are also reported by the walrus hunters to be present in shallow areas at the entrance to the Uummannaq fjord in May (Born et al. 2017).

This general scarcity of walruses in the Uummannaq and Upernavik areas was confirmed during March–April 2009–2013, when a helicopter-based search for polar bears over the fast ice and the offshore pack ice covered the area between 70° 22′ N and 76° 15′ N (*i.e.* between Vaigat and Savissivik). During ca. 245 hours searching "on effort", a total of only eight walruses were observed all of which were south of 72° N (Born et al. 2017).

Of 23 individual walruses that were tagged with satellite transmitters at Store Hellefiskebanke during spring (2005–2008), two males moved north to Disko Banke demonstrating a connection between walruses at these two wintering grounds. Two other male walruses took a northward route 75–100 km offshore and reached as far north as ca. 71° 50′ N and ca. 73° 15′ N, respectively, in the Upernavik area until they both turned southward again in late May (Dietz et al. 2014).

The demographic affinity of the relatively few walruses occurring in the Uummannaq-Upernavik area although remains undetermined. But the two tracked individuals mentioned above, indicate that they belong to the WG-SBI population. For management purposes they are considered to be a part of the West Greenland-Southeastern Baffin Island subpopulation (NAMMCO 2018).

The abundance of walruses wintering in the assessment area was estimated after three systematic aerial surveys in 2006, 2008 and 2012). The results were 1,105 (95% confidence interval, CI: 610–2,002) in 2006, 1,137 (95% CI: 468–2758) in 2008 and 1408 (95% CI: 922–2150) in 2012. These estimates did not differ significantly and the median point estimate of the abundance of walruses wintering in West Greenland in 2006–12 was estimated at about 1,100 animals (Heide-Jørgensen et al. 2014). During the surveys about 85% of the sightings were made in the Store Hellefiskebanke area, and the remainder north of this area.

The present distribution of walruses within the assessment area is basically similar to their historical distribution (cf. Born et al. 1994b, 1995). However, various information and modelling of population trend indicate that walruses were much more abundant in West Greenland at the beginning of the 20th century, and they then also used haul-outs on the coast (Born et al. 1994b, Witting & Born 2005, 2014). But recently the trend has been positive: An analysis of the results from a series of aerials surveys conducted over the West Greenland wintering grounds since 1981, indicated an increasing trend in abundance from 1981 through 2017 (NAMMCO 2018). This is also observed by local hunters, who had observed more walruses within the hunting areas and deduced that this was a sign of a population increase, which they mainly attributed to a reduction in level of exploitation. (Born et al. 2017).

Historically both male and female walruses used several terrestrial haul-outs situated on small islands and on the mainland coast in West Greenland between approximately 67° 25′ N and 67° 47′ N from September until November–December. However, due to hunting by these haul-outs were permanently abandoned sometime during the first half of the 20th Century (Born et al. 1994b, 1995). During the 2010-interview survey some hunters living in the study area reported having seen walruses on land (Born et al. 2017).

During 1993–2012 the catches reported in *Piniarneq* decreased significantly at Store Hellefiskebanke, along western Disko Island and in the Uummannaq-Upernavik area (Born et al. 2017). During the 2010-interview survey the walrus hunters offered several explanations for this decrease: (1) the introduction of a quota on walrus, (2) decrease in market demands, (3) a general decrease in number of hunters, and (4) climate changes resulting in walruses spending less time on the traditional hunting grounds—and bad ice and weather conditions negatively influencing the ability of hunters to access the walruses Born et al. 2017).

Critical and important areas: Walruses from the West Greenland-Southeast Baffin Island subpopulation concentrate December to May in the assessment area 30 to 100 km off the coast between approx. 66° 30′ N and approx. 68° 15′ N (Store Hellefiskebanke), and on the banks along the western coast of Qeqertarsuaq/Disko Island between approx. 69° 15′ N and approx. 70° 30′ N. These areas encompass the main distribution areas of walruses wintering in West Greenland (Born et al. 1994b, 2017; Christensen et al. 2016).

Conservation status: Globally the walrus is listed as 'Vulnerable' (VU) on the IUCN red list of Threatened Species primarily because of the climate changes, which will reduce their habitat (Lowry 2016a). The local population is assessed as 'Vulnerable' (VU) on the Greenland red list (Boertmann & Bay 2018). In Canada the population is classified as of 'Special Concern' (COSEWIC 2019).

Sensitivity: Walruses are particularly sensible to disturbance when they are hauled out on land (e.g. Born et al. 1995, Øren et al. 2018). In several areas prolonged or repeated disturbances – and in particular hunting on land – resulted in traditionally used terrestrial haul-outs being abandoned in the assessment area (Born et al. 1994b, 1995 and referenced therein) and elsewhere in the distribution area of Atlantic walruses (e.g. Gjertz & Wiig 1994, COSEWIC, 2006, 2017).

It is also generally accepted that walrus avoid areas with human activities, even if that does not include hunting (NAMMCO 2019). See also Chapter 6 on sensitivity to oil spills.

3.8.3 Seals

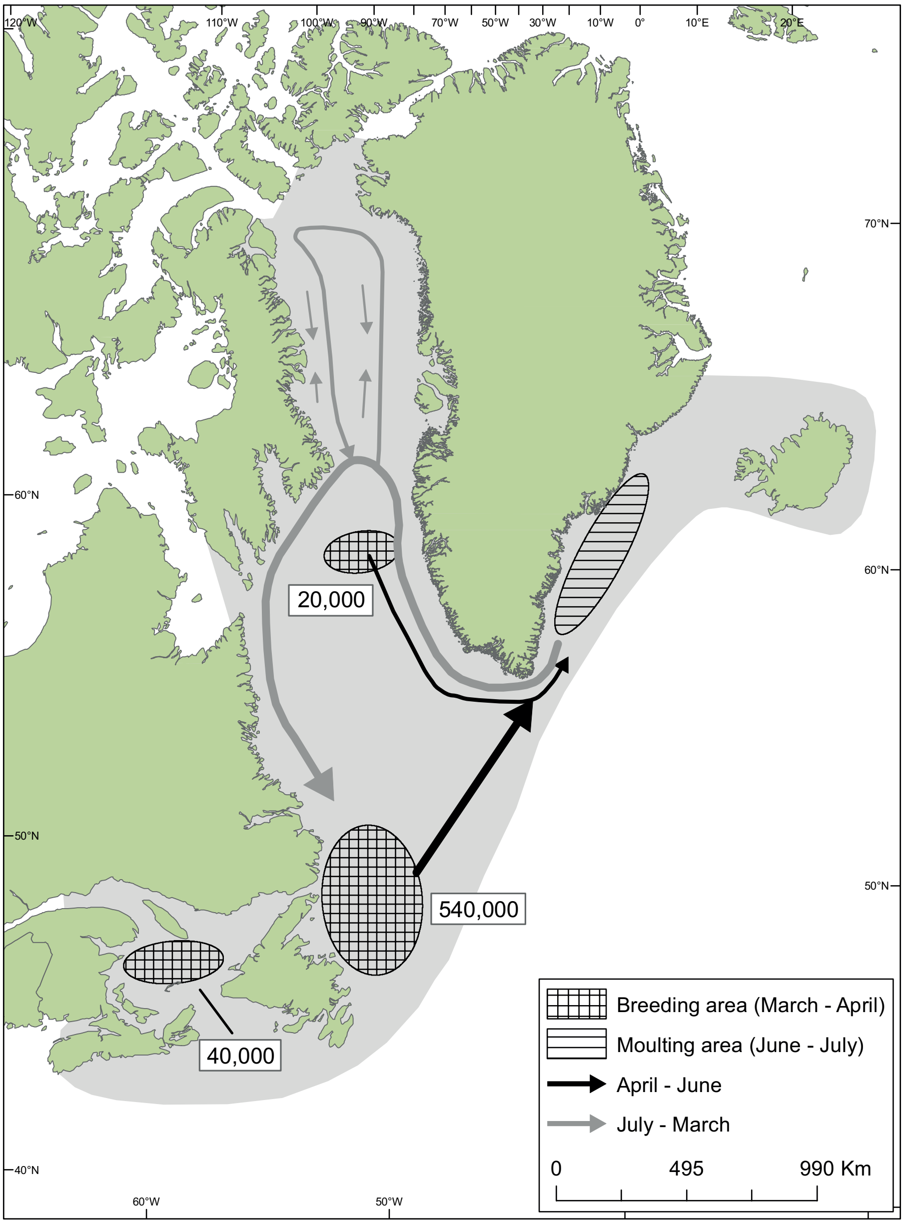
Aqqalu Rosing-Asvid (GINR)

Four seal species; the ringed seal, harp seal, hooded seal and bearded seal are common in the Disko West assessment area (Table 5). They are all included in the subsistence hunt and they rank from being very numerous to relatively common. Harbour seals are also present in the assessment area, but they have become very rare and hunt on this species is now prohibited (Rosing-Asvid 2010). Harp and hooded seals are migrants occurring only during the open water season, and they whelp outside the assessment area. Ringed seals occur mainly in ice-covered waters and in the assessment area they have pups on the fast ice in the fjords and on consolidated pack ice in offshore areas. Bearded seals also tend to stay near sea-ice and they can make and maintain breathing holes, but unlike the ringed seal, they mainly stay in areas with access to open water or relatively thin ice. Some follow the pulse of the pack ice that reaches into the assessment area during winter and spring.

Hooded seal (*Cystophora cristata*)
Biology: Hooded seals are migratory seals. The vast majority of the West Atlantic population concentrate in the whelping areas around Newfoundland, where they give birth during March–early April, but a small part of this population (variable in numbers from year to year) whelp in Davis Strait south of the assessment area (Stenson et al. 1996). In late April–May most adult hooded seals swim toward Southeast Greenland where they moult on drift ice during late June and July (Figure 43). There is some uncertainty about the seasonal distribution of the juvenile seals, but many can be seen year round on the drift ice off the Greenland east coast. The adult seals start a migration from the moulting area toward Davis Strait and Baffin Bay during the end of July (Andersen et al. 2009). A large fraction of the adult seals move into the Baffin Bay in September and until November they forage on the steep part of the shelfbreak in Baffin Bay (most of them will stay west of the assessment area). They mainly feed on large fish and squids (Andersen et al. 2009a) and they regularly dive deeper than 500 m (maximum recorded dive depth of 1652 m (Andersen et al. 2013). In spring they return to the whelping areas.

Conservation status: The hooded seal population, is listed as 'Vulnerable' (VU) both on the Greenland red list and the global red list, mainly due to a sig-

Figure 43. 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.



nificant population decrease in the Greenland Sea stock (Kovacs 2016a). The relative small catches in Greenland are not considered to be a problem for this large population. The hooded seals are managed internationally through a working group under ICES, NAFO and NAMMCO and catches are considered sustainable (ICES 2006b).

Distribution and abundance: The total pup production in the West Atlantic (seals that whelp around Newfoundland and in Davis Strait) was estimated to be 116,900 (SE: 7,918, CV: 6.8%) in 2005. This corresponds to a total population of about 592,100 seals (SE: 94,800; 95% CI: 404,400–779,800) (ICES 2006a). Commercial sealing on hooded seals stopped after 2006 and no new assessment has been made since then.

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

Sensitivity: Non-whelping hooded seals are not particularly sensitive to oil spills and disturbance, but hooded seals can be affected by oil spills in the same way as all other seals (see also Chapter 6).

Bearded seal (*Erignathus barbatus*)

Biology: Bearded seals are widespread in the Arctic, but little is known about their numbers and seasonal changes in distribution. Male bearded seals vocalize a lot during the breeding season in spring and their 'song' can be used to recognize individual seals. Long-term studies of bearded seal vocalization show a high degree of site fidelity among male bearded seals (Risch et al. 2007). Some bearded seals are known to be stationary, but seasonal changes in their densities in other areas indicate that a part of the seals move around. These distribution changes seem to be linked to the seasonal changes in the sea-ice conditions. Bearded seals do make and maintain breathing holes, but mainly in relatively light ice conditions, 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 are known to feed mainly on fish and benthic invertebrates found in waters down to 100 m depth (Burns 1981b, Gjertz et al. 2000). Ongoing studies show that bearded seals in South Greenland spend considerable time in much deeper water (>300 m) and shrimps are found to be the most important prey in that area (GINR unpublished).

Whelping 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). Bearded seals whelp in the assessment area every year, but the numbers are unknown.

Distribution and abundance: Bearded seals can be found in most the parts of the assessment area throughout the year. Highest concentrations are present when the Davis Strait pack ice expands into the assessment area during midwinter and spring (GINR, unpublished data from aerial surveys).

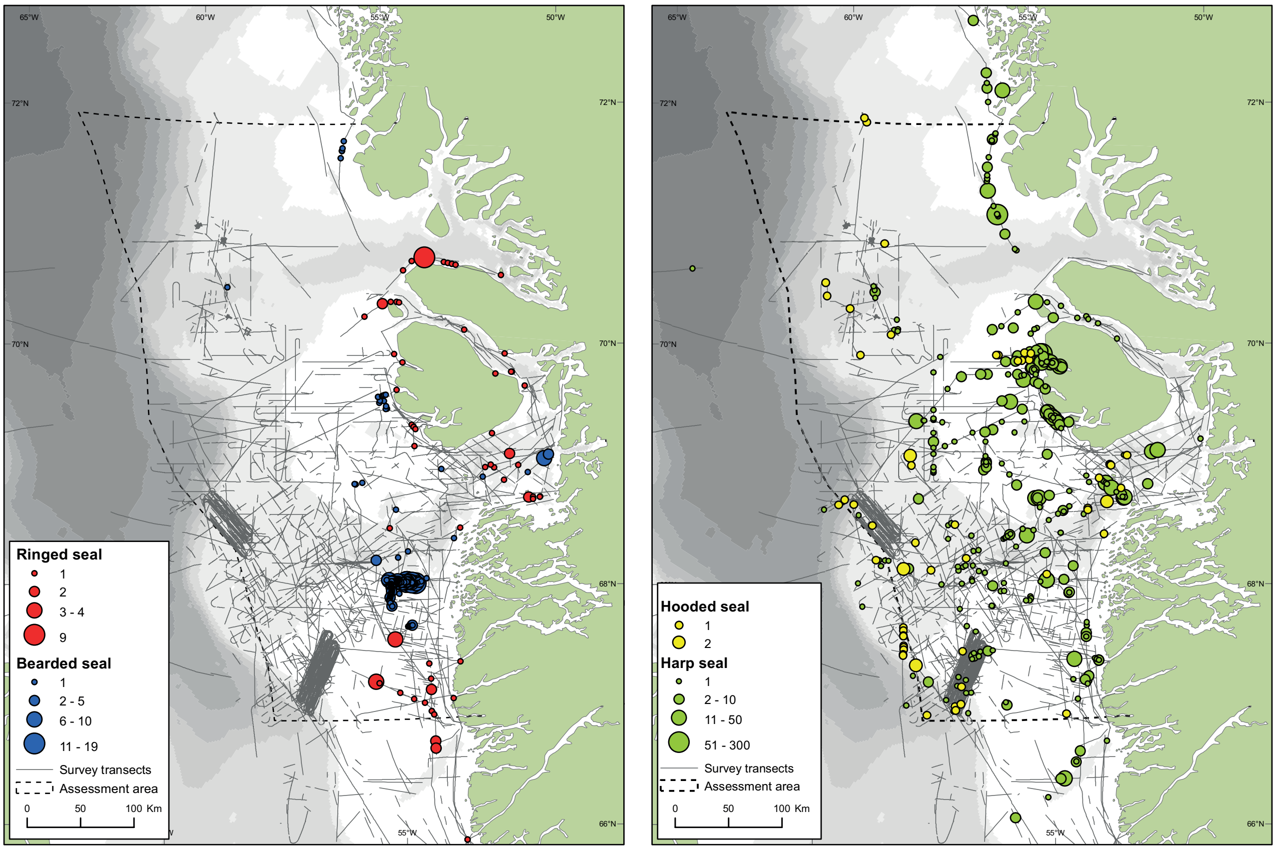


Figure 44. Sightings of seals made during 34 systematic seabird and marine mammal surveys from seismic vessels and biological research vessels between 1988 and 2017 (DCE Seabirds-at-Sea Database, unpublished). The spatial distribution of effort is indicated by the transect lines. The surveys were conducted between April and November, but with a major peak in August and September.

Figure 44 show where bearded seals have been observed during various research vessels in the open water period. They are, however, usually observed (and caught) along the ice edge during spring.

Conservation status: The bearded seal is listed as 'Least Concern' (LC) both on the Greenland red list and on the global red list (Kovacs 2016b), because of its uniform and widespread distribution, which is believed to be a good protection against over-exploitation.

Critical and important habitat: In the Disko West assessment area the Store Hellefiskebanke and especially the northern rim, seems to be an important habitat during winter and spring (Frederiksen et al. 2008).

Sensitivity: Bearded seals often vocalize, especially during the breeding season in spring (Burns 1981a, Boye et al. 2020b) and may therefore be sensitive to acoustic disturbances (noise). The benthic feeding habits will also make them vulnerable to oil-polluted benthos and bearded seals can be affected by oil spills in the same way as all other seals (i.e. tissue damage and poisoning).

Harp seal (*Pagophilus groenlandicus*)
Biology: 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 also on the ice 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 45).

During summer most adult harp seals will forage in pods typically consisting of 5–20 individuals. Juvenile seals forage alone, but all ages 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, and unpublished data from the Greenland Institute of Natural Resources).

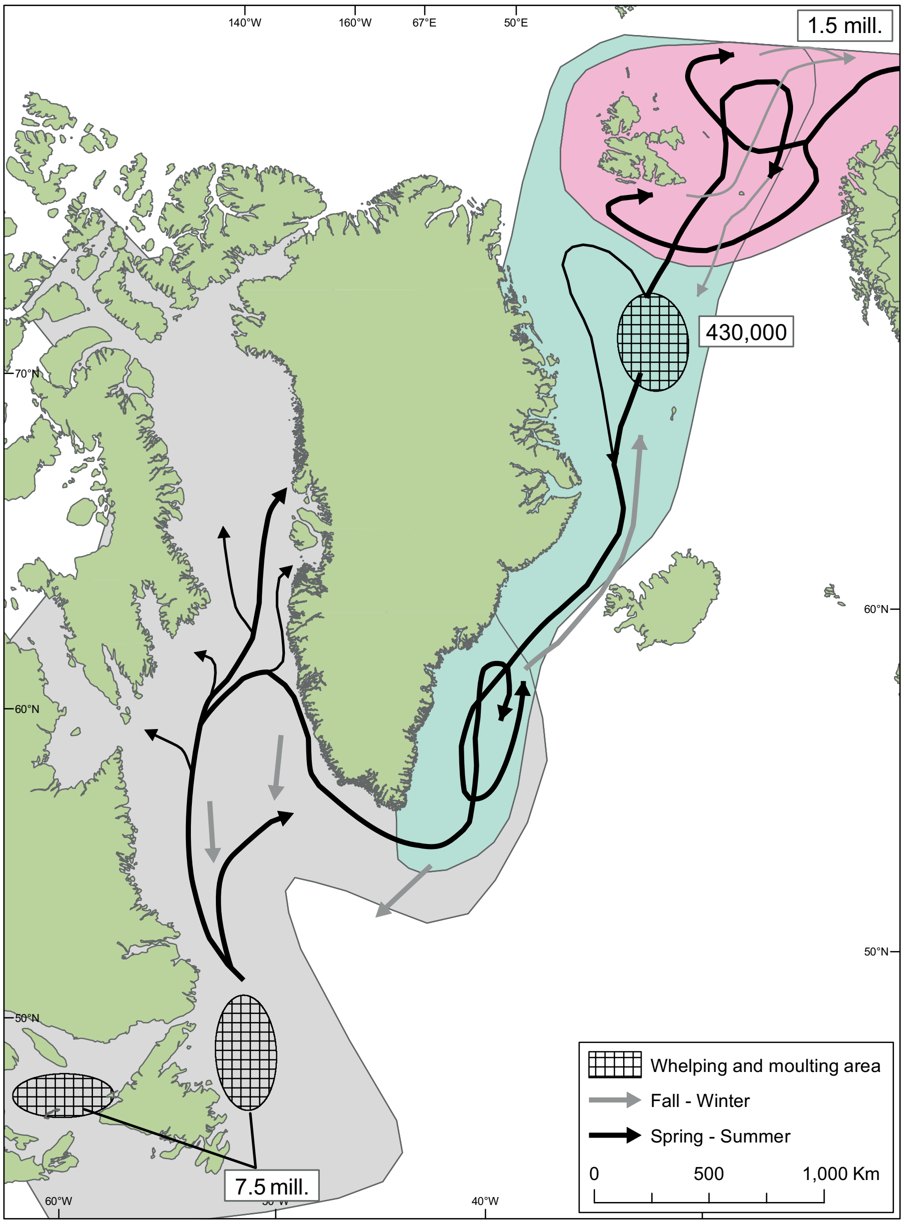
Distribution and abundance: Harp seals are widely distributed in the assessment area (Figure 45) and their numbers increase throughout the summer and early fall, but when the sea-ice starts to form they migrate back towards the whelping areas off Newfoundland. However, some remain until February before they move towards the whelping areas.

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 peak about 7.8 million individuals in 2008 followed by a drop to 7.4 mill in 2012 (ICES 2011). A new pup production survey was conducted in 2017, and a preliminary result was 700,000 pups which is lower the the previous estimate in 2012 (ICES 2019b).

The proportion of the population that enters or passes through the assessment area is likely to vary from year to year. It is probably more than a million seals, but the number of seals in the area at any given time is significantly lower. The highest number of seals in the area is during summer and early fall.

Conservation status: The population occurring in the assessment area has a favourable conservation status. Harp seal is the most numerous marine mammals on the northern hemisphere and the West Atlantic population is probably around the highest level in historic time. It is listed as of 'Least Concern' (LC) on both the Greenland red list and the global red list.

Figure 45. Harp seal distribution and numbers associated with known whelping areas.



Critical and important habitats: No particularly important areas are known for harp seals within the assessment area, but many seals pass through the area.

Sensitivity: The harp seals are not whelping in the assessment area, which makes them less vulnerable to oil spills and disturbance, but harp seals can be affected by oil spills in the same way as other seals (see also Chapter 6).

Ringed seal (*Pusa hispida*)
Biology: Ringed seals are present in all parts of the Arctic that have annual sea-ice. They can make and maintain breathing holes in fjords with fast ice, but also in glacier fjords and areas with consolidated pack ice where they make breathing holes in the small spaces in between the icebergs or between ice floes. Adult seals might establish territories in these areas, whereas the juvenile seals mainly spend the winter in areas with loose unconsolidated sea-ice. In the assessment area ringed seal breeding areas can be found in fjords and bays and in the offshore pack ice in Baffin Bay (Finley et al. 1983). Ringed seals give birth in March–April in lairs dug out in a snowdrift that is covering a breathing hole and the pups lactate for up to 7 weeks (Hammill et al. 1991). The ringed seals start to moult in April–May and the regrowth of new hairs occurs mainly in May–June. The seals will need to haul out in order to

rise the skin temperature to a level that allow regrow of the hairs. Some seals, therefore, move into ice filled glacier fjords whereas others follow the pack-ice that retreats west and northward out of the assessment area. When the sea-ice expands again during early winter, many seals (especially juveniles) follow the expansion. The adult seals tend to be more sessile and to have a smaller home range, whereas many of the juvenile seals stray long distances (Yurkowski 2016).

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

Distribution and abundance: Aerial surveys in the 1980s revealed large concentrations of ringed seals 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).

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 offshore and in fjords and along the coast), why it is difficult to designate any especially important areas.

Sensitivity: Breeding ringed seals depend on stable sea ice during the two months when they give birth and nurse their pups (April–May). This stationary behaviour makes them vulnerable, particularly to activities that can disrupt the stable ice (see also Chapter 6).

Harbour seal (*Phoca vitulina*)

Biology: Most harbour seals rarely swim more than a few kilometers away from the coast. They concentrate in certain areas during breeding and moulting, and they show strong site fidelity toward terrestrial haul-out sites throughout the year. Whelping usually takes place in June, while moulting in August–early September. The breeding and moulting sites are often the same.

Distribution and abundance: Up until the 1950s harbour seals were relatively common in the assessment area, but hunting has driven them to near extinction (Rosing-Asvid 2010). In the recent decade only one active breeding area has been reported in the assessment area (and it is only used by a few seals).

This locality is Qasigissat on the west coast of the Disko Island (69° 52′ N, 54° 47′ W). There are also observations of small groups of harbour seals in other parts of the assessment area, indicating that other small populations exist.

Conservation status: Harbour seals are listed as 'Critically Endangered (CR)' on the Greenland red list. Worldwide they are of Least Concern (LC) (Lowry 2016b). They are protected from hunting.

Sensitivity: Harbour seal populations often have strong site fidelity to certain haul-out sites on land and oil spills or disturbing activities near these locations might affect the entire population in the area.

Critical and important habitats: The breeding locality Qasigissat on the west coast of the Disko Island is a very important habitat for this remnant population of harbour seals.

3.8.4 Whales, dolphins and porpoises

Fernando Ugarte (GINR), Tenna Boye (GINR), Malene Simon (GINR) & Mads Peter Heide-Jørgensen (GINR)

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 46 and in Table 6.

Figure 46. The main frequency range of sounds used by cetaceans in the assessment area. See also Table 6 for details

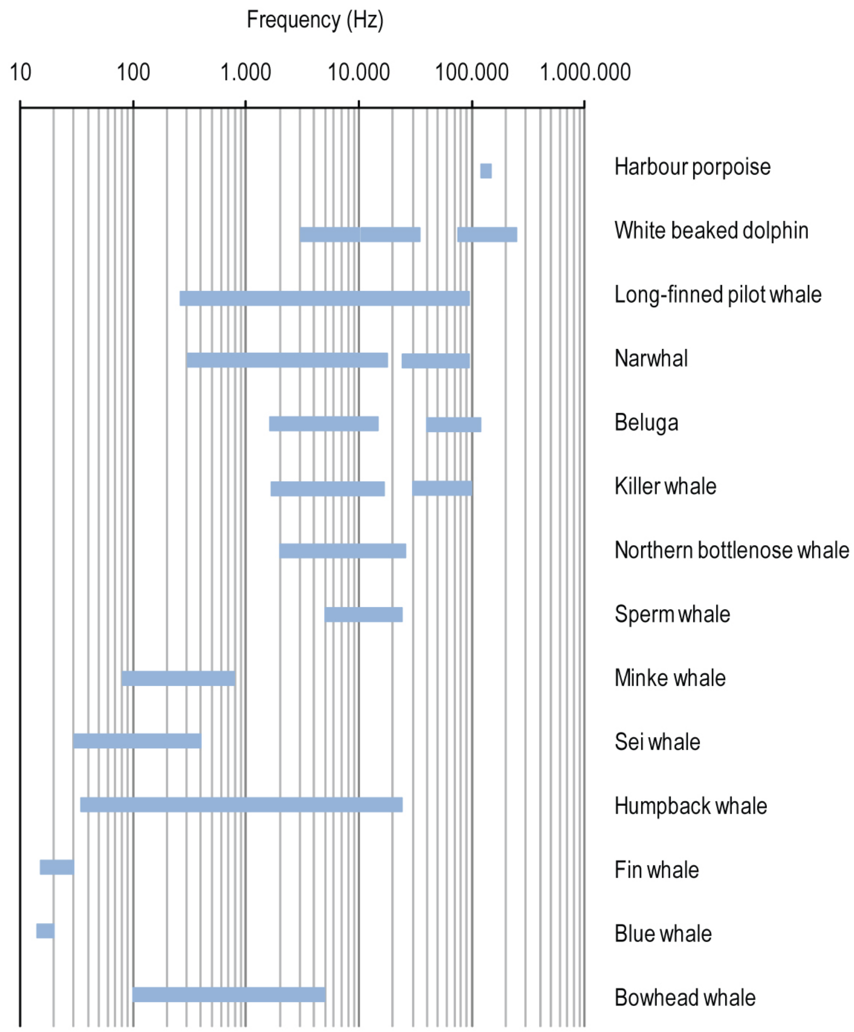


Table 6. The frequency range of the most commonly used sound types of cetaceans in the assessment area. The frequency range is given by the minimum and maximum frequencies in hertz (Hz).

Species	Sound type	Min freq. (Hz)	Max freq. (Hz)	References
Toothed whales				
Harbour porpoise	Click	120,000	150,000	(Villadsgaard et al. 2007)
White beaked dolphin	Click	75,000	250,000	(Rasmussen & Miller 2002)
	Whistle	3,000	35,000	(Rasmussen & Miller 2002)
Long-finned pilot whale	Click	4,100	95,000	(Eskesen et al. 2011)
	Whistle	260	20,000	(Rendell & Gordon 1999)
Narwhal	Click	24,000	95,000	(Miller et al. 1995)
	Whistle	300	18,000	(Ford & Fisher 1978)
White whale	Click	46,600	112,600	(Au et al. 1985)
	Whistle	1,400	14,000	(Belikov & Bel'kovich 2006, 2007)
Killer whale	Click	30,000	100,000	(Simon et al. 2007c)
	Whistle/call	1,500	18,000	(Ford 1989, Thomsen et al. 2001)
Northern bottlenose whale	Click	2,000	26,000	(Hooker & Whitehead 2002)
Sperm whale	Click	5,000	24,000	(Madsen et al. 2002a, b)
Baleen whales				
Minke whale	Call / song	80	800	(Mellinger et al. 2000)
Sei whale	Call / song	30	400	(Rankin & Barlow 2007)
Humpback whale	Call / song	35	24,000	(Payne & Payne 1985)
Fin whale	Call / song	15	30	(Watkins et al. 1987)
Blue whale	Call / song	14	20	(Cummings & Thompson 1971)
Bowhead whale	Call / song	100	5,000	(Ljungblad et al. 1982)

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, have a fluctuating abundance in the assessment area 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 2017 information is available concerning the occurrence of the four baleen whale species that are regularly present in the assessment area (Figure 47). The rorquals undertake long migrations to take advantage of the summer peak of productivity in northern waters.

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 46). Due to their ability to communicate acoustically over very long distances, the baleen whales are sensitive to activities that raise the ambient noise level (acoustic pollution – masking of the sounds) from sources such as seismic airguns, drilling, offshore construction, aircrafts and vessel activities. Moreover, baleen whales avoid such sound sources and potentially can be displaced from important feeding areas etc. regarding sensitivity to oil spills there is no information available, but e.g. Werth (2001) speculate that oil on the baleen may affect filtration.

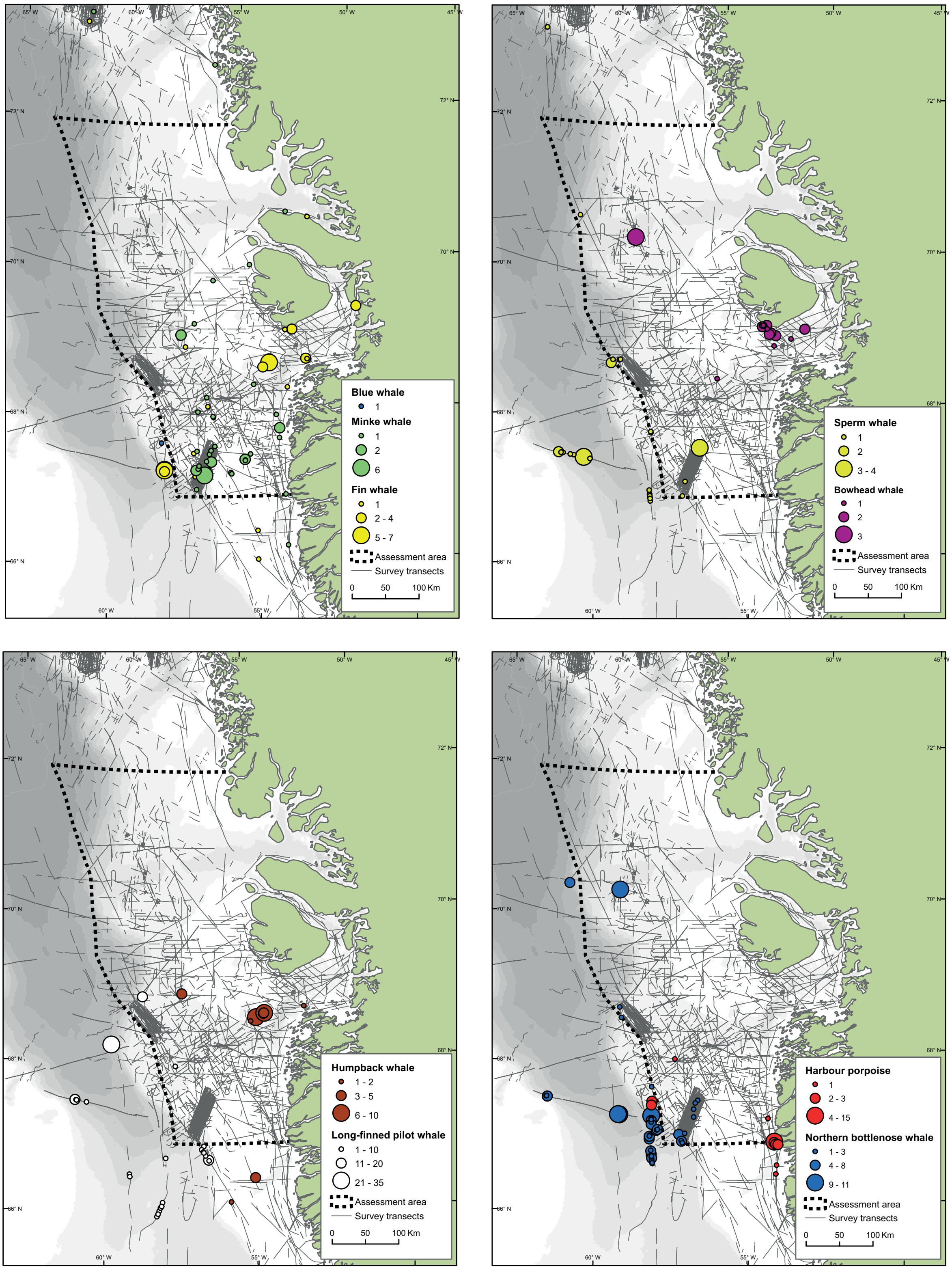


Figure 47. Sightings of different species of whales made during 34 systematic seabird and marine mammal survey from seismic vessels and biological research vessels between 1988 and 2017 (DCE Seabirds-at-Sea Database, unpublished). The spatial distribution of effort is indicated by the transect lines. The surveys were conducted between April and November, but with a major peak in August and September.

Bowhead whale (*Balaena mysticetus*)

Biology: The bowhead whale is the only baleen whale that remains year round in Arctic and Sub-Arctic waters. Four populations of bowhead, i.e. Okhotsk Sea, Bering-Chukchi-Beaufort Sea (BCB), Eastern Canada-West Greenland (ECWG) and Spitsbergen are currently recognized (Cooke & Reeves 2018).

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 years of age) relative to other mammals. Calving intervals of 3–4 years (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 been estimated to exceed 200 years by measuring aspartic acid racemization of their eye lenses (George et al. 1999).

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). Near the seabed densities of copepods are very high (Laidre et al. 2007). Given the ability 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. 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. in press a). 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).

Bowhead whales prefer waters colder than 2 °C, so they leave West Greenland when temperatures begin to increase in June, even though this means they miss the peak on abundance of *Calanus* prey at the surface (Chambault et al. 2018).

Distribution and abundance: Satellite tracking studies in Canada and Greenland (Box 7) show 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 – the ECWG population (Heide-Jørgensen et al. 2006).

The bowhead whales belonging to this population spend most of the year in the Canadian high Arctic around Baffin Island (Heide-Jørgensen et al. 2010f). 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. 2006, Laidre et al. 2007, Heide-Jørgensen et al. 2010f). Besides feeding the whales may use the area as a mating ground (Heide-Jørgensen et al. 2010f).

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.

Box 7. Movements and space-use patterns of bowhead whales in the Baffin Bay, 2009 and 2010

Mads.Peter Heide-Jørgensen (GINR) & Kristin Laidre (GINR)

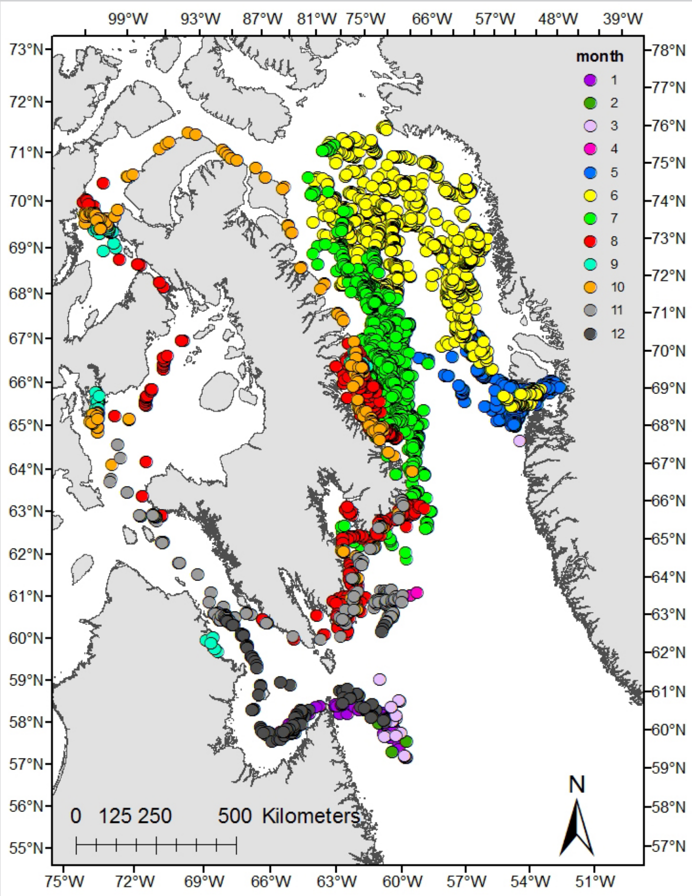
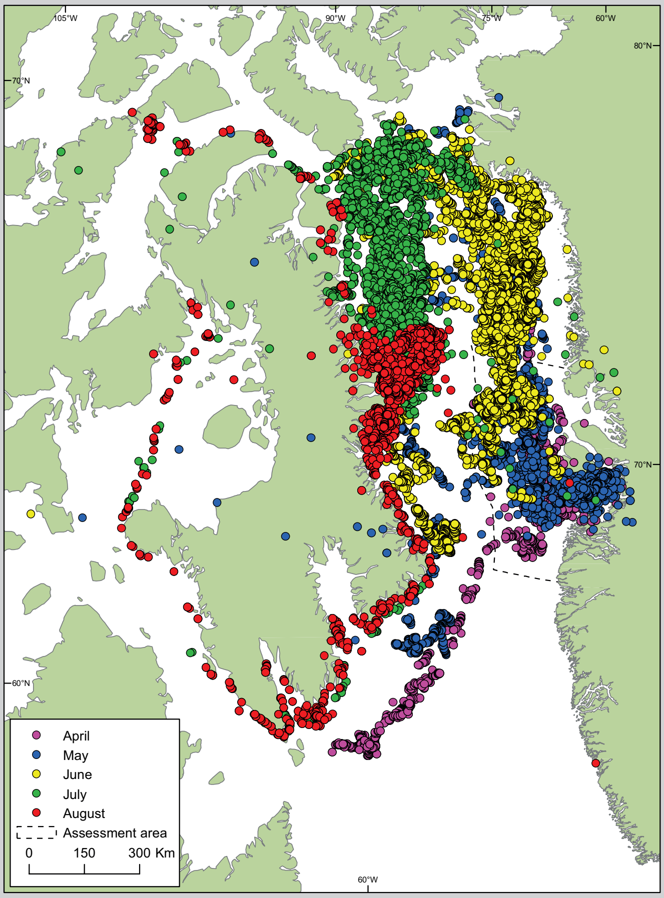


Figure 1. Locations of all bowhead whales tagged in 2009 in Disko Bay and tracked through December 2009 (n = 28).



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 (Figure 1, 2, 3, 4 5) and seven tags are still transmitting at the time of the completion of this report.

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

Winter: January – March

Two tags deployed on 27 April and one deployed on 17 May 2009 in Disko Bay provided positions in January-March 2010 and they were all located at the northern Labrador Coast at the entrance to Hudson Strait in January at a time when bowhead whales are not regularly seen in Disko Bay. In March-April two of the whales made a move towards Disko Bay where they were located in April in the very same areas where bowhead whales were located and tagged in 2010. The tracks of the two whales from Northern Labrador to Disko Bay in winter are the first actual demonstrations of the return migration of bowhead whales to West Greenland from the summer and 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).

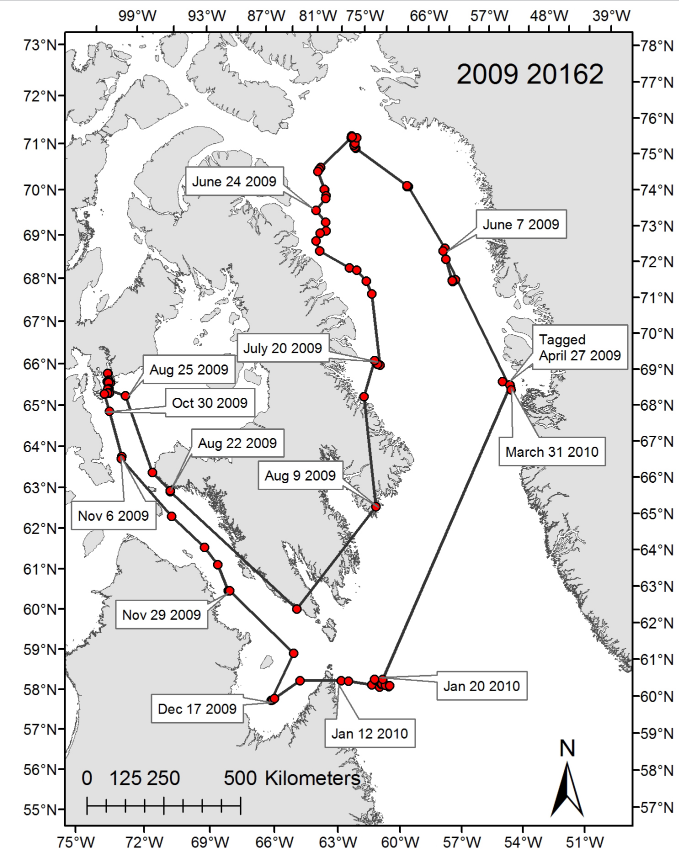


Figure 3. Track of a female bowhead whale (Id. no. 20162) tagged on 27 April 2009 in Disko Bay and tracked through March 2010.

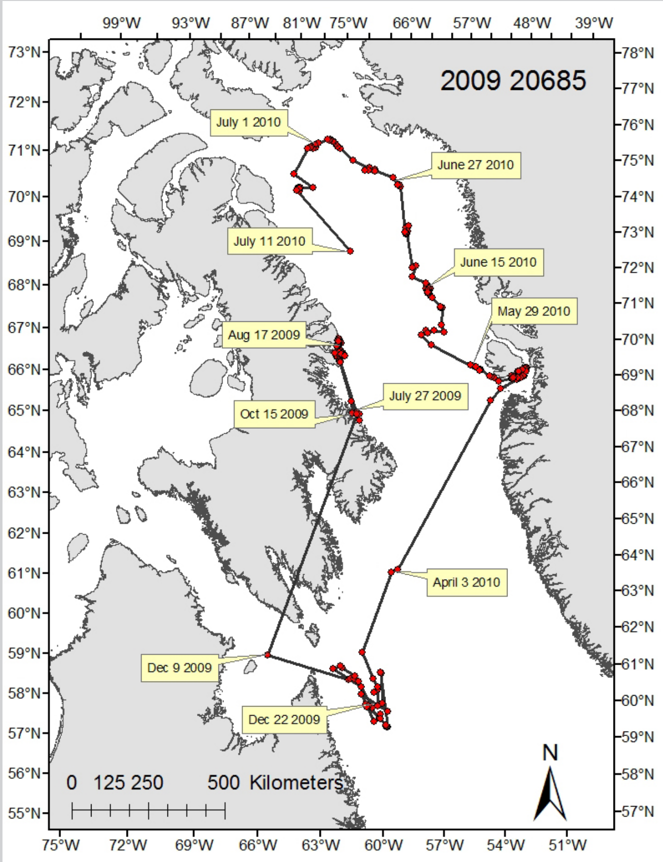


Figure 4. Track of a female bowhead whale (Id. no. 20167) tagged 17 May 2009 in Disko Bay and tracked through 11 July 2010.

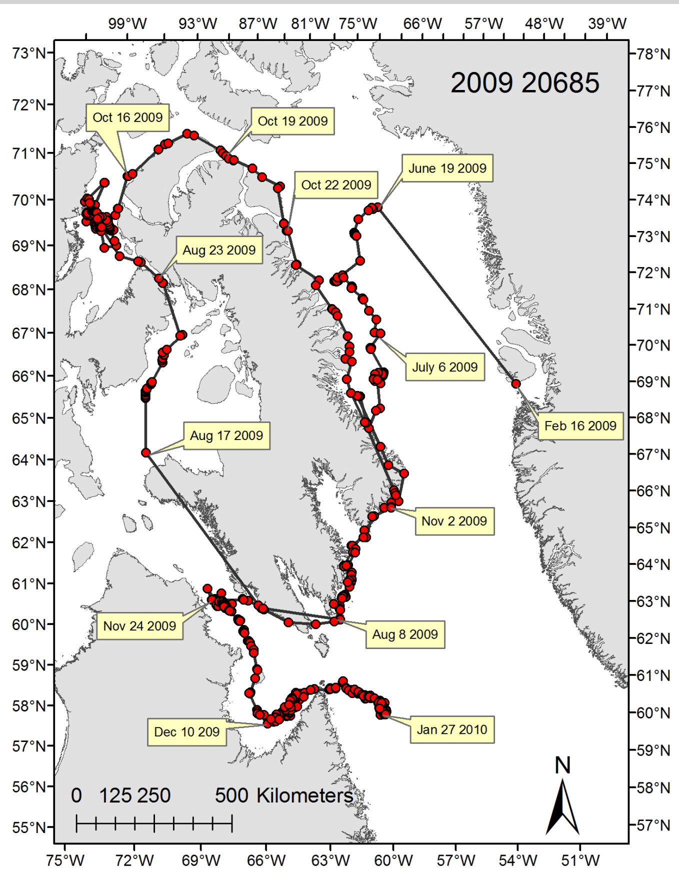


Figure 5. Track of a bowhead whale (sex unknown, Id. no 20685) tagged 27 April 2009 in Disko Bay and tracked through 27 January 2010.

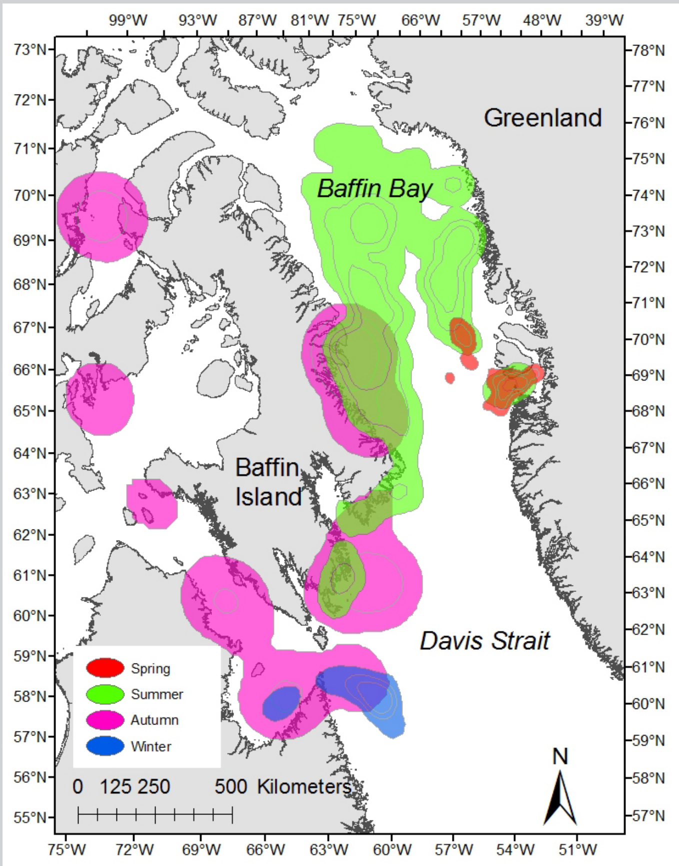


Figure 6. Seasonal home range distributions (calculated by the kernel method) of bowhead whales from 2009 (n = 28).

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

Summer: June – August

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

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

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

The summer home range demonstrated the vast area over which the bowhead whales range during these months (Figure 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 (Figure 6).

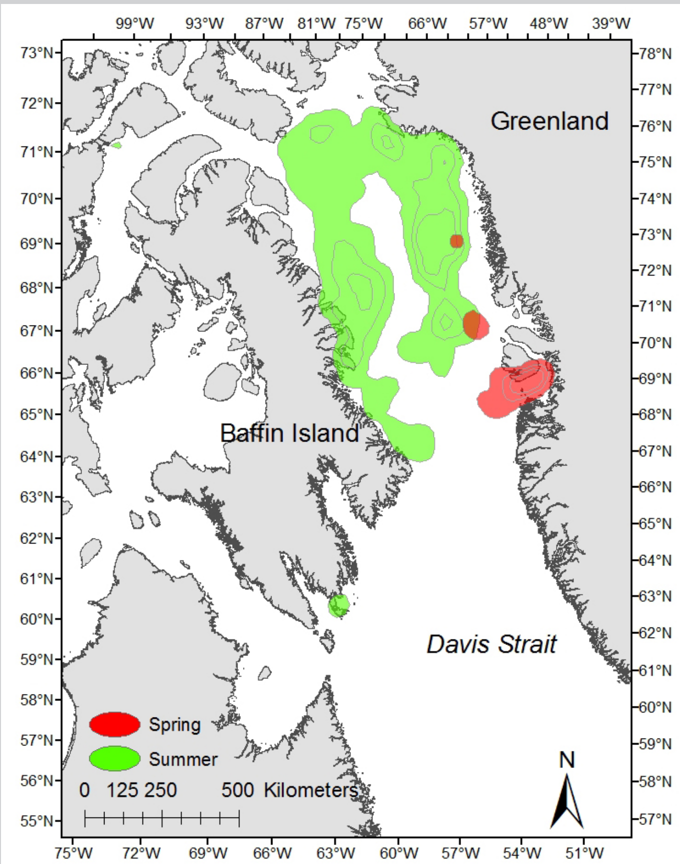


Figure 7. Seasonal home range distributions (calculated by the kernel method) of bowhead whales from 2010 (n = 50).

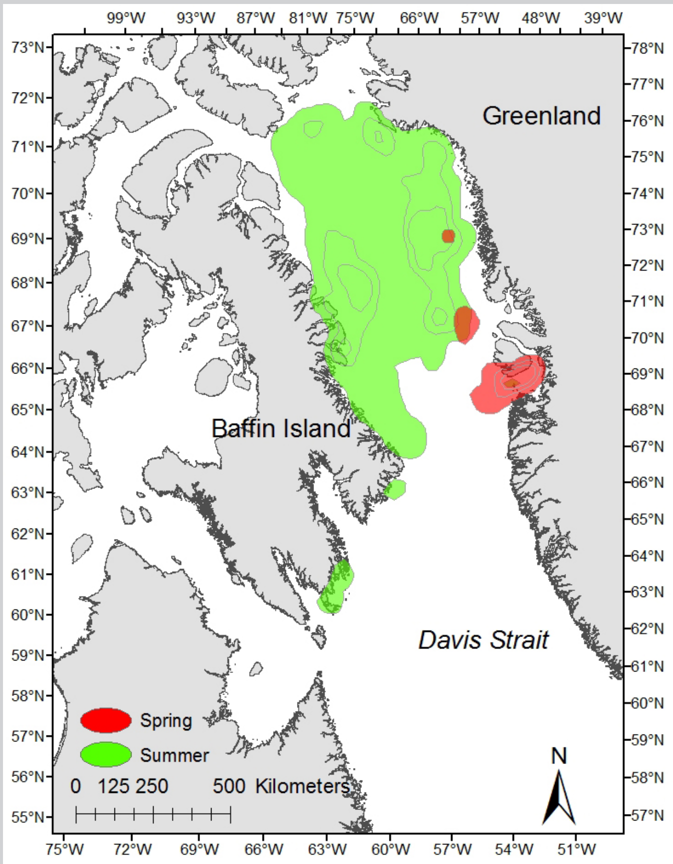
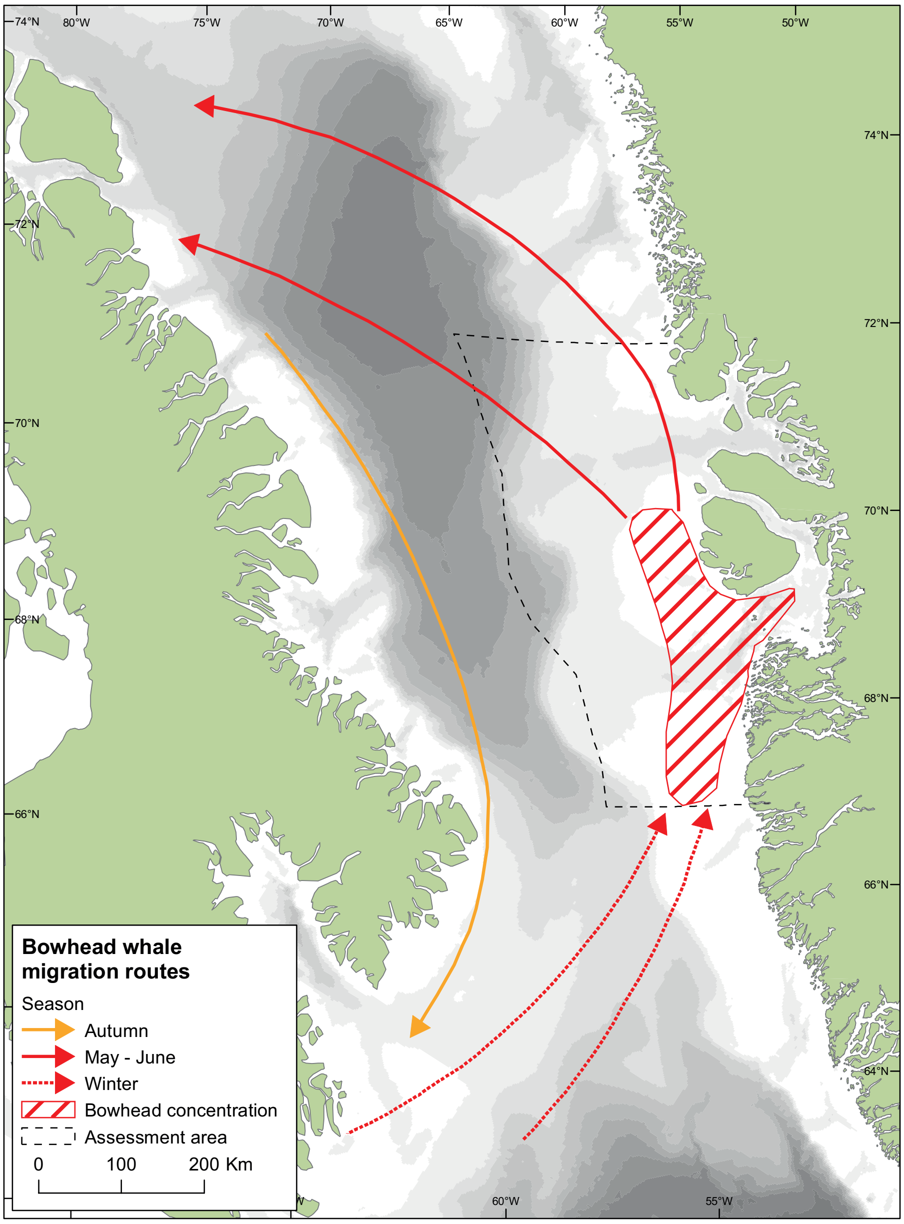


Figure 8. Combined spring and summer home ranges (calculated by the kernel method) for bowhead whales tracked in 2009 and 2010 (n = 78).

Figure 48. 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).



There is evidence for considerable age and sex segregation between Hudson Bay-Foxe Basin and West Greenland. 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. 2010a). Genetic sex determinations of 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 (Palsbøll et al. 1997), and length estimates suggest all were mature exceeding 12–14 m of body length (Heide-Jørgensen et al. 2010a). Very few calves have been seen in West Greenland, thus the large proportion of females must be either pregnant, resting or in oestrous (post-lactating). Acoustic studies in Disko Bay suggest that the bay is also a mating ground, as there is intense singing activity, usually associated with mating (Stafford et al. 2008, Tervo et al. 2009). Mating is believed to occur in March and April (Reese et al. 2001).

Today bowheads are primarily winter and spring visitors off West Greenland, found along the coast between Sisimiut and Qaanaaq (Box 7 and Figure 48). The core area for bowhead whales is the Disko Bay and offshore waters in Baffin Bay north of Disko Island. It is anticipated that the historical range of bowhead whales may at some point be re-inhabited with the increasing abundance.

The first bowhead whales appear in Disko Bay in February 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 late May (Laidre & Heide-Jørgensen 2012). The predominant migration route is taken in a northwest direction across the Baffin Bay, probably through leads and cracks in the pack ice (Heide-Jørgensen et al. 2003a, Heide-Jørgensen et al. 2006). This likely requires that whales move north along the West Greenland coast until they find a lead that intersect Baffin Bay running towards northwest, facilitating open water availability during the relatively short time span the whales use to cross the bay (Box 7).

Based on a variety of data collected until 2012, including DNA fingerprinting from biopsy samples and aerial surveys, Rekdal et al. (2014) estimated that around 1538 bowhead whales winter in West Greenland (95% CI: 827–2249) and Frasier et al. (2015) estimated the abundance at 2854 (95% CI: 1230–6460). These whales constitute a part of the total population moving through the Baffin Bay to the Canadian summer grounds, where the population was estimated at 11,747 bowhead whales (95% CI: 8169–20,043), based on genetic mark recapture analyses from biopsies obtained in 2013 and before (Frasier et al. 2020).

Conservation status: Bowhead whales in West Greenland are listed as 'Near Threatened' (NT) on the Greenland red list (Boertmann & Bay 2018) 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) (Cooke & Reeves 2018, IUCN 2010).

Critical and important areas: The assessment area is extensively used by bowhead whales, e.g. as feeding and mating ground (Figure 48). 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. in press a). 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.

Minke whale (*Balaenoptera acutorostrata*)

Biology: 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 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 sandeel (Larsen & Kapel 1981).

Distribution and abundance: 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 have recently been reported as far north as Siorapaluk in the Qaanaaq area, a range extension most likely as an effect of climate change.

For management purposes, the International Whaling Commission (IWC) recognizes four different minke whale management stocks in the North Atlantic (Figure 49). These management regions were established based on studies of catch statistics, biological characteristics and tagging. Molecular studies tend to confirm the established subdivisions (Andersen et al. 2003, Born et al. 2007).

The available data indicate an excess of female minke whales in West Greenland (Laidre et al. 2009). This indicates that only a portion of the population 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, the most recent in 2015 (Hansen et al. 2019). 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.

Figure 49. Minke whale management stocks in the North Atlantic. In the assessment area only one stock occurs (West Greenland stock).

The large fluctuations in abundance of minke whales in West Greenland are evident when comparing results from surveys in 2007 and 2015. In 2007, there were around 16,609 minke whales in West Greenland (95 % CI 7,172-38,461; Heide-Jørgensen et al. 2010e). The estimate from 2015 was only 5,095 (95% CI: 2171–11,961, Hansen et al. 2019b). A fluctuation of such magnitude can only be explained if a large part of the population was elsewhere in the North Atlantic during the 2015 survey.

Conservation status: The population occurring in the assessment area has a favourable conservation status. Both the global red list (Cooke 2018a) and the Greenland red list (Boertmann & Bay 2018) 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. 2010a) 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*)
Biology: 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.

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 and abundance: 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 occur regularly in the assessment area (Figure 47), but exact numbers are not known, and they seem to be observed more frequently in recent years (GINR, unpublished observations). Acoustic data indicates that blue whales frequently use the Davis Strait area, including the area immediately south of the assessment area (Simon 2010).

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.

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: Blue whales have been protected since 1966. As is the case with other baleen whales that were heavily hunted during last century, blue whales in the North Atlantic may be increasing in numbers (Cooke 2018c, Pike et al. 2019) The number of blue whales in the Western North Atlantic (including West Greenland) is unknown. In the Central and Eastern North Atlantic, there were estimated 3,000 blue whales (95% CI: 1377–6,534), based in surveys from 2015 (Pike et al. 2019). Blue whales are listed as 'Vulnerable' (VU) on the Greenland red list (Boertmann & Bay 2018). On the global red list, blue whales are classified as 'Endangered' (EN) (Cooke 2018c) because of the depleted populations on the southern hemisphere.

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. An increase in recent observations suggest that Disko Bay may be an important area for blue whales during summer.

Fin whale (*Balaenoptera physalus*)
Biology: 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 catch statistics (Simon et al. 2007b) 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 and abundance: Fin whales are found worldwide from temperate to polar waters but are less common in the tropics. Fin whales are common and numerous during summer in the Disko West assessment area (Figure 47).

The population of fin whales is probably increasing. However, as with minke whales, there seem to be large annual fluctuations in the numbers of fin whales migrating to West Greenland during summer. This is illustrated by results from aerial surveys in September 2007 and 2015. The abundance estimate for 2007 was 4468 (95% CI: 1343–14,871) fin whales (Heide-Jørgensen et al. 2010d). For the 2015 survey, the estimate was 2215 (95% CI: 1107–4823, Hansen et al. 2019b). The actual number of fin whales in West Greenland must be larger because the surveys did not cover the northernmost parts of the fin whale's range.

Conservation status: Fin whales are categorised as 'Vulnerable' (VU) on the global red list (Cooke 2018d). 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 (Boertmann & Bay 2018).

Critical and important areas: Fin whales use Disko Bay extensively. 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*)

Biology: 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 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). 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 (Payne & Payne 1985, Cerchio et al. 2001). Peak frequencies tend to be around 315 Hz and 630 Hz (Parsons et al. 2008), (Figure 46).

The main prey items of humpback whales in West Greenland are probably capelin, which is abundant in coastal and fjord waters; sandeel, 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.

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 2007b). 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).

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 50): Gulf of Maine, eastern Canada, West Greenland and the eastern North Atlantic (Stevick et al. 2006). Several individual humpback whales have been identified at summer feeding grounds off West Greenland and winter breeding grounds off the Dominican Republic.

Distribution and abundance: Humpback whales are common and numerous in the Disko West assessment area (Figure 47), and they 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).

The abundance estimate of the West Greenlandic humpback whale was 3272 (95% CI: 1300–8233) 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. As observed with minke whales and fin whales, the numbers of humpback whales in West Greenland fluctuated widely between 2007 and 2015, when the estimate of abundance in West Greenland was only 933 (95% CI: 434–2272) humpback whales (Hansen et al. 2019).

Figure 50. Feeding aggregations of humpback whales in the North Atlantic: Gulf of Maine, Eastern Canada, West Greenland, East Greenland. Iceland and Svalbard.

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. 2012). This high rate of increase is consistent with reports from other humpback whale feeding grounds in the North Atlantic. Another indication of this rapid increase is that most of the humpback whales in West Greenland are young, less than 20 years old (Boye et al. 2020a).

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.

Conservation status: The population occurring in the assessment area has a favourable conservation status as it is abundant and increasing. During the 1900s, 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 downlisted from 'Vulnerable' (VU) to 'Least Concern' (LC) in the global red list (Cooke 2018e)). Their classification in the Greenland red list is also 'Least Concern' (LC) (Boertmann & Bay 2018).

Critical and important areas: Humpback whales use most of the assessment area and are abundant both offshore and inshore, and for example are near shore sightings from towns and settlements frequent. As for fin and minke whales, the fishing banks (especially Store Hellefiskebanke) are important areas for humpback whales during summer.

Sei whale (*Balaenoptera borealis*)

Biology: 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 undertake 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. in press, 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 and 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: 690–3705). The overall distribution of these rorquals is correlated with high densities of krill occurring deeper than 150 m (Laidre et al. 2010a).

*Conservation status***:** 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 (2008). They are also classified as 'Endangered' (EN) in the Greenland red list (Boertmann & Bay 2018).

*Critical and important areas***:** No critical areas for sei whales in the assessment area have been identified so far.

Toothed whales

Fernando Ugarte (GINR) & Nynne H. Nielsen (GINR)

Eight species of toothed whales occur in the Disko West assessment area, and of these the narwhal and the white whale are specialised inhabitants of the Arctic and occurs 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, bottlenose whale and harbour porpoise. These all 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[5] and communication. In addition, killer whales produce pulsed calls made of clicks in very rapid succession. Narwhals, white whales, white-beaked dolphins, pilot whales and killer whales produce whistle-like sounds. Pulsed calls serve several purposes, including long-range communication and transmission of information about kinship and group cohesion. Whistles are important during short-range social contacts and may include information about the identity of the whistler. Fig-

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

ure 46 shows the frequency ranges of echolocation clicks, calls and whistles produced by toothed whales in the assessment area.

Toothed whales are sensitive to underwater noise and may be displaced by seismic shooting and other strong sound sources, this is especially the case for narwhals (Heide-Jørgensen et al. 2013). Regarding sensitivity to oil spills, there is very little information available. A remarkable observation was the increased mortality among killer whales after the *Exxon Valdez* incident (Matkin et al. 2008), and it is very likely that this effect will apply to other toothed whales if they are exposed to oil on the water surface. See further on sensitivity in Chapter 6.

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

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

Distribution and abundance: The pilot whale occurs in temperate and sub-polar zones of the North Atlantic including West Greenland (e.g. Jefferson et al. 2008). Greenlandic catch statistics (APNN, unpublished data) show that pilot whales occasionally occur as far north as Upernavik in the in late summer or early autumn.

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 by an aerial survey in 2015 to be 9190 (95 % CI: 3635–23,234) (Hansen et al. 2018). The survey covered only the area between the coast and the shelf break, and not the whole range of pilot whales in West Greenland thus it must be considered a minimum estimate. Pilot whales have also been observed during seismic surveys and other research cruises performed between 1988 and 2017 (Figure 47).

Conservation status: Long-finned pilot whale is listed as of 'Least Concern' (LC) according to both the IUCN global red list (Minton et al. 2018) and the Greenland red list (Boertmann & Bay 2018).

Critical and important areas: Numerous observations have been documented from the south-western part of the assessment area (Hansen 2010a), but no especially important or critically areas are known.

White-beaked dolphin (*Lagenorhynchus albirostris*)
Biology: The species has been very little studied in Greenland 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.

The preferred habitat of white-beaked dolphins in western Greenland consists of both deep water over steep slope areas and more shallower areas closer to land (Hansen 2010a).

Distribution and abundance: 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 2009). However, unpublished and unverified catch statistics may indicate that white-beaked dolphins occur as far north as Upernavik, north of the assessment area. However, during the latest survey in 2015, there were observations of white-beaked dolphins just south of the assessment area, but none inside the area.

Abundance of white-beaked dolphins on the banks of West Greenland was estimated in 2015 to be 15,264 (95 % CI: 7048–33,046) (Hansen 2018). The surveys only covered part of the range of white-beaked dolphins in West Greenland and the estimate must be considered a minimum.

Conservation status: White-beaked dolphin is listed as of 'Least Concern' (LC) according to both the IUCN global red list and the Greenland red list (Boertmann & Bay 2018, Kiszka & Braulik 2018).

Critical and important areas: None is known in the assessment area.

Killer whale (*Orcinus orca*)

Biology: Killer whales are top predators that occur in all oceans, but tend to concentrate in colder regions with high productivity. They feed on prey 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.

Killer whales are typically found in groups of 3–30 animals, but they can be as large as 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 whales produce calls and whistle-like sounds for communication and clicks for echolocation (Simon et al. 2007a). Calls serve several purposes and group-specific call repertoires play a fundamental role in the social organisation and mating system of killer whales (Barrett-Lennard 2000). Whistles are important during short-range social contact (Thomsen et al. 2002).

Distribution and abundance: Killer whales are not common in the assessment area but are occasionally observed. 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 around Qaanaaq, Disko, Nuuk and Qaqortoq. From aerial surveys in summer in West Greenland (1988, 1989, 1992, 2007 and 2015) there has only been observed killer whales in 2015 in South Greenland, underlining the scarcity of this species in West Greenland.

Conservation status: Due to the scarce knowledge in Greenland, killer whales are listed as 'Data Deficient' (DD) on both the IUCN global red list (Reeves et al. 2017) and on the Greenland red list (Boertmann & Bay 2018).

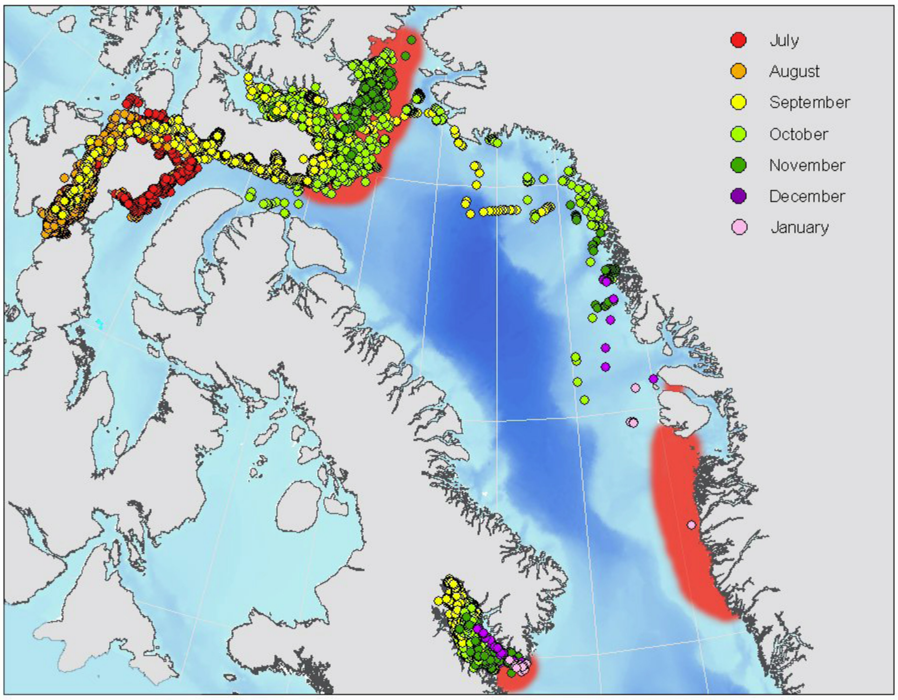


Figure 51. Positions of satellite-tracked white whales distributed according to month. Red areas indicate the winter grounds. Only two whales have been tracked in Greenland waters (GINR unpublished).

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*)

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

White whale migration between summering grounds in Canada and wintering grounds in West Greenland have been documented two whales equipped with satellite transmitters (Figure 51) (Heide-Jørgensen et al. 2003b).

White whales are expected to acquire the major part of their annual food intake in their winter quarters in West Greenland and in the North Water.

Distribution and abundance: White whales can be found along the whole northwest coast of Greenland during migration between winter and summer grounds, and an important wintering ground is located in the Disko West assessment area (Figure 52). As sea-ice is reducing in West Greenland, it seem as the whales stay further from the coast than previously (Heide-Jørgensen et al. 2010b).

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

Aerial surveys flown in West Greenland between 1981 and 1994 document that the numbers of white whale decreased by 62 % during that period and 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 (Heide-Jørgensen & Acquarone 2002).

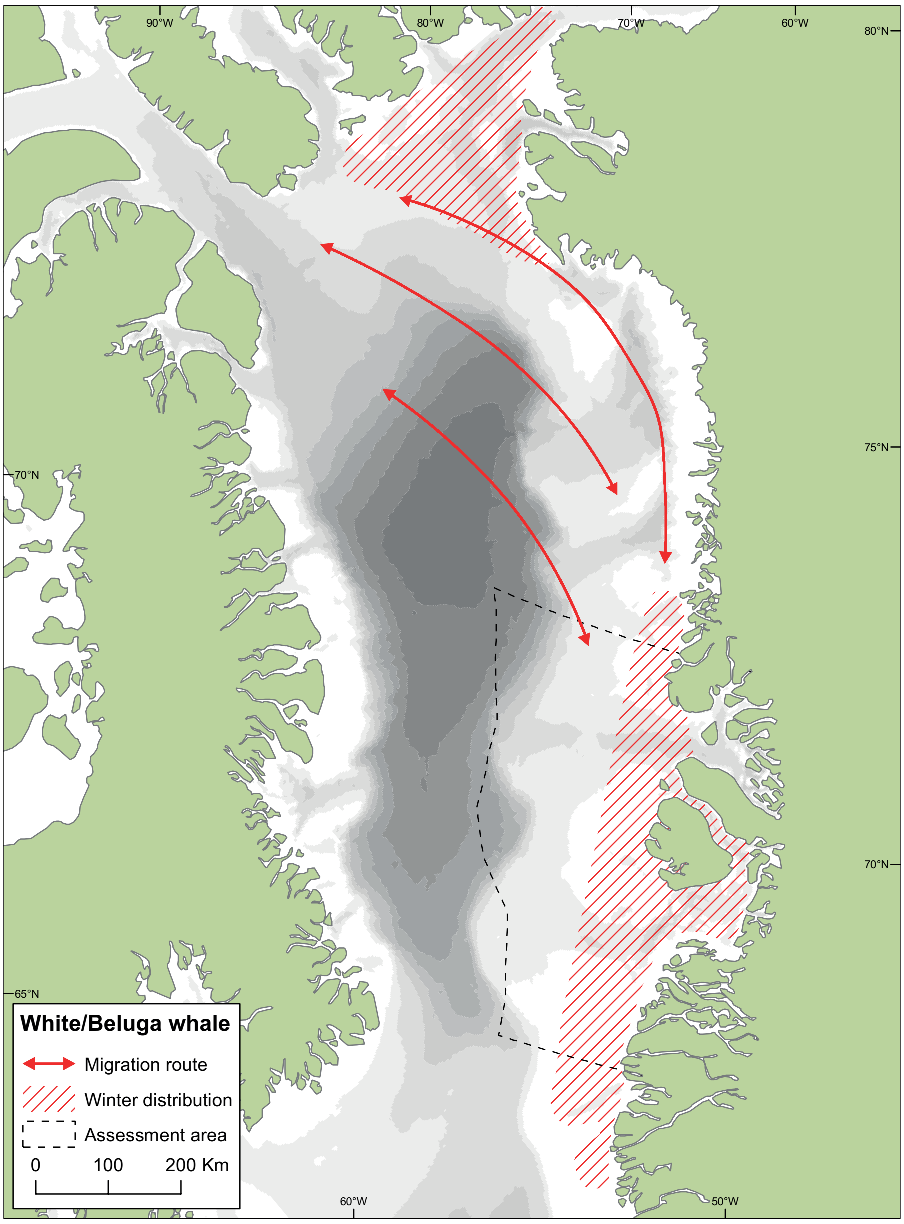


Figure 52. Map showing the known wintering grounds and migration routes of white whales in West Greenland and the Disko West assessment area.

In 2012, the total abundance of white whales in West Greenland was estimated to be 9,072 (95 % CI: 4895–16,815) white whales. The greatest abundance of white whales in 2012 was found in the areas south of Disko Bay at the northern part of Store Hellefiskebanke, a pattern similar to that found in previous surveys of white whales conducted since 1981. The whales were mainly observed at the eastern edge of the West Ice that covers Baffin Bay and Davis Strait. The survey from 2012 suggested that the population is increasing after a period with significantly reduced catches (NAMMCO 2015, Heide-Jørgensen et al. 2016).

Conservation status: The abundance of white whales has increased due to reduction of catches in compliance of catch quotas (Heide-Jørgensen et al. 2016). Because of the population recovery, white whales in West Greenland have recently been downlisted from "Critically Endangered' (CR) to 'Vulnerable (VU)' on the Greenland red list (Boertmann & Bay 2018). On a global scale, the white whale is listed as of 'Least Concern' (LC) (Lowry et al. 2017).

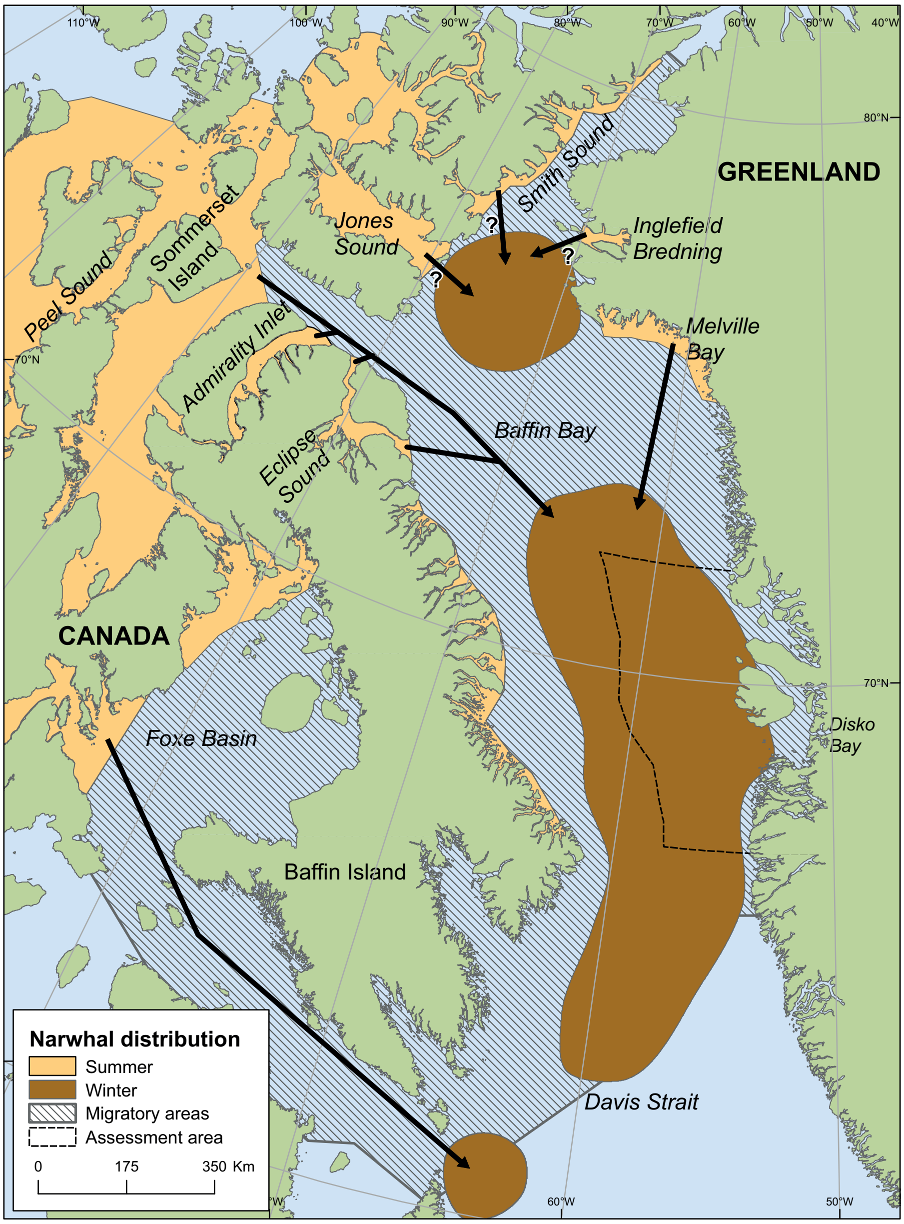
Critical and important areas: The northern part of Store Hellefiskebanke has proved to be a very important winter habitat for white whales.

Narwhal (*Monodon monoceros*)

Biology: 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. 2003c). In the summer months, narwhals stay in inshore bays and fjords in the Canadian Arctic Archipelago and Greenland (Figure 53). 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. 2003c, Dietz et al. 2008).

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* shrimps 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) long and had a weight of 430 g (sd = 275) and *Gonatus* prey weighted on average 35.6 g (sd = 31.1) and had a mean mantle lengths of 95.1 mm (sd = 36.2).

Figure 53. Distribution of narwhal in the Baffin Bay area, with indication of different stocks and their summering and wintering areas.



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 Greenland halibut 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 (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.

Distribution and abundance: Figure 54 shows the global distribution range of narwhals.

Narwhals leave their summering grounds at about the same time each year and they follow similar routes during their autumn migration. Narwhals also use the same general areas for wintering, and they are 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.

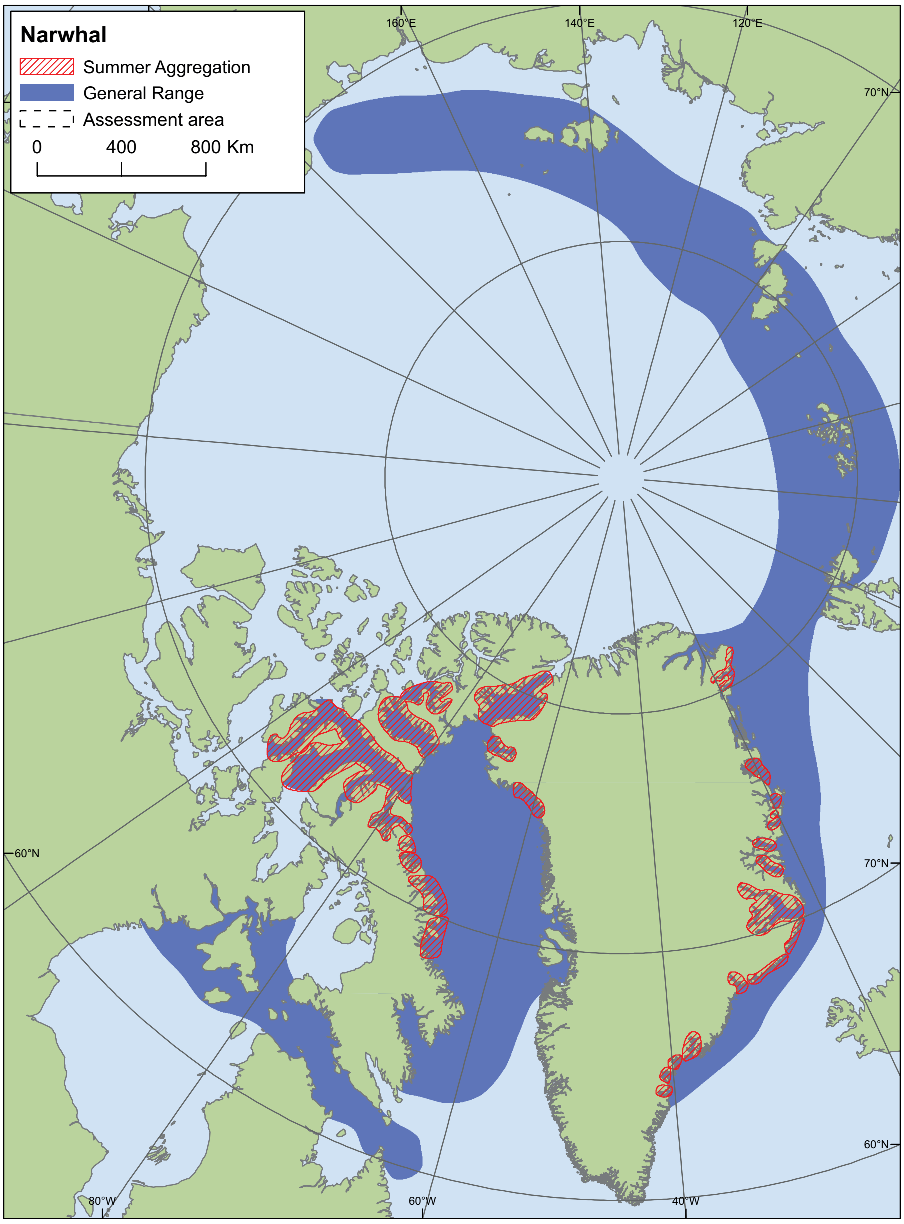


Figure 54. The total range of narwhal.

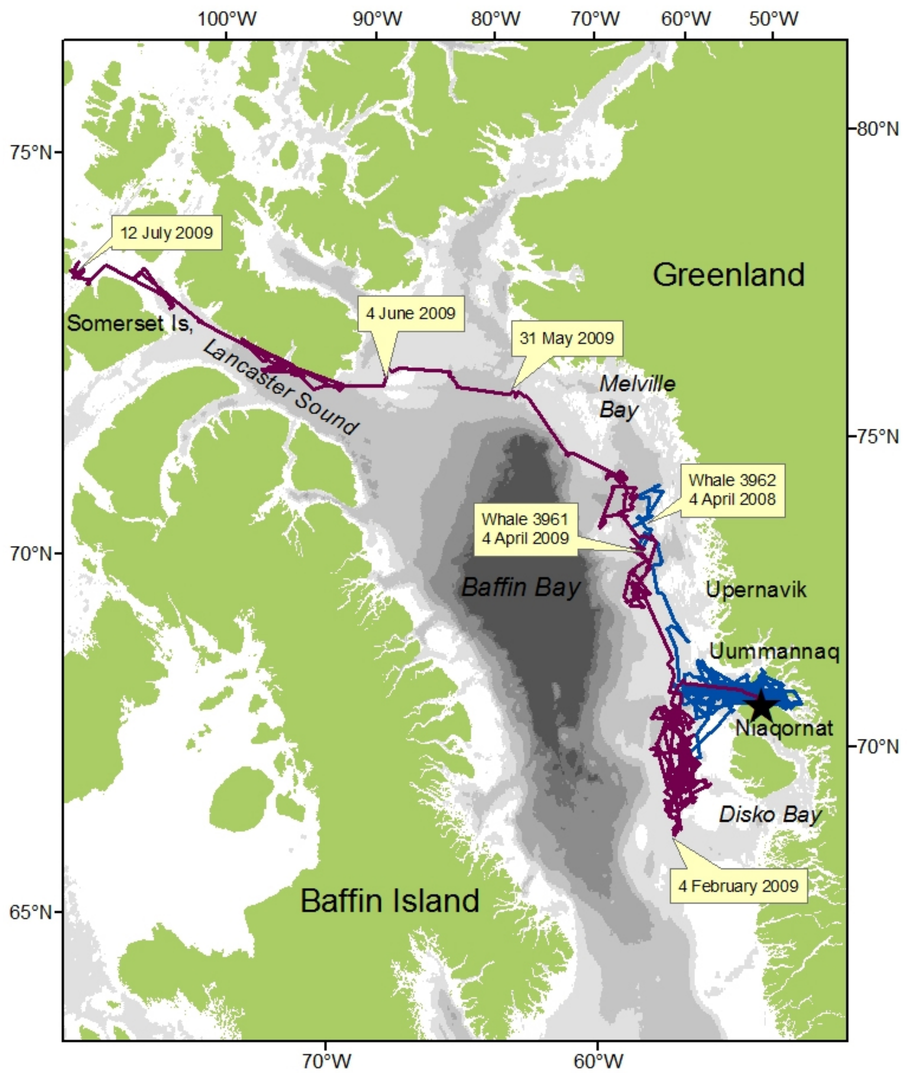


Figure 55. Tracks of two narwhals tagged in Uummannaq in 2007.

During winter months, narwhals are widely dispersed in Baffin Bay and Davis Strait with high concentrations between 68° and 71° N and 55° and 64° W and off Disko Bay (Heide-Jørgensen et al. 1993, Koski & Davis 1994, Dietz et al. 2001, Heide-Jørgensen & Acquarone 2002, Dietz et al. 2008, Laidre & Heide-Jørgensen 2011). During spring, concentrations of narwhals are seen along ice edges on the east coast of Baffin Island, at the entrances of Lancaster and Jones Sound, and in Smith Sound (e.g. Bradstreet 1982, Koski & Davis 1994). Narwhals are also known to move along the ice edges off West Greenland and to concentrate in the North Water Polynya in spring before entering Inglefield Inlet (Born et al. 1994a, Heide-Jørgensen 2004, GINR unpubl. data). An important winter (late November through March) concentration area 'the Northern Wintering Ground' is located at the northern and western parts of the Disko West assessment area (Figure 53).

Narwhals stocks or management units 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. 2003c, Dietz et al. 2008). Judging from the satellite tracking data, the three summer stocks in the Canadian high Arctic: Eclipse Sound (including Pond Inlet and Navy Board Inlet with adjacent fjords), Admiralty Inlet and Somerset Island (including Prince Regent Inlet and Peel Sound) have limited exchange during summer (Figure 53). Other Canadian summer aggregations exist along the east coast of Baffin Island and their stock identity is unknown. Jones Sound and Smith Sound also have smaller aggregations that likely constitute separate stocks.

In November, an aggregation occurs in Uummannaq, West Greenland. This is not a wintering ground because the whales are forced to leave the fjord in late 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 (Figure 55); a more detailed account is presented below.

The winter aggregation in Disko Bay is visited by whales from both Melville Bay, Tremblay Sound and Admiralty Inlet (Figures 56, 57), Richard et al. 2010). Disko Bay apparently is a mixing ground for narwhals from several summering stocks.

Abundance of narwhals along the West Greenland coast was assessed from an aerial survey conducted in March–April 2012 and the resulting estimate was 18,583 (95 % CI: 7308–47,254) narwhals for the surveyed area (NAMMCO 2015).

Abundance of narwhals at the summering grounds in Inglefield Inlet and Melville Bay was estimated in 2007 and were 8368 (95 % CI: 5209–13,442) and 6024 (95 % CI: 1403–25,860) respectively (Heide-Jørgensen et al. 2010c).

Data on migrations are available from satellite tracking of 85 individual narwhals from five different coastal localities in Arctic Canada (n = 3) and West

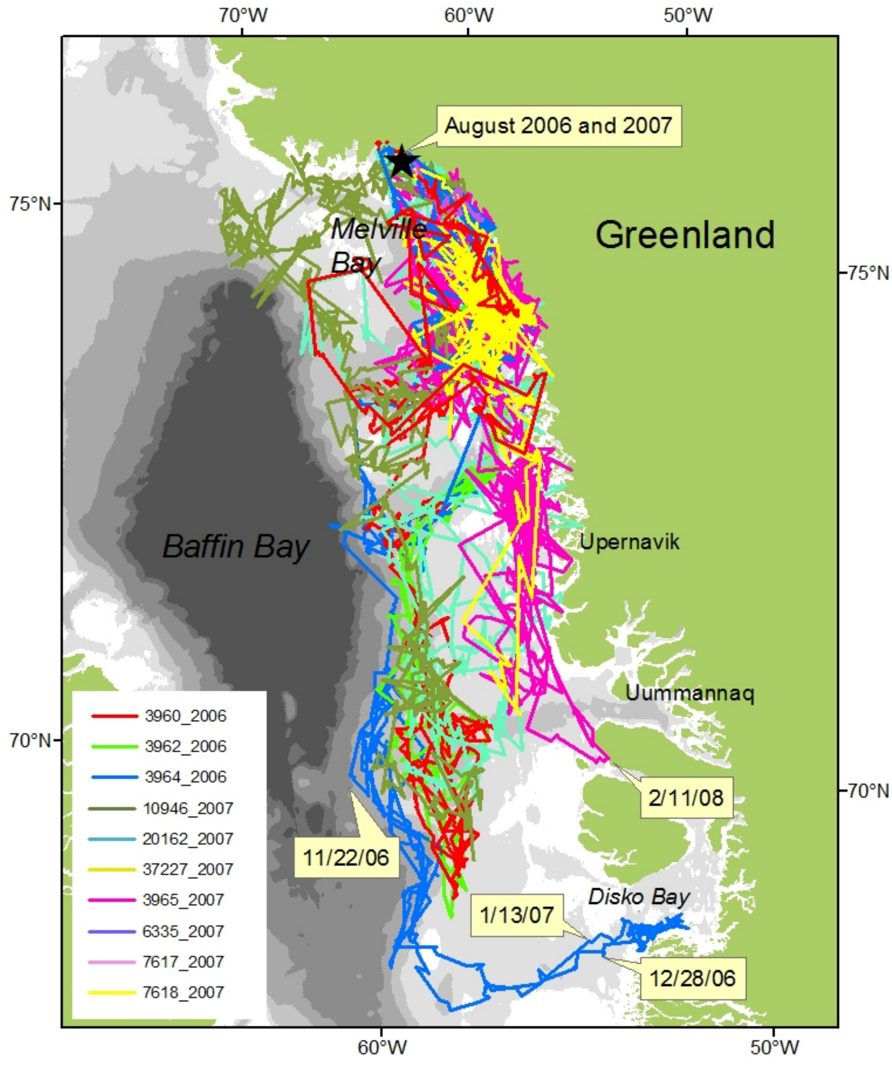


Figure 56. Tracks of 10 narwhals tagged in Melville Bay in 2006 and 2007.

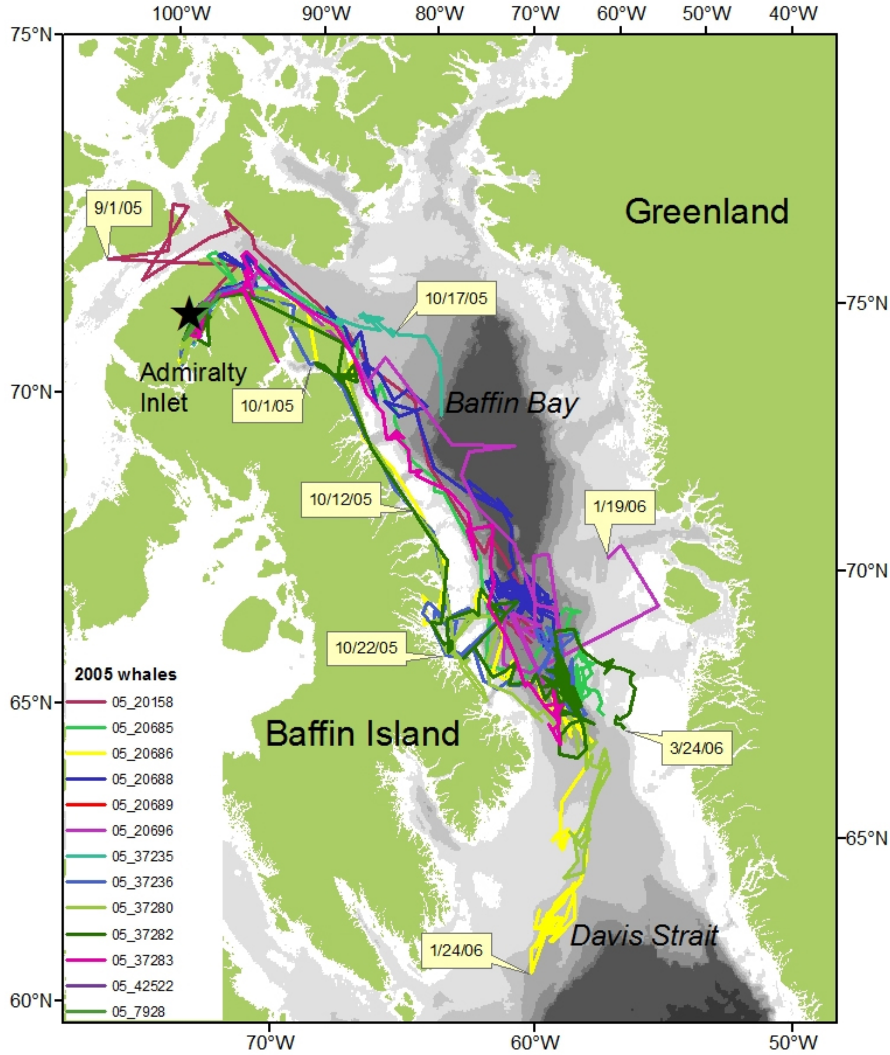


Figure 57. Tracks of 13 narwhals tagged in Admiralty Inlet in 2005.

Greenland (n = 2). Published results from tagging before 2005 are summarized in Figure 58 whereas recent tracking results from 2005–2008 are presented in the Figures 55, 56, 57).

Critical and important areas: The narwhals depend on the assessment area for winter feeding, and this is the most important period and area for their annual food consumption. The Baffin Bay is moreover where the world's largest abundance of narwhals is found. These facts makes the assessment area extremely important for narwhal stocks from Canada and Northwest Greenland. 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 so far known most important wintering areas within the assessment area are the southern and the northern offshore wintering grounds, Uummannaq Fjord (mainly in November) and the outer Disko Bay (Figure 53).

Conservation status: Narwhals in West Greenland are considered as 'Near Threatened' on the Greenland red list (Boertmann & Bay 2018) and on the IUCN global red list, narwhals are abundant and are placed in the category 'Least Concern' (Lowry et al. 2017).

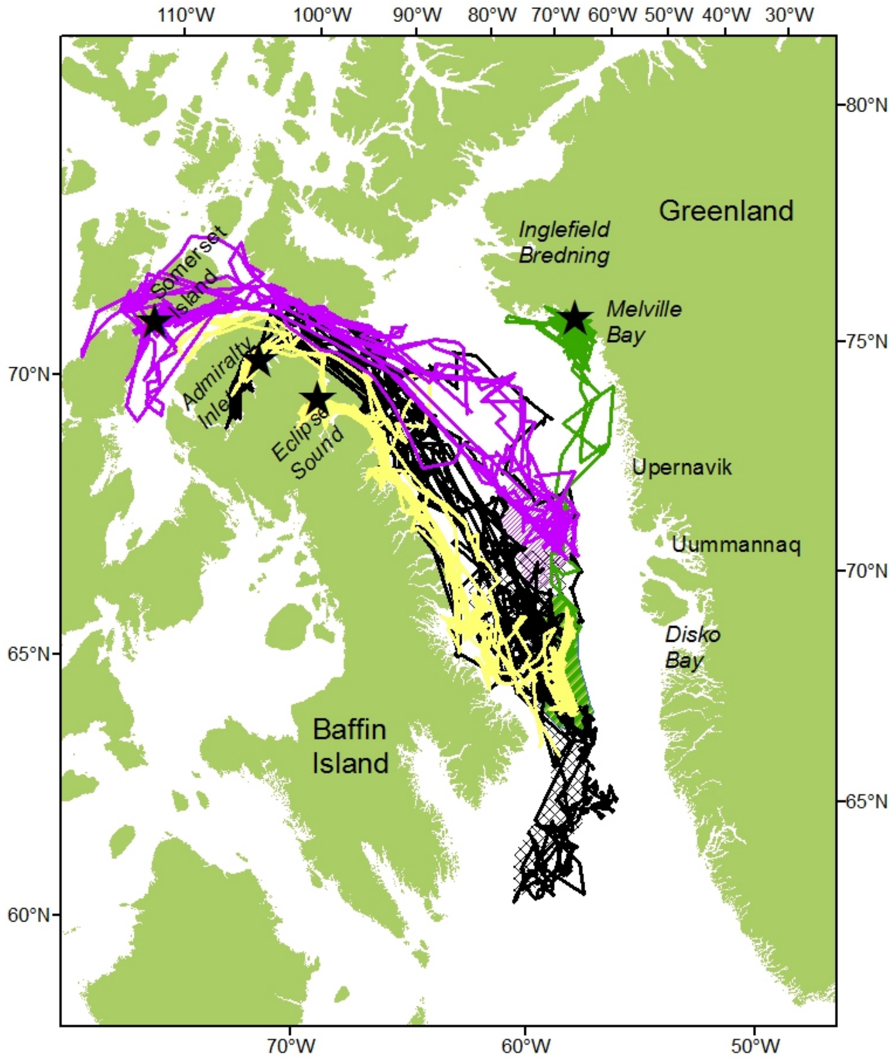


Figure 58. Tracks of narwhals from Canada and Greenland tagged before 2005 (n = 60). Asterisks indicate tagging sites. Each whale is indicated by a different colour.

Sperm whale (*Physeter macrocephalus*)
Biology: The sperm whale is the largest toothed whale as males attain a length of 18 m (average 15 m) and a weight of 50 t (average 45 t), while females are significantly smaller; on average 11 m and 20 t. 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 (Best 1979, Mendes et al. 2007). The larger males, in their late twenties or older migrate to lower latitudes in search of mating opportunities (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 were feeding 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 and abundance: Berzin (1971) reviewed captures of sperm whales in the Davis Strait as far back as 1812, including 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 several times in the assessment area between 1988 and 2017 (Figure 47) and in the winter of 2010 six sperm whales were found dead in 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 status: 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. Sperm whales are categorised as 'Vulnerable' (VU) on both the IUCN global red list and on the Greenland red list (Boertmann & Bay 2018, Taylor et al. 2019).

Critical and important habitats: As sperm 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.

Northern bottlenose whale (*Hyperoodon ampullatus*)
Biology: Next to the sperm whale, the northern bottlenose whale is the largest toothed whale in the North Atlantic, with adult females measuring up to 9 m in length and males up to 11 m. They are found in deep waters, often seaward of the continental shelf and near submarine canyons, from the ice edges south to 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. 2001). 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 this is a general trait among northern bottlenose whales.

Distribution and abundance: 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 operating in deep waters. In the assessment area they have been sighted mainly in the deeper offshore areas (Figure 47).

Conservation status: Due to the scarce knowledge on bottlenose whales in Greenland, and the lack of data regarding the effects of anthropogenic disturbance along with depletion of stocks due to previous whaling, the species is listed as 'Data Deficient' (DD) on both the Greenland red list and the IUCN global red list (Taylor et al. 2008, Boertmann & Bay 2018).

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.

Harbour porpoises (*Phocoena phocoena*)

Biology: Harbour porpoise is the smallest cetaceans found in Greenland and reach a length of 1.7 m and a weight of up to 80 kg. Their main prey consists of several fish species and squid, and in West Greenland capelin is the predominant part of their diet (Lockyer et al. 2003, Heide-Jørgensen et al. 2011).

Distribution and abundance: The harbour porpoise is among the most abundant whale species in the North Atlantic and this is also the case in West Greenland, where it occurs from the southernmost tip to the Avanersuaq district in Northwest Greenland (Teilmann & Dietz 1998). However, the main distribution of harbour porpoise lies between Sisimiut and Paamiut (Teilmann & Dietz 1998). During summer, harbour porpoises in West Greenland mainly inhabit coastal and continental shelf areas, but they occasionally utilize the fjords (Hansen 2010b, Hansen & Heide-Jørgensen 2013, Hansen et al. 2018). This is confirmed by tracking data of 30 harbour porpoises instrumented with satellite transmitters in West Greenland (Maniitsoq) (Nielsen et al. 2018). Although ice formation forces harbour porpoises to leave the area north of approx. 66° N, catch statistics and tracking data confirm their presence year-round in West Greenland. The tracking study also showed—quite unexpected—that the harbour porpoises undertook long travels in offshore Atlantic waters (APNN, unpubl. data, Nielsen et al. 2018).

The abundance of harbour porpoises in West Greenland has been estimated to approximately 83,300 animals (Hansen 2010b, Hansen et al. 2018). It is believed that this stock is separated from neighbouring populations in Iceland and Newfoundland and genetic, behavioural and morphological evidences advocate that this population potentially constitute its own ecotype (Lemming 2019, Nielsen et al. 2018).

Conservation status: Harbour porpoises are listed as 'Least Concern' (LC) on both the Greenland red list and the global IUCN global red list (Hammond et al. 2008, Boertmann & Bay 2018).

4 Protected areas and threatened species

David Boertmann (AU) & Daniel S. Clausen (AU)

4.1 International designations

According to the Convention on Wetlands (the Ramsar Convention, Link), Greenland has designated twelve 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. This occurred in 2016, when the government issued order no. 12 of June 1, 2016 (Link). The purpose of the executive order is to ensure the conservation status for nature and wildlife within the Ramsar areas. Further one of the sites (Kitsissunguit), that is included in this assessment area, was protected with a legal basis in the Greenland Nature Protection Act (Landsting lov No 29 of December 2003) by the executive order no. 11 of April 17, 2008 (Link). Six of the twelve Greenlandic Ramsar sites are found within the assessment area (Figure 59). One of them is so far away from the outer coasts that it is not likely it could be affected by offshore oil and gas activities, whereas this could be the case for the other five ones (Egevang & Boertmann 2001). The six Ramsar sites are described here: Link 1, Link 2, Link 3, Link 4, Link 5, Link 6.

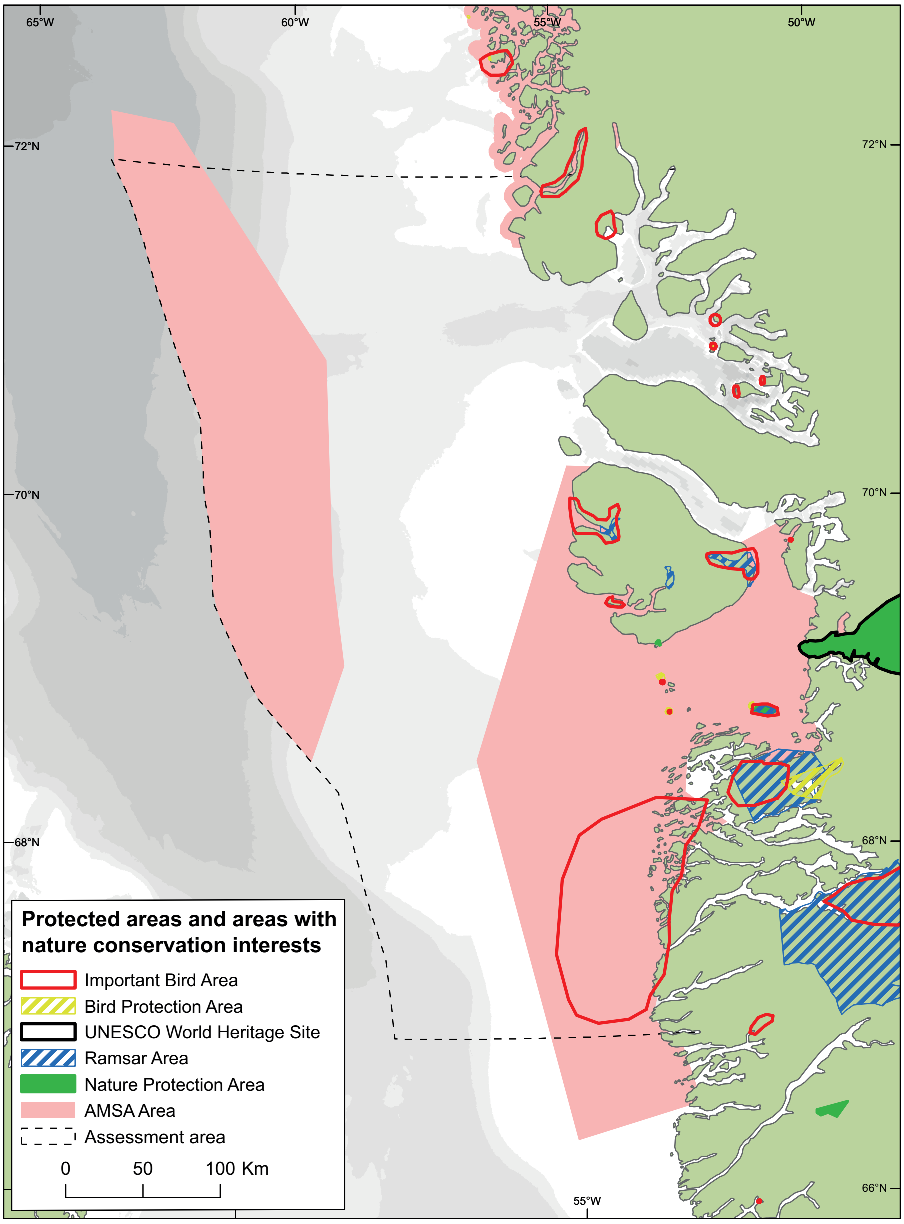


Figure 59. Areas protected according to international agreements (Ramsar areas or Word Heritage Sites) and the Greenland Nature Protection Act (Nature protection area and Bird Protection areas); areas designated as Important Bird Areas (IBAs) by BirdLife International and the areas under designation by PAME using the PSSA and EBSA criteria (AMSA, see text).

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 act. This remarkable area is situated in the inner part of Disko Bay (Figure 59).

As a follow up to the Arctic Marine Shipping Assessment (AMSA) (PAME 2009) conducted by the Arctic Council working group *Protection of The Arctic Marine Environment* (PAME), Arctic Council decided to identify areas of heightened ecological and cultural significance in the Circumpolar Arctic. It was decided to use the International Marine Organizations (IMO) criteria to identify Particular Sensitive Sea Areas (PSSA) in this work. It was also recommended to protect such areas in relation to impacts of increased shipping due to the climate changes (PAME 2009). Two areas within the assessment area are identified as fulfilling the criteria for PSSA's. 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.

The same two areas are also identified as 'ecologically valuable and sensitive marine areas' in relation to shipping activities in a national identification (Christensen et al. 2015, 2017), using the same criteria (PSSA) supplemented with the criteria for identifying 'Ecologically or Biologically Significant Areas' (EBSA) and Super EBSAs by the IUCN (Link). Among twelwe Arctic Super EBSA identified by IUCN (see link above), the Store Hellefiskebanke/Disko Bay-area was included.

IUCN and UNESCO also point on Store Hellefiskebanke and Disko Bay as of *Outstanding Universal Value (OUV) with respect to the natural criteria for World Heritage status* (Speer et al. 2017).

4.2 National nature protection legislation

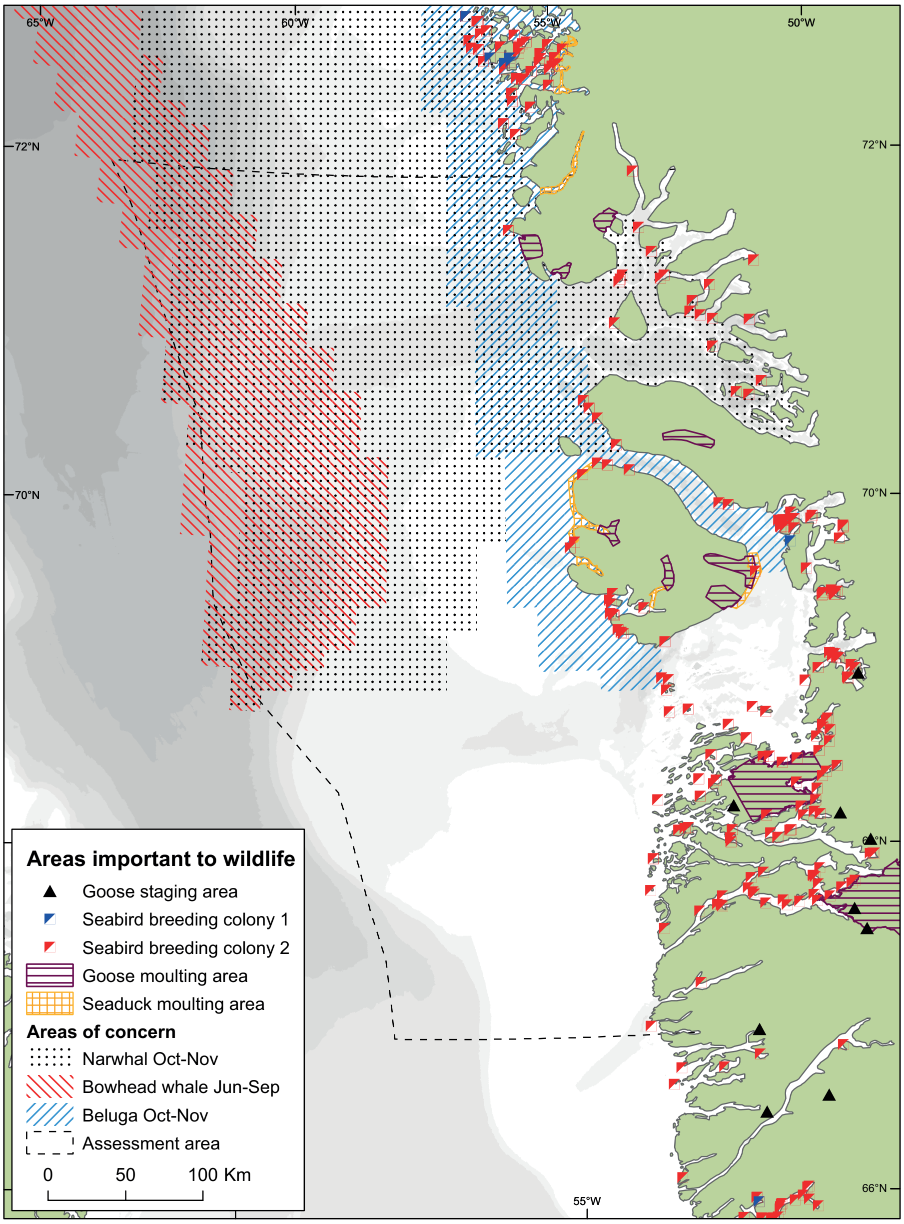
According to the Greenland Nature Protection Act several areas within the assessment area are nature reserves (Figure 59). The executive order about protection of birds also designates bird protection areas, where access is prohibited in the breeding season (Figure 59). Moreover, seabird breeding colonies are protected. In all these areas human activities are restricted and regulated in order to protect the conservation interest.

The Greenland Nature Protection Act further protects certain nature types in general, including hot springs, streams and the coastlines.

With reference to the Mineral Extraction Act, a number of 'areas important to wildlife' are designated and in these, mineral (and oil and gas) exploration activities are regulated in order to protect wildlife (Link to text, Link to maps). There are several of these areas important to wildlife within the assessment area and they also include the most important seabird breeding colonies (Figure 60). Moreover some important narwhal-areas in the assessment area have been designated as narwhal-protection areas in relation to seismic surveys (EAMRA 2015).

According to the sixth national report to the convention of Biological Diversity – CBD, (Link) Greenland has initiated a national project analysing existing biodiversity hotspots and important habitats. The project compiled a report (Christensen et al. 2016) that identifies biodiversity hotspots based on occurring species and ecosystem data. Included in this study is a thorough analysis of the distribution of species (including red listed species), nature types, and

Figure 60. Areas designated as 'important to wildlife' by Environmental Agency for Mineral Activities (EAMRA) as a part of the field rules for prospecting and exploration activities (Link). Seabird breeding colony 1 refer to colonies with a large protection zone (5 km), and seabird colony 2 with a smaller protection zone (200 m). The 'areas of concern' refer to the guidelines for seismic surveys (Link). The designated sites are under revision and will be presented on NatureMap in the future (Link).



areas with high biological diversity. Each of the identified areas is mapped in GIS where all occurring resources/species are represented by a separate layer. These layers are given rank, based on internationally accepted criteria and nationally formulated criteria (such as importance of ecosystem services etc.). Based on this a number of biological hotspots were identified. Within the Disko West-area, five such hotspots were identified (Figure 61).

4.3 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 eight species of mammals and eleven species of birds (Table 7), although some are rare within the assessment area (Boertmann 2008).

A few species have been categorized as 'Data Deficient' (DD) and they may become red-listed when additional information is available (Table 8).

Globally threatened or near threatened species occurring in the assessment area include eight marine mammals and five birds (Table 9) (IUCN 2020).

Figure 61. Map of biologically important areas based on a GIS-based overlay analysis of the spatial distribution of 59 species/ecosystem components in West- and Southeast Greenland (after Christensen et al. 2016). Species are weighted differentially based on a set of criteria relating to biological importance, as are the different portions of their distribution range (e.g. known concentration areas weighted more than general distribution range). Results are shown on a percentile scale from deep red, denoting the 5% of the area with the highest overlay score, to deep blue colour, denoting the 5% area with lowest overlay score. Red areas tend to be areas where important species/ecosystem components with a limited spatial distribution occur, or areas where many different species/ecosystem components overlap. The five framed sub-areas are particularly important areas, which also are vulnerable to shipping activities.

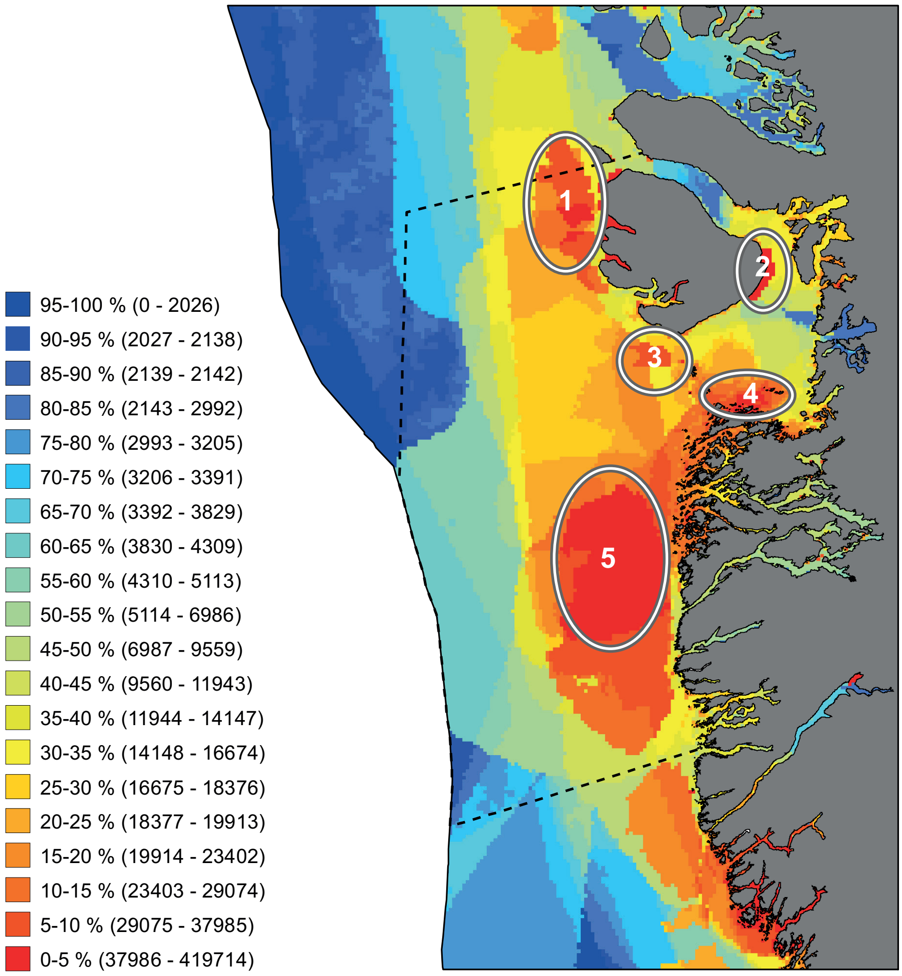


Table 7. Nationally red-listed species occurring in the Disko West assessment area (Boertmann & Bay 2018).

Species	Red List category
Polar bear	Vulnerable (VU)
Harbour seal	Critically endangered (CR)
Walrus	Vulnerable (VU)
Hooded seal	Vulnerable (VU)
Bowhead whale	Near threatened (NT)
Blue whale	Vulnerable (VU)
White whale	Vulnerable (VU)
Narwhal	Near threatened (NT)
Great northern diver	Near threatened (NT)
Greenland white-fronted goose	Endangered (EN)
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	Vulnerable (VU)

Table 8. National responsibility species (defined as more than 20 % of the global population in Greenland), species with isolated population in Greenland and species listed as 'Data Deficient' (DD) occurring in the assessment area. Only species which occur in marine habitats included.

National responsibility species	Species listed as Data Deficient (DD)	Species with isolated population in Greenland
Bowhead whale	Killer whale	Great cormorant
Narwhal	Northern bottlenose whale	Red-breasted merganser
Walrus		Harlequin duck
Hooded seal		
Harp Seal		
Polar bear		
Light-bellied brent goose		
Greenland white-fronted goose*		
Mallard*		
Common eider		
Iceland Gull		
Black guillemot		
Little auk		

*endemic subspecies

Table 9. Globally threatened species occurring in the assessment area include some marine mammals and birds (IUCN 2020).

Species	Red List category
Common eider	Near Threatened (NT)
Long-tailed duck	Vulenrable (VU)
Ivory gull	Near Threatened (NT)
Razorbill	Near Threatened (NT)
Atlantic puffin	Vulnerable (VU)
Polar bear	Vulnerable (VU)
Walrus	Vulnerable (VU)
Hooded seal	Vulnerable (VU)
Blue whale	Endangered (EN)
Fin whale	Endangered (EN)
Sperm whale	Vulnerable (VU)
Narwhal	Near Threatened (NT)
White whale	Near Threatened (NT)

4.4 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 59). These areas are designated using a large set of criteria, for example, that at least 1% of a bird population should occur in the area. 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 4 and Chapter 3.7). For further information see the IBA website (Link, including the global criteria). 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.

5 Environmental status and pressures in the assessment area

5.1 Background levels of contaminants

Frank Rigét (AU)

Knowledge on background levels of contaminants in areas with oil and gas exploration and exploitation is important, mainly as a baseline for monitoring the potential contamination of the environment from the activities.

There exists relative little knowledge on contaminants in the terrestrial and freshwater environment of the assessment area. No systematic monitoring has been performed but some scattered information exists derived from different investigations carried out through the years.

However, more systematic monitoring of contaminants in the marine environment in West Greenland area in context with the Arctic Monitoring and Assessment programme (AMAP) have been performed mainly in Qeqertarsuaq (in the assessment area) and Avanersuaq, and will be included in the following overview as proxy for the expected general level of contamination stress in the assessment area.

5.1.1 Heavy metals

Heavy metals, such as mercury (Hg), cadmium (Cd) and lead (Pb), in the environment are derived from both anthropogenic sources to the atmosphere (e.g. coal burning and mining) and from natural sources (e.g. volcanoes and weathering of rocks). The air provides a fast transport route – bringing contaminants from Europe to the Arctic within days. Ocean transport is slower, but more important for contaminants that partition into water and sediments rather than air and aerosols (AMAP 2011). Once in the Arctic, contaminants can be taken up in the food chains, in particular in the relative long marine food chains.

In 2017, the Minamata Convention on Mercury entered into force. The treaty deals with protection of human health and the environment from the adverse effect of mercury.

Hg profiles in dated marine sediment cores from Greenland including five cores from Disko Bay supported that Hg have increased in the environment during the last 100 years (Asmund & Nielsen 2000), and Hg concentrations in surface sediment ranged between 0.024 and 0.1 mg/kg dry weight; highest closest to Ilulissat. According to OSPAR (2009) the level for background concentration of Hg in sediment is 50 µg/kg (0.05 mg/kg). Hence, the surface sediment closest to Ilulissat must be considered as contaminated.

Baseline data on number of elements (Cd, Cu, Fe, Ni, Pb, Zn, V, Cr,, Fe, Zn, As, Se and Hg) in the moss (*Hylocomium splendens*) and the lichens (*Flavocetraria nivalis*) at several Greenland locations was reported by Pilegaard & Rasmussen (1989) Generally, there was no clear regional pattern in concentrations of these elements in Greenland. Dust derived from soil erosion in areas appeared to be the factor controlling the levels seen.

Baseline data on Pb, Cd, Hg and Se levels in molluscs, crustaceans, fish, seabirds, seals, walruses, whales and polar bears have been compiled for different geographical regions, including northern part of central West Greenland defined as the area between Uummannaq as the northern border and Kangaatsiaq in the south (Dietz et al. 1996) almost corresponding to the assessment area.

Table 10 shows selected geometric mean concentrations in the marine environment from central West Greenland found in the late 1980s. More recent concentrations in a few species obtained by the regularly contaminant monitoring's programme (Arctic Monitoring and Assessment Programme (AMAP)) are shown in Table 11.

Table 10. Geometric mean concentrations (µg/g wet weight) of Pb, Cd, Hg and Se in biota sampled in the 1980s from the northern part of central West Greenland (selected data from Dietz et al. 1996).

Species	Tissue	Pb	Cd	Hg	Se
Molluscs					
Blue mussels	Soft tissue	0.467	0.599		
Crustacea					
Parathemisto libellula	Whole		1.38		0.28
Shrimp	Whole > 5g		5.20	0.119	1.58
Fish					
Capelin	Whole	0.147	0.029		
Greenland cod	Muscle		<0.015		
Spottet wolffish	Muscle		<0.015		
Spottet wolffisk	Liver	0.013	2.11		
Shorthorn sculpin	Muscle	<0.010	<0.015		
Sorthorn sculpin	Liver	0.011	0.423		
Greenland halibut	Muscle	<0.010	<0.015		
Seabirds					
Common eider	Muscle	<0.018	0.122	0.100	0.907
Common eider	Liver	0.048	3.12	0.644	6.37
King eider	Muscle		0.316	0.109	0.539
King eider	Liver		4.52	0.440	6.34
Glaucuos gull	Muscle		0.041		
Glaucous gull	Liver		2.90		
Black guillemot	Muscle	<0.018	0.133	0.170	0.620
Black guillemot	Liver	<0.018	3.40	0.595	2.32
Marine mammals					
Ringed seal (1 year old)	Muscle	0.029	0.068		
Ringed seal (1 year old)	Liver	0.366	0.229		

In general, the highest Hg concentrations in biota are found in top predators in the marine food chains and reach mean levels of above 1 mg/kg wet weight in liver of juvenile ringed seals from Qeqertarsuaq. When comparing with the more recent concentrations of Cd, Hg and Se (Table 10) no large differences are notable. In a study covering the period from 1994 to 2018 a significant increase of 6.6% annually was found in sculpins from Qeqertarsuaq, while no trend was found in ringed seals from the same area (Figure 62, Rigét unpublished).

Table 11. Mean concentrations (µg/g wet weight) of Cd, Hg and Se in biota sampled in Qeqertarsuaq (unpublished data from the AMAP monitoring programme.

Species	Year	Tissue	Cd	Hg	Se
Blue mussel	2004	Soft tissue	0.564	0.008	0.584
Shorthorn sculpin	2018	Liver	2.33	0.065	0.887
Ptarmigan	2004	Liver	1.97	0.030	0.223
Ptarmigan	2004	Kidney	9.20	0.042	0.624
Black guillemot	2006	Liver	1.15	0.225	2.25
Black guillemot	2000	Egg		0.260	0.489
Ringed seal juvenile	2018	Liver	6.28	1.68	1.36

Mercury concentrations will likely increase in the West Greenland environment and wildlife due to expected increases of mercury emissions (UNEP, 2013). However, in the long run, the Minamata Convention on Mercury may bring about a global reduction of emissions.

The highest levels of Cd in Arctic biota are found in kidney and liver of marine mammals from the eastern Canadian Arctic and West Greenland (AMAP 2005). Cd levels in biota probably reflect the geochemical environment rather than anthropogenic gradients (AMAP 2005), e.g., expressed as an increased Cd level in caribou across the Canadian Arctic to West Greenland, where the geometric means in liver ranged from 0.121 to 0.695 mg/kg wet weight.(Aastrup et al. 2000). In Greenland, Cd concentrations are in general higher in marine biota from the north western part of Greenland compared to southern areas (Dietz et al. 1996). Cd in liver of shorthorn sculpin and ringed seal from Qeqertarsuaq had levels of 2.33 and 6.28 mg/kg wet weight, respectively (Table 11). During the period from 1994 to 2018 no temporal trend were found of Cd concentrations in sculpins and ringed seals from Qeqertarsuaq (Rigét unpublished).

The atmospheric deposition of Pb has been reduced dramatically in Arctic regions as a result of banning the use of leaded gasoline during the 1970s and 1980s in many countries (AMAP 2005). Pb do not bio-magnify in the food chains and in the assessment area the highest concentration was found in the 1980s found in blue mussels of approximately 0.5 mg/g wet weight (Table 10). Pb from lead shots used during bird hunting is another source and appears to be an important source of human exposure (Johansen et al. 2006). However, the use of Pb for hunting game birds was banned in 2012 in Greenland.

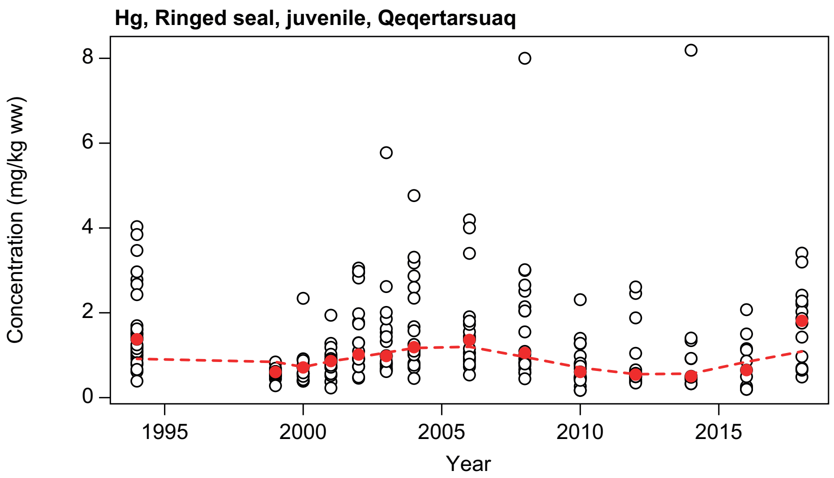


Figure 62. Temporal development 1994-2018 in concentrations in ng/g ww (wet weight) of mercury (Hg) in juvenile ringed seals from Qeqertarsuaq in the assessment area (F. Rigét unpublished).

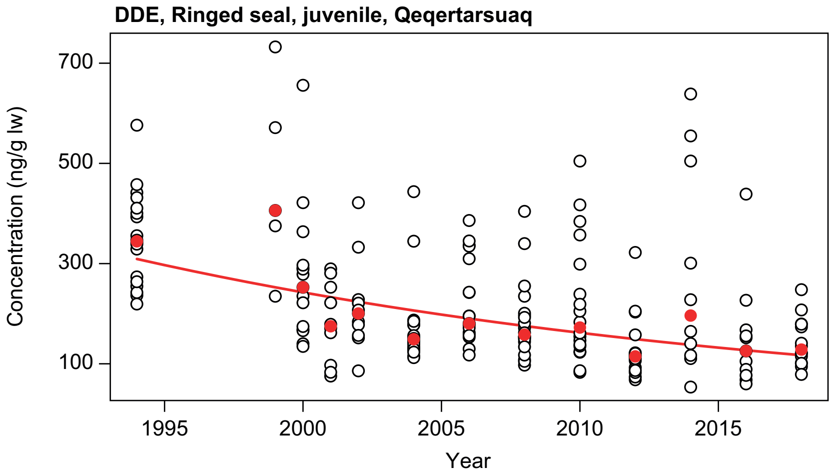


Figure 63. Temporal development 1994-2018 in concentrations in ng/g lw (lipid weight) of DDE (degradation product of DDT) in juvenile ringed seals from Qeqertarsuaq in the assessment area (F. Rigét unpublished).

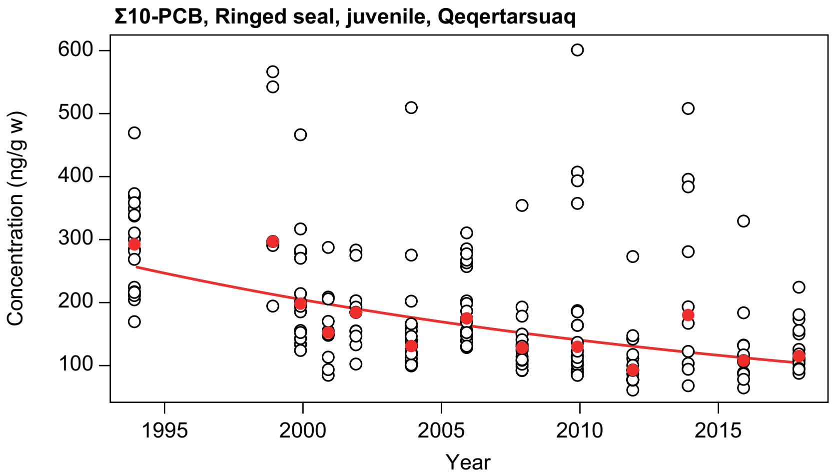


Figure 64. Temporal development 1994-2018 in concentrations in ng/g lw (lipid weight) of a PCB's in juvenile ringed seals from Qeqertarsuaq in the assessment area (F. Rigét unpublished).

5.1.2 Persistent organic pollutants (POP's)

Persistent organic pollutants (POP's) have a long lifetime in the environment, and therefore have the potential to be transported over long distances. Most of the total quantity of POP's found in the Arctic environment is derived from the industrialised southern regions (AMAP 2010b). POP's are mainly transported to the Arctic by the atmosphere and ocean currents. However, the increased human activities in the West Greenland area in connection with oil and gas exploration and exploitation constitute a risk of local contamination with POP's. POP's bio-accumulate and bio-magnify in the Arctic food chains. Most of them are lipophilic, which means they are found in highest concentrations in fatty tissues. The use of several POP's has been banned or restricted since 1970s and 1980s and international actions have been established to reduce emissions and releases to the environment, such as the UNEP Stockholm Convention on POP's and the POP's Protocol to the Convention on Long-range Trans-boundary Air Pollution. Many of these POP's show declining concentrations in Arctic biota (Rigét et al. 2019), e.g. dichlorodiphenyltrichloroethane (DDT's), drins (aldrin, endrin and dieldrin), polychlorinated biphenyls (PCB's) and chlordanes. In ringed seals collected in Qeqertarsuaq declining levels of these compounds are also seen (Rigét et al. 2013b) (Figures 63, 64). In human blood from the Arctic including from people living in the Disko area most POP's are also decreasing (Krüger et al. 2012, Long et al. 2015) probably due to a combination of the international regulation and reduction in the consumption of traditional food such as seals and whales (Long et al. 2015). However, many POP levels in Arctic biota are still so high that certain species, including many top predators, may be

Table 12. Recent mean concentrations (ng/g lipid weight) of POPs in biota from Disko. Unpublished data from the AMAP monitoring programme.

POPs mean concentration	Year	Biota	Conc.	Reference
$\sum_{10}$PCB	1994	Blue mussel soft tissue	0.59	Cleemann et al. 2000a
$\sum_{10}$PCB	2001	Black guillemot egg	803	Rigét, unpublished
$\sum_{10}$PCB	1994	Glaucous gull liver	469	Cleemann et al. 2000b
$\sum_{10}$PCB	1994	Icelandic gull liver	37.9	Cleemann et al. 2000b
$\sum_{10}$PCB	2016	Ringed seal blubber	131	Rigét, unpublished
∑DDTs	1994	Blue mussel soft tissue	0.24	Cleemann et al. 2000a
∑DDTs	2001	Black guillemot egg	435[1]	Rigét, unpublished
∑DDTs	1994	Glaucous gull liver	396	Cleemann et al. 2000b
∑DDTs	1994	Icelandic gull liver	35.8	Cleemann et al. 2000b
∑DDTs	2016	Ringed seal blubber	176	Rigét, unpublished
HCB	1994	Blue mussel soft tissue	0.027	Cleemann et al. 2000a
HCB	2001	Black guillemot egg	228	Rigét, unpublished
HCB	1994	Glaucous gull liver	32	Cleemann et al. 2000b
HCB	1994	Icelandic gull liver	11	Cleemann et al. 2000b
HCB	2016	Ringed seal blubber	11.3	Rigét, unpublished
∑HCH	1994	Blue mussel soft tissue	0.39	Cleemann et al. 2000a
∑HCHs	2001	Black guillemot egg	54.9	Rigét, unpublished
∑HCHs	1994	Glaucous gull liver	3.2	Cleemann et al. 2000b
∑HCHs	1994	Icelandic gull liver	1.4	Cleemann et al. 2000b
∑HCHs	2016	Ringed seal blubber	24.9	Rigét, unpublished
Toxaphene	2001	Black guillemot egg	515	Rigét, unpublished
Toxaphene	2016	Ringed seal blubber	11.0	Rigét, unpublished
∑CHLs	2001	Black guillemot egg	363	Rigét, unpublished
∑CHLs	2016	Ringed seal blubber	108	Rigét, unpublished
PBDE-47	2016	Ringed seal blubber	3.6	Rigét, unpublished
PFOS[2]	2018	Ringed seal liver	15.0	Rigét, unpublished

$\sum_{10}$PCB = cb18+cb31+cb52+cb101+ cb105+cb118+cb138+cb153+cb156+cb180
∑DDTs = *p,p*-dde + *p,p*-ddd + *p,p*-ddt
∑CHLs = *trans*- and *cis*-chlodane + *trans*- and *cis*-nonachlor + oxychlordane
∑HCHs = α-, β- and γ-HCH
Toxaphene = chb26+chb40+chb41+chb50+chb60
[1] p,p-dde + p,p-ddd
[2] ng/g wet weight

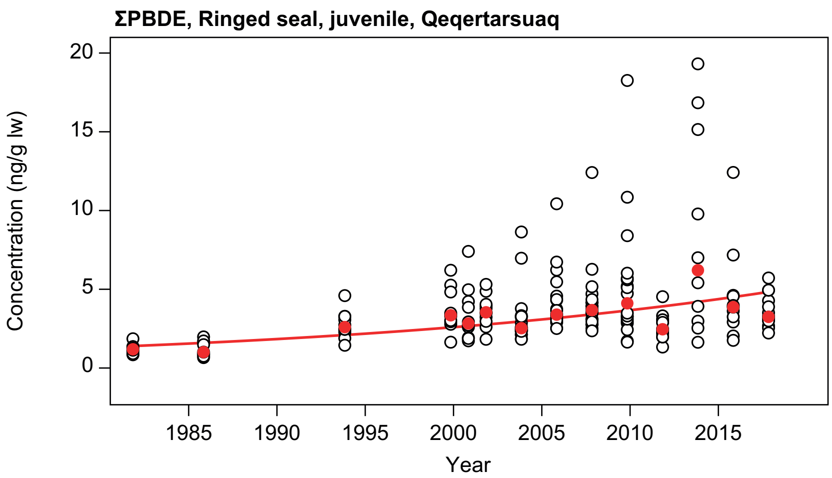


Figure 65. Temporal development 1982-2018 in concentrations in ng/g ww (wet weight) of PBDE in juvenile ringed seals from Qeqertarsuaq in the assessment area (F. Rigét unpublished).

at risks for biological effects from these compounds (AMAP 2018b). POP's are also found in human maternal blood indicating foetus exposure and possible influencing foetus development (Long et al. 2015).

Levels of POP's concentrations (ng/g lipid weight) in biota from Qeqertarsuaq are summarized in Table 12.

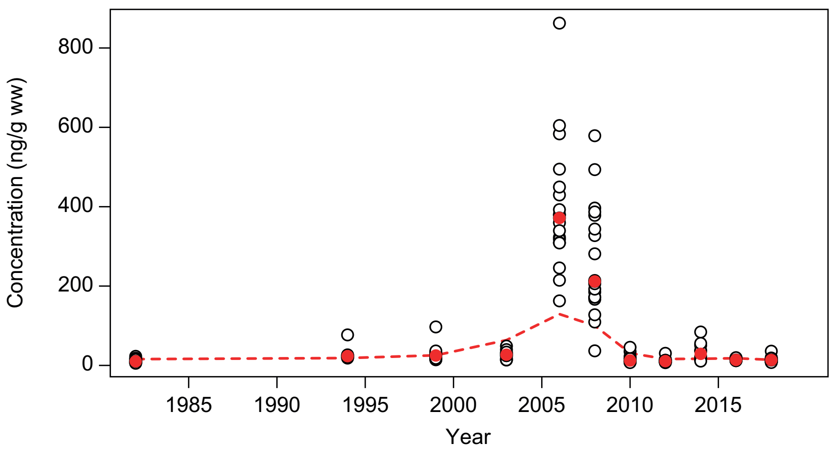
The levels of POP's are generally decreasing in the order ∑PCB > ∑DDT's > ∑CHL's > Toxaphene > HCB > ∑HCH's, as also seen in marine biota from Disko (Table 12). In general, the levels of POP's found in biota from West Greenland are lower than in biota from East Greenland (Rigét et al. 2015).

Polybrominated diphenyl ethers (PBDE's) is a group of POP's, which was phased out at a national level (U.S., Canada and European Union) in the mid-2000s, and in 2009 the technical mixtures PentaBDE and OctaBDE were included in the Stockholm Convention. Levels of PBDE's in both animals and humans are much lower than the above mentioned POP's, which have been regulated for a longer period. In juvenile ringed seals from Qeqertarsuaq the levels of the congener PBDE-47 has increased in the last three decades with an annual increase of ca. 4% and is now at a level of about 4 ng/g lipid weight (Table 12, Figure 65). This temporal pattern is different from several other trend patterns found in Arctic biota, where the levels have increased until the mid-2000s, after which concentrations have either decreased or stabilized (Rigét et al. 2019).

Perfluorinated alkylated substances (PFAS's) are another group of compounds which is very persistent in the environment. In biota and humans, PFAS's bind to blood proteins and, therefore, bio-accumulate mainly in liver, kidneys and bile secretions in contrast to most other POP's which are lipophilic.

Perfluorooctane sulphonate (PFOS) is usually found in much higher concentrations compared to other fluorinated compounds in Arctic wildlife. The largest producer of PFOS, the 3M US company, announced in 2000 that it would phase out its production. PFOS was banned in the EU in June 2008, and in 2009 PFOS was included in the Stockholm Convention on POP's. Likely as a response to the regulation PFOS concentrations in several wildlife species are now declining after a period with increasing levels (Rigét et al. 2019). Also in ringed seals from Qeqertarsuaq PFOS concentrations have decreased after it peaked around 2006, and is now at a level of 14 ng/g wet weight in the liver of juvenile ringed seal (Rigét et al. 2013a) (Figure 66). However, in blood from Greenlanders from Nuuk in West Greenland, PFOS increased in the period from 1998 to 2005 (Long et al. 2012).

Figure 66. Temporal development 1982-2017 in concentrations in ng/g lw (lipid weight) of PFOS in juvenile ringed seals from Qeqertarsuaq in the assessment area (F. Rigét unpublished).



Concentrations of persistent organic pollutants (POP's) that are subject to national and international regulations will likely decrease. Monitoring results show that the concentrations of most POP's that are regulated under the Stockholm Convention have been decreasing in Arctic air and wildlife over the past decade. Some POP's have been declining since the 1990s, at which time many of the original Stockholm Convention POP's had already been banned by most industrialized nations.

Chemicals of emerging Arctic concern will likely be found in the environment for the first time or will be found to increase in the environment. Arctic monitoring programs are constantly expanding their analytical protocols to include new chemicals whose characteristics (physical/chemical properties) suggest the potential for them to contaminate the Arctic environment. Arctic monitoring data is critical for a new chemical to be classified as a POP under the Stockholm Convention.

5.1.3 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). Biomagnification to higher trophic levels has been documented in walleye pollock, for a range of marine mammal species as well as for glaucous gull (AMAP 2018a). TBT was banned for use in 2008 and included in the Rotterdam and OSPAR Conventions.

5.1.4 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 (PAH's), which originate from two main sources: combustion (pyrogenic) and crude oil (petrogenic). PAH's represent the most toxic fraction of oil, they have serious long-time environmental effects and are released to the environment through oil spills and discharge of produced water (see also Chapter 6.2.4). Sixteen PAH's are included on the lists of priority chemical contaminants by the World Health Organization and the U.S. Environmental Protection Agency (EPA), and PAH's are ranked as high priority substances in the European Water Framework Directive (Directive 2000/60/EC) (European Commission 2001).

Levels of petroleum hydrocarbons (incl. PAH's) are generally low in the Arctic marine environment and often close to background concentrations, except in areas with anthropogenic impact such as harbours. Presently, the majority of petroleum hydrocarbons in the Arctic originate from natural sources such as seeps (Skjoldal et al. 2007).

Total petroleum hydrocarbons (TPH) and PAH levels were measured at suspected 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 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).

The higher PAH concentrations in some areas off the coast of the Nuussuaq Peninsula (Figure 67) could probably be attributed to the Marrat oil seep, which has been studied some years ago (Mosbech et al. 2007b).

As part of a baseline study performed by the company Capricorn before their drilling campaigns in 2010 and 2011, PAH content in surface sediments were analysed west of Disko Island to document background level prior drilling. The results showed that the PAH content in the sediments was low (Figure 68).

Figure 67. Background levels of PAH in sediments in West Greenland.

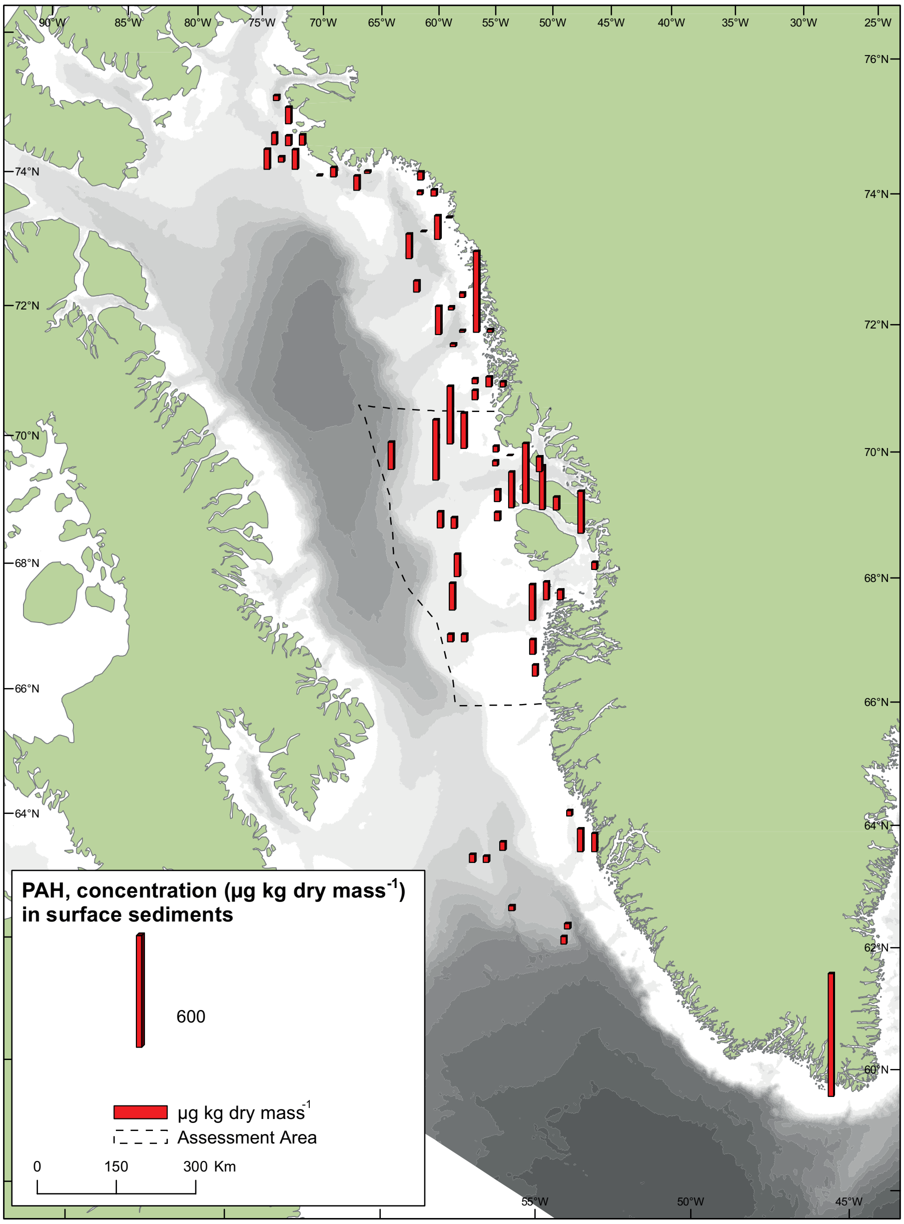
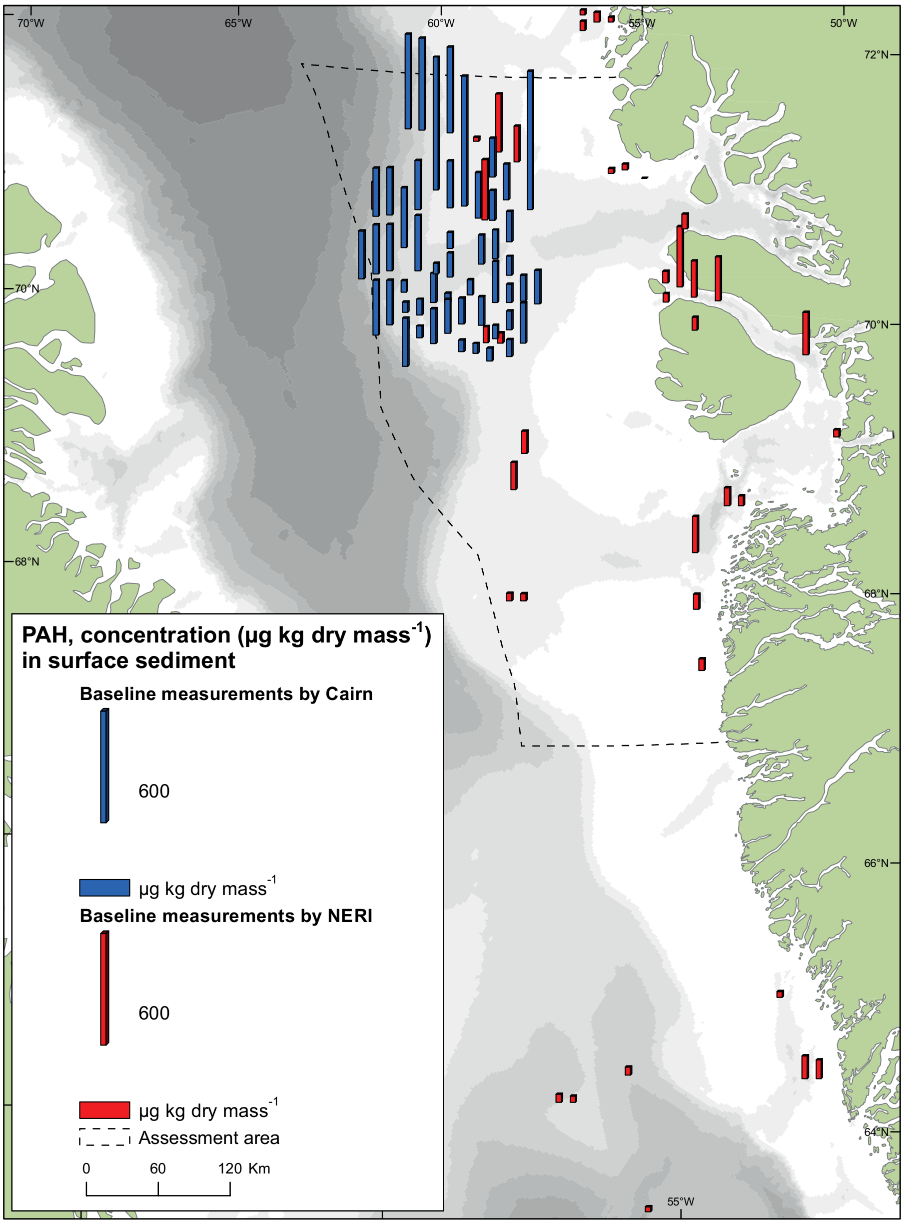


Figure 68. Background levels of PAH's in the assessment area



5.1.5 Biological effects of contaminants in the Arctic

POP's and mercury

Rune Dietz (AU), Christian Sonne (AU) & David Boertmann (AU)

The research and monitoring activities described in the previous section clearly indicate the presence of different kinds of contaminants (e.g. POP's and among those organohalogenated substances (OHC's) and heavy metals) in biota from Greenland. Temporal and regional trends have been documented 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) leading to very high exposure in the Inuit hunters due to the biomagnification properties of these contaminants. However, contaminant levels are often still lower than in biota from more temperate regions, e.g. the North Sea or the Baltic Sea, but as the local human consumption consists of a larger proportion of marine and high trophic level species the Arctic, Inuit populations are higher exposed than human populations at lower latitudes despite being closer to the sources.

The most recent AMAP Effect Assessment by Dietz et al. (2019) update the state of knowledge of POP's (OHC's) and mercury; exposure and/or associated effects in key Arctic marine and terrestrial mammal and bird species as well as in fish. The literature published since the last AMAP assessment in 2010 (Letcher et al. 2010, Dietz et al. 2013) is reviewed, and the knowledge of how single – and combined health effects – are or can be associated to the exposure to single compounds or mixtures of OHC's is updated. Hence, the potential individual effects - and for the first time *including* examples of population health impacts - were *studied* by Dietz et al. (2019) using post 2000 exposure data, to avoid too much temporal impacts, from marine and terrestrial mammals and birds across the Arctic regions.

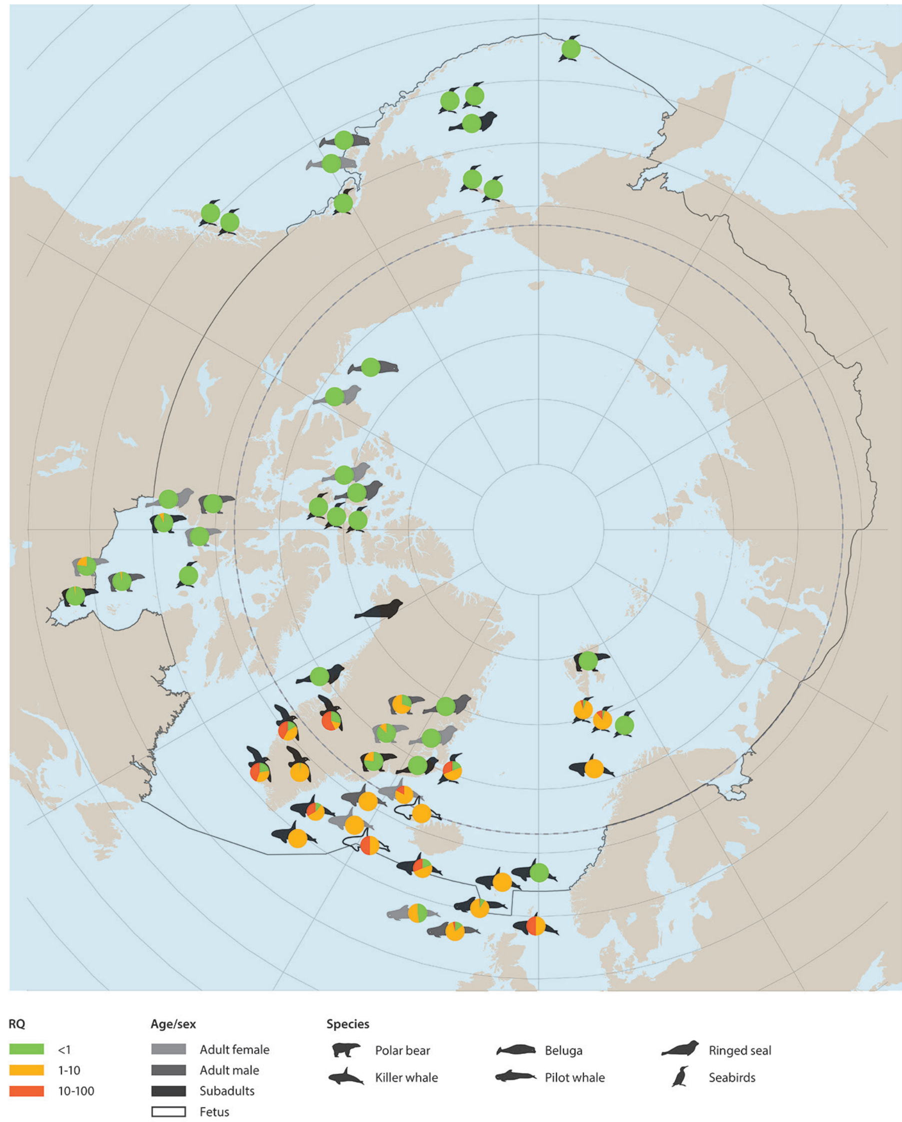
The latter example was illustrated by the Desforges et al. (2018) study combining PCB effects on calf survival and disease mortality to determine population effect predictions of PCB's on killer whale populations around the world including several Arctic subpopulations. It was hence shown that PCB-mediated effects on reproduction and immunity can have potentially severe consequences for the long-term population viability of 10 of the assessed 19 killer whale populations (Desforges et al. 2018).

The Arctic effect assessment by Dietz et al. (2019) likewise identified quantifiable effects on vitamin metabolism, immune functioning, thyroid and steroid hormone balances, oxidative stress, tissue pathology, and reproduction. As with the previous assessment, a wealth of documentation was generated for biological effects in marine mammals and seabirds, and sentinel species such as the sledge dog and Arctic fox. Information for terrestrial vertebrates and fish remain scarce, however, fish and invertebrates are in the process of being assessed for the effects of mercury (Dietz et al. submitted, in review).

While hormones and vitamins are thoroughly studied, oxidative stress, immunotoxic and reproductive effects need further investigation. Depending on the species and population, some POP's and mercury tissue contaminant burdens post 2000 were observed to be high enough to exceed putative risk threshold levels that have been previously estimated for non-target species or populations outside the Arctic. A couple of studies by Sonne et al. (2009) and Dietz et al. (2015; 2018) used risk quotient calculations by comparing critical body residues to the actual tissue exposures to summarise the cumulative effects of POP's from which it became evident that PCB was the major threat with respect to reproductive, immunological and carcinogenic effects. Dietz et al. (2019) used PCB and mercury for which critical body burdens was estimated for wildlife across the Arctic to estimate the effects of these substances in Arctic wildlife at the individual, population and ecosystem level (Figures 69, 70). Several hot spots were detected in marine mammal top predators including polar bears and various toothed whales in Canada, East Greenland and Faroe Islands. The toothed whales seem to be higher exposed to PCB's and mercury due to their limited abilities to break down and excrete these contaminants which carnivores such as polar bears are capable of. This again also have implications for the Greenland Inuit and other Arctic human population consuming large amounts of toothed whales (Dietz et al. 2018).

It was however, also concluded that there remain numerous knowledge gaps on the biological effects of exposure in Arctic biota. These knowledge gaps include the establishment of concentration thresholds for individual compounds as well as for realistic cocktail mixtures that in fact indicate biologically relevant, and not statistically determined, health effects for specific species and subpopulations. Finally, Dietz et al. (2019) concluded how future

Figure 69. Risk quotients (RQs) for PCB-mediated effects on the immune and hormone systems based on post-2000 sampling of Arctic key species and their ΣPCB loads using a conservatively determined critical body residue of 10 µg/g lw PCBs (Dietz et al. 2019).



assessments would benefit from significant efforts to integrate human health, wildlife ecology in a "OneHealth" perspective.

PAH's

PAH's are taken up by marine organisms directly from the water (via the body surface or gills) or through the diet, and as they are non-polar and lipophilic compounds they tend to accumulate in the fatty tissues. They are acutely toxic down to 0.9 mg oil/l (0.9 ppm or 900 ppb), and Johansen et al. (2003) applied a safety factor of 10 to reach a PNEC (Predicted No Effect Concentration) of 90 ppb oil for 96-hour exposure. This was based on fresh oil which leaks a dissolvable fraction, mostly toxic for fish eggs and larvae, while weathered oil is less toxic.

Many studies have indicated that PAH's are more or less easily metabolised by invertebrates and generally efficiently metabolised by vertebrates such as fish (review by Hylland et al. 2006). Therefore, and in contrast to other organic pollutants, PAH's are not bio-magnified in the marine food web. Dietary exposure to PAH's may, however, be high in species that preferentially feed on organisms with low ability to metabolise PAH's, such as bivalves (Peterson et al. 2003), and filter feeding zooplankton can be exposed to high levels through filtering out oil droplets containing PAH's from the surrounding water (Hylland et al. 2006).

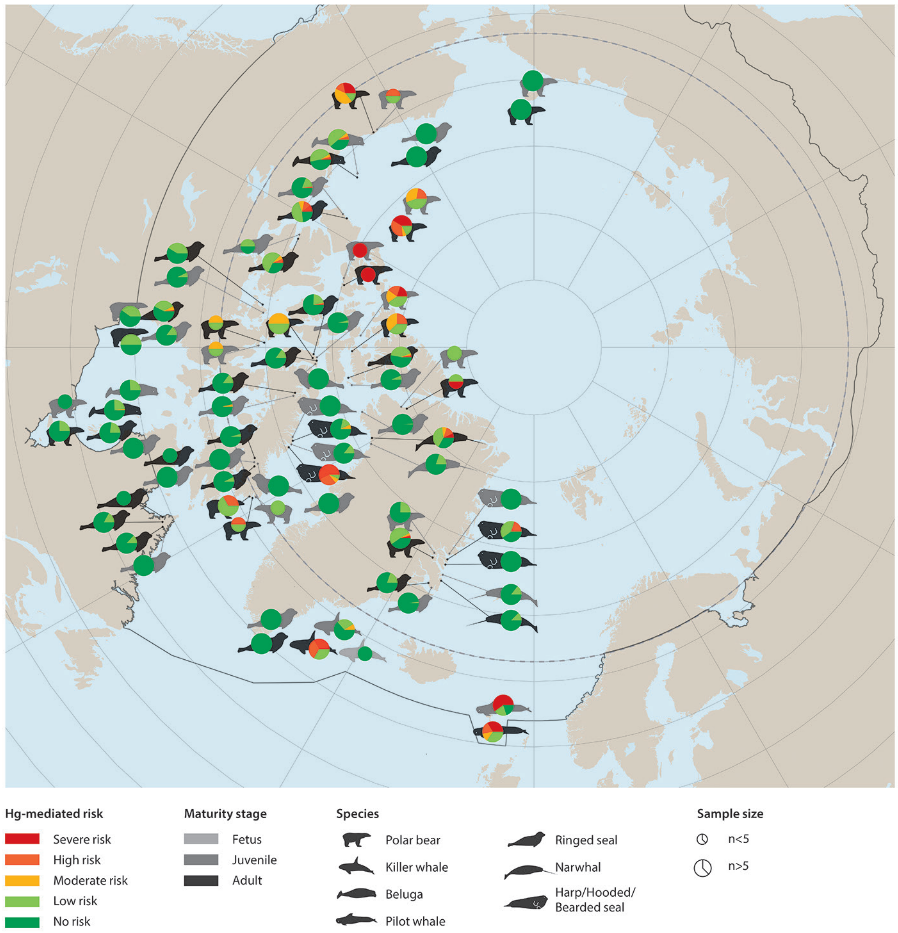


Figure 70. Geographical overview of the proportion of individuals of specific Arctic marine mammal populations that are at risk of Hg-mediated health effects; based on post-2000 monitoring data grouped according to maturity where possible (Dietz et al. 2019).

Marine sediments function as an ultimate sink for PAH's, and these are therefore useful for environmental monitoring (Beyer et al. 2010, HELCOM 2010). PAH's tend also to accumulate in bivalves due to low biotransformation capabilities, and bivalves can also be useful for assessments in the environment. Fish, as other aquatic vertebrates, have well developed enzymatic systems that efficiently metabolise PAH's so assessment of environmental PAH levels can be done by analysing enzymatic activity (as a biomarker) in the bile of exposed fish (Beyer et al. 2010).

Since some PAH's are known to be potent carcinogens, this contaminant class is generally regarded as a high priority for environmental pollution regulation and in ecological risk assessment of industrial effluent discharges (Hylland et al. 2006, Neff 2002).

Toxicity data is a key factor in risk assessment, and since there is limited information on effects of toxic substances in Arctic organisms, further data on local species is essential for risk assessment in Arctic ecosystems (Chapman & Riddle 2003, 2005, Mosbech 2002, Olsen et al. 2011). There is a particular need for toxicity data on early life stages, as they are most vulnerable (Frantzen et al. 2012, Khan & Payne 2005, Short et al. 2003). This data gap has for PAH's and other toxic oil components been addressed in recent years: Nahrgang et al. 2016 (polar cod), Beirão et al. (2018, 2019) (capelin), Toxværd et al. (2018a, 2018b) (*Calanus*), Agersted et al. (2018) (*Calanus*), Skottene et al. (2019) (*Calanus*), Gustavson et al. (2019, in prep.) (*Calanus*), Zairova et al. (2019) (capelin).

5.2 Plastic in the assessment area

Jannie Fries Linnebjerg (AU)

Plastic pollution in the marine environment is of increasing concern due to its effect on marine life and possibly human health, and has therefore been recognised as one of the largest global environmental problems currently faced (UNEP 2011, 2014). Marine plastic pollution is commonly observed across all oceans and has been documented in all compartments of the ocean from coastal shallow waters to the deep seafloor, as well as in sea ice (Barnes et al. 2009, Schlining et al. 2013, Obbard et al. 2014, Woodall et al. 2014, van Sebille 2015, Halsband & Herzke 2019). It is assessed that on a global scale, that most of the plastic litter in the marine environment comes from land-based sources in regions with inadequate waste management systems (Jambeck et al. 2015). Once in the sea, the plastic is redistributed by the wind and sea currents. The impact of plastic pollution is multiple and complex and can affect biota, habitats and ecosystems (Law 2017). Marine plastic litter affects marine species in many different ways depending on the size and type of plastic. The shape, size and type of the organisms also determines the potential effects (Werner et al. 2016). The main impacts on organism are through ingestion or entanglement. Mortality by entanglement is the most visible, with species (particularly seabirds and marine mammals) being caught in fishing gear, rope and plastic bags (Laist 1986, 1997, Provencher et al. 2017). If not causing acute death, it is to be expected that entanglement by, and ingestion of, plastic litter will affect the performance of individuals by hampering their ability to capture and digest food, reproduce, as well as reducing their body condition leading to constrained locomotion, including migration and escape from predators (CBD 2012). Due to their small size (< 5 mm), microplastics can be ingested by a much broader range of marine organisms than macroplastics, ranging in size from zooplankton and bivalves to fish, seabird and marine mammals. Ingestion of microplastics can result in physical damage such as obstruction or internal abrasions (Wright et al. 2013). Larger fish, seabirds and marine mammals can in some cases also ingest larger plastic particles, i.e. mesoplastic (5-25 mm) and marcoplastic (>25 mm). In addition to physical effects, marine plastic can potentially also impact marine species by the transfer of chemicals leaked to the marine environment, and as a vector for alien species since various types of animals have been found to use marine debris as a mobile home, particularly bryozoans, barnacles, polychaete worms, hydroids and molluscs (Barnes 2002, Hermabessiere 2017). To date, over 690 marine species have been reported to have been affected by marine litter including whales, seals, seabirds, turtles, fish, and crustaceans, and plastic litter accounted for 92% of these encounters (Gall & Thompson 2015).

Despite its remote location away from intensive human activities, plastic pollution has been detected in the Arctic region, where fisheries-related activities have been identified as a major source of the plastic litter (PAME 2019). Recent studies have reported concentrations of macroplastics on beaches (PAME 2019), of floating plastics in the Greenland Sea, Fram Strait and Barents Sea (Bergmann 2016, Cózar et al. 2017), on the seabed in Fram Strait (Parga-Martinez et al. 2020), in seabirds, especially fulmars (see review by PAME 2019, Baak et al. 2020) and whales (Panti et al. 2019). Polar bears are also know to ingest plastics (anecdotal evidence).

Microplastics have been found in snow (Bergmann et al. 2019), in surface and sub-surface water samples (Lusher et al. 2015, Kanhai et al. 2018), on the seafloor down to depth of 5500 m (Bergmann & Klages 2012, Bergmann et al. 2016) as well as in the lower turbid layer of sea ice (Obbard et al. 2014, Peeken et al. 2018). Recently, microplastics have been reported from amphipods (*Gammarus setosus*; Iannilli et al. 2019), blue mussels (Sundet et al. 2016, Bråte et al. 2020), snow crabs (Sundet et al. 2014), fish (Morgana et al. 2018), seabirds (Amélineau et al. 2016, Provencher et al. 2018) and white whales (Moore et al. 2020).

Strand et al. (2018) surveyed 17 Greenland beaches for plastics in 2016 and 2017, of which two were inside the assessment area. They concluded that the occurrence of plastics was high and with relatively high contributions from single use plastic items, indicating that the sources at the West Greenland sites were mainly local and from land-based sources. For instance, the dump-sites of the towns and settlements, where the garbage management at most sites is insufficient and limited to deposition at the coast and burning in open fires, can be important sources. Only the larger towns like Nuuk and Sisimiut have well-functioning incinerators. Waste water effluents from the cities can also be a sources, because no efficient cleaning technology are installed. Other local sources are the shipping and fishery activities taking place. In addition, also long transported micro-plastics occur (Obbard 2018).

The only marine species investigated for plastic ingestion in the assessment area are the northern fulmar and thick-billed murres (Strand et al. 2018, Provencier et al. 2014). Thirty one percent of the fulmars were found to have more than 0.1 g of plastic in their stomachs, and 11% of the murres had plastic in their stomachs, indicating that seabirds in West Greenland is relatively highly exposed to plastic pollution. A study from Arctic Canada also found plastic in fulmars (72% of examined birds) and moreover in kittiwakes (15%), but no plastic in thick-billed murres and black guillemots (Baak et al. 2020).

Regarding interactions with, and impacts on, marine organisms, the assessment area is no different than other marine areas. Potential consequences of ingestion of macro- and microplastics by marine species is still poorly studied and documented in the Arctic (Halsband & Herzke 2019). Some studies have established a link between the interaction with plastic and lethal effects of individuals, but knowledge of implications at the population level is still lacking.

5.3 Human activities

5.3.1 Commercial fisheries

AnnDorte. Burmeister (GINR), Adriana Nogueira (GINR), Søren Post (GINR) & Rasmus Nygaard (GINR)

Commercial fisheries represent the most important export industry in Greenland, underlined by the fact that fishery products accounted for more than 93% of the total Greenlandic export revenue (4.1 billion DKK) in 2018 (Stat. gl. 2019) .

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 2018: 1,678 million DKK), Greenland halibut (1.093 million DKK), Atlantic cod (350 million) and snow crab (85 million DKK) (Greenland Statistics 2020).

Other species utilized on commercial and recreational basis include lumpfish, Atlantic salmon, Arctic char, Icelandic scallop, Atlantic halibut, capelin, redfish and spotted wolffish.

In the assessment area the following species are of importance in relation to commercial fisheries:

Northern Shrimp

In West Greenland waters the northern shrimp fishery extends from 59° 30′ N to 76° 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 and peaked with total catch of up to 150,000 t/year (2004 - 2008), but declined in the following years and amounted 95,000 t in 2018. The major part of the catch is taken by large modern trawlers, which process the catches on board. In the Disko Bay and other inshore waters smaller vessels are used and the catches are usually delivered to land based factories. The fishery takes place whenever the sea-ice allows. Since the late 1990s the fishery has contracted northward and the majority of the fishing effort is concentrated offshore north of 66° N and in Disko Bay.

In the period 2014-2018 catches taken in the assessment area (inshore as well as offshore) varied from 72-84% of the total Greenland catch (Burmeister & Rigét 2019b) and thus clearly documenting the importance of the assessment area for the shrimp fisheries (Figure 71).

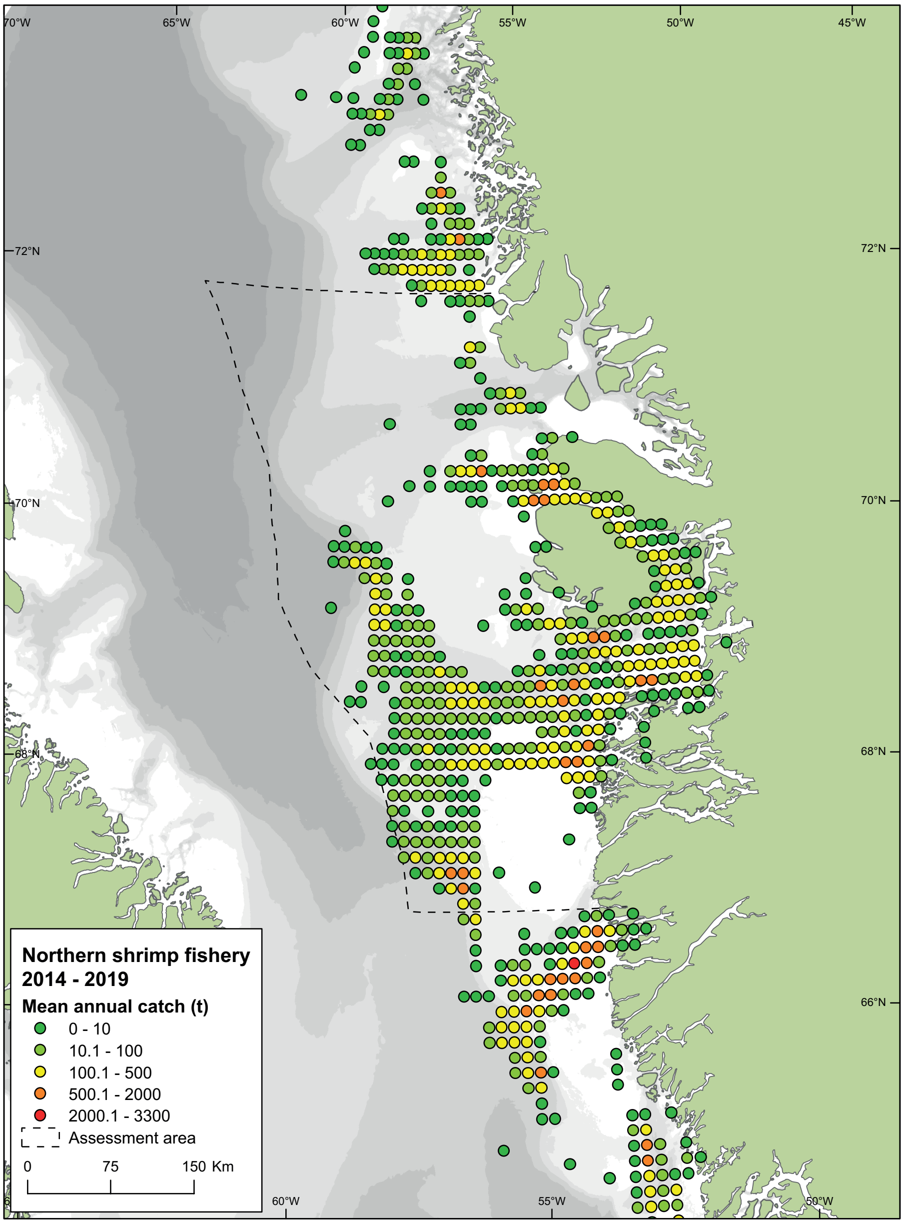


Figure 71. Distribution and amounts of the northern shrimp catches in and adjacent to the assessment area. Catch size shown as the mean annual catch over the period for 2014 to 2019 and distribution based on the NAFO-grid.

Greenland halibut

The fishery on Greenland halibut can be divided into an offshore fishery and an inshore or fjord fishery (Figure 72). The offshore component is based on large vessels and the inshore fishery is based on small boats, small vessels and fishery from the sea ice. The inshore fishery takes place throughout the year and is mainly concentrated in the Disko Bay and the Uummanaaq and Upernavik districts. In 2019, catches were 8759 t in the Disko Bay, 10,143 t in Uummannaq and 7668 t in Upernavik (Nygaard 2020 in prep.). Furthermore 221 t were caught in the Inglefield Inlet north of the assessment area and a total of 1585 t were caught in the fjords from Sisimiut to South Greenland.

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 greenlandfishery peaks during summer and autumn, where 65.5% of the total catches are fished in third quarter and 32.5% in fourth quarter (Jørgensen & Hanmmeken-Arboe 2013). The fishery is distributed from 70° N to 75° N on the edge of shelf at 600-1800 m depth and the main

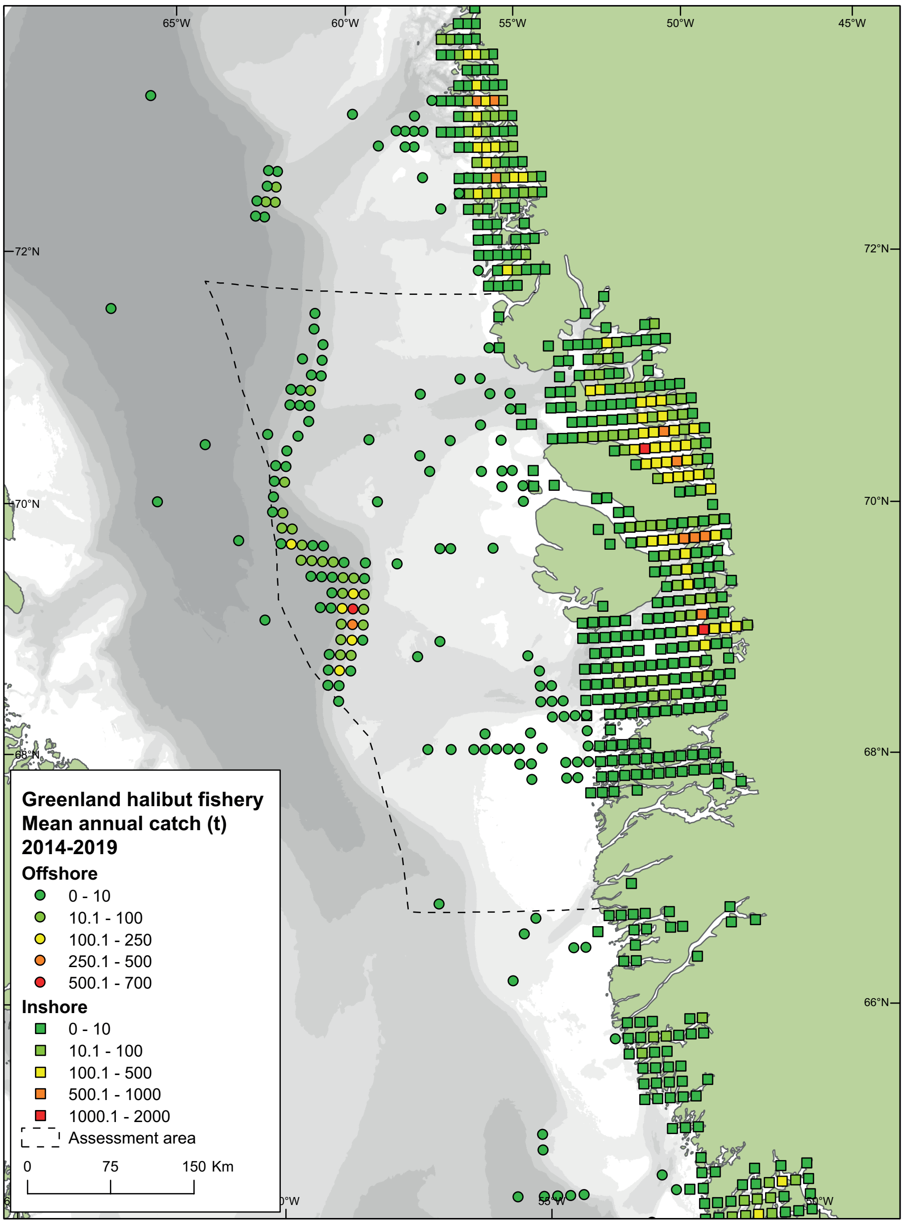


Figure 72. Distribution of the Greenland halibut landings in the assessment area for inshore and offshore fisheries, mean annual catch 2014-2019. Distribution based on the NAFO-grid.

fishery is situated west of Disko between 68° and 70° 30′ N, see Figure 72 (Jørgensen & Hanmmeken-Arboe 2013). Before 2000 the commercial catches in the Greenlandic part of Baffin Bay were limited, but increased gradually from 96 t in 2000 to approx. 6200 t in 2006 and have since remained on that catch level. The annual catch level in the Canadian part of Baffin Bay is approx. 6200 t. The commercial catches from the Davis Strait amounted 14,000 t of which 50% is based on fishery in Canadian waters (Jørgensen 2012).

Snow crab

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, however depends on the sea ice coverage. The fishery was initiated in 1992 in the Disko Bay area and around Sisimiut and increased rapidly. In the period from 2000 to 2009, the catches in the inshore area from 67° to 71° N comprised 23% to 38% of the total catches along the west coast of Greenland, with annual mean catches of 1842 t. Since 2010 annual inshore catches has varied between 185 and 559 t, with annual mean catches at 375 t (Burmeister 2019) (Figure 73).

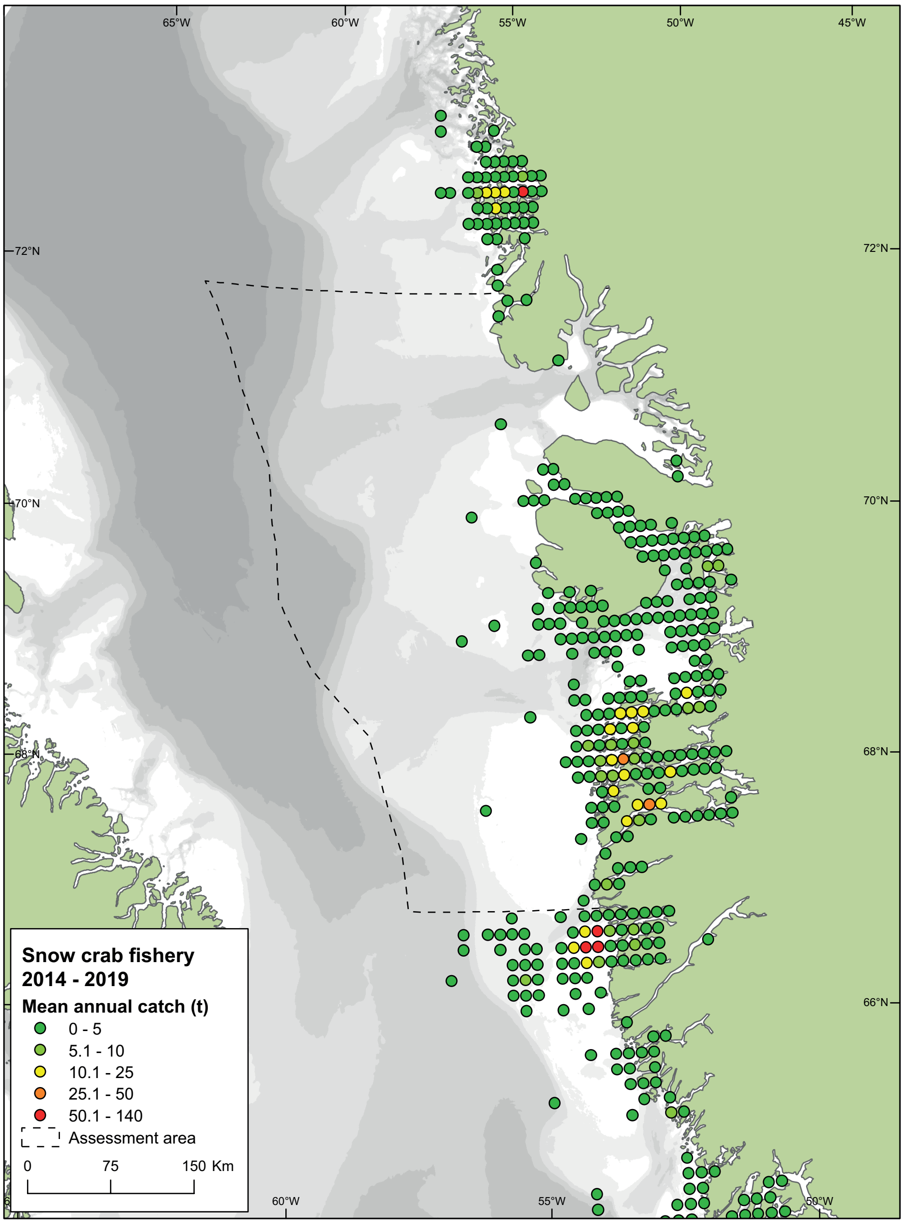


Figure 73. Distribution of snow crab catches in and adjacent to the assessment area, mean annual catch 2014-2019. Distribution based on the NAFO-grid.

Iceland scallop

Iceland scallops are caught in rather shallow water where currents are strong. This fishery was previously relatively important in the assessment area. In the years 2003 and 2004 the fraction of the total catch in Greenland (about 2500 t) ranged between 58 and 68% (Mosbech et al. 2007a). Presently, no fishery for scallops takes place in the assessment area.

Lumpsucker

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. Figure 74 shows the distribution of the catches.

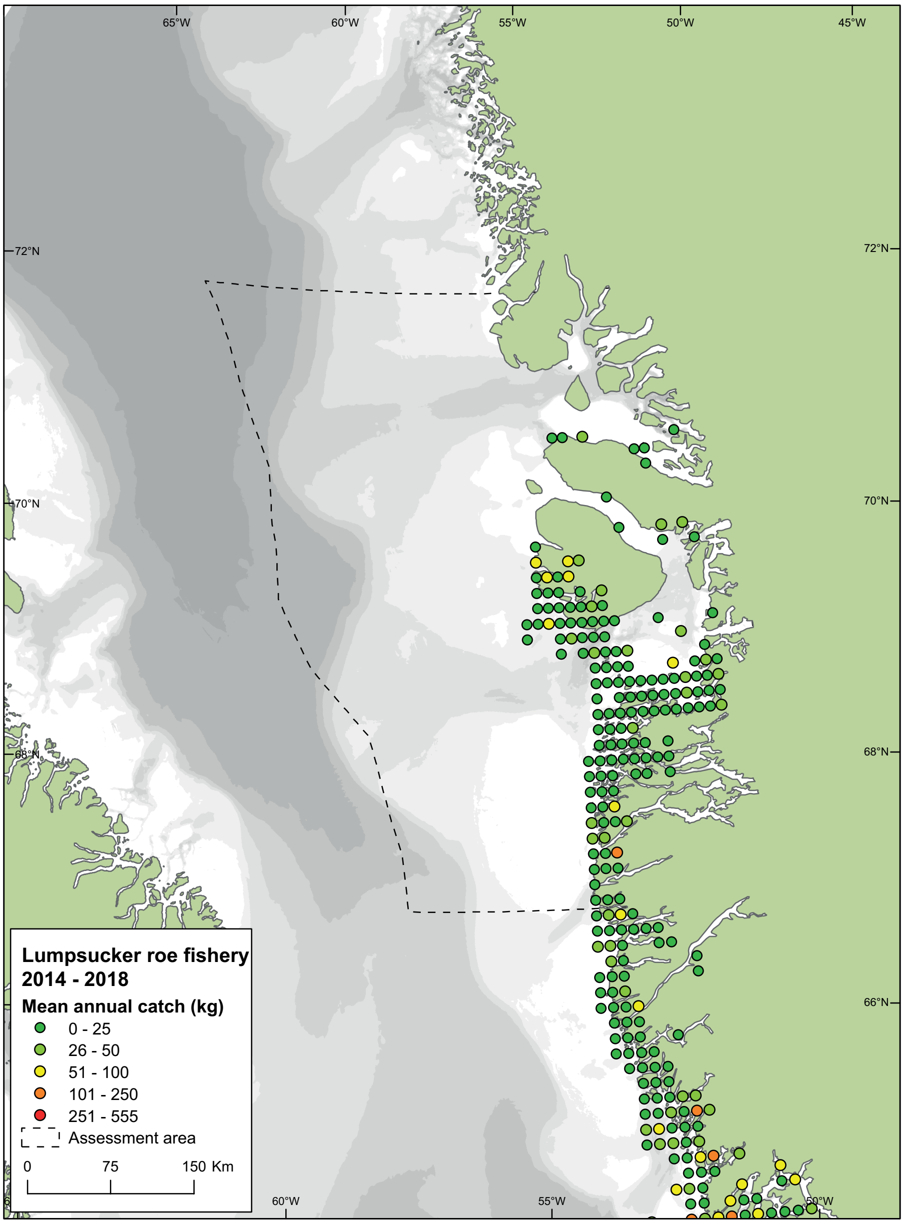
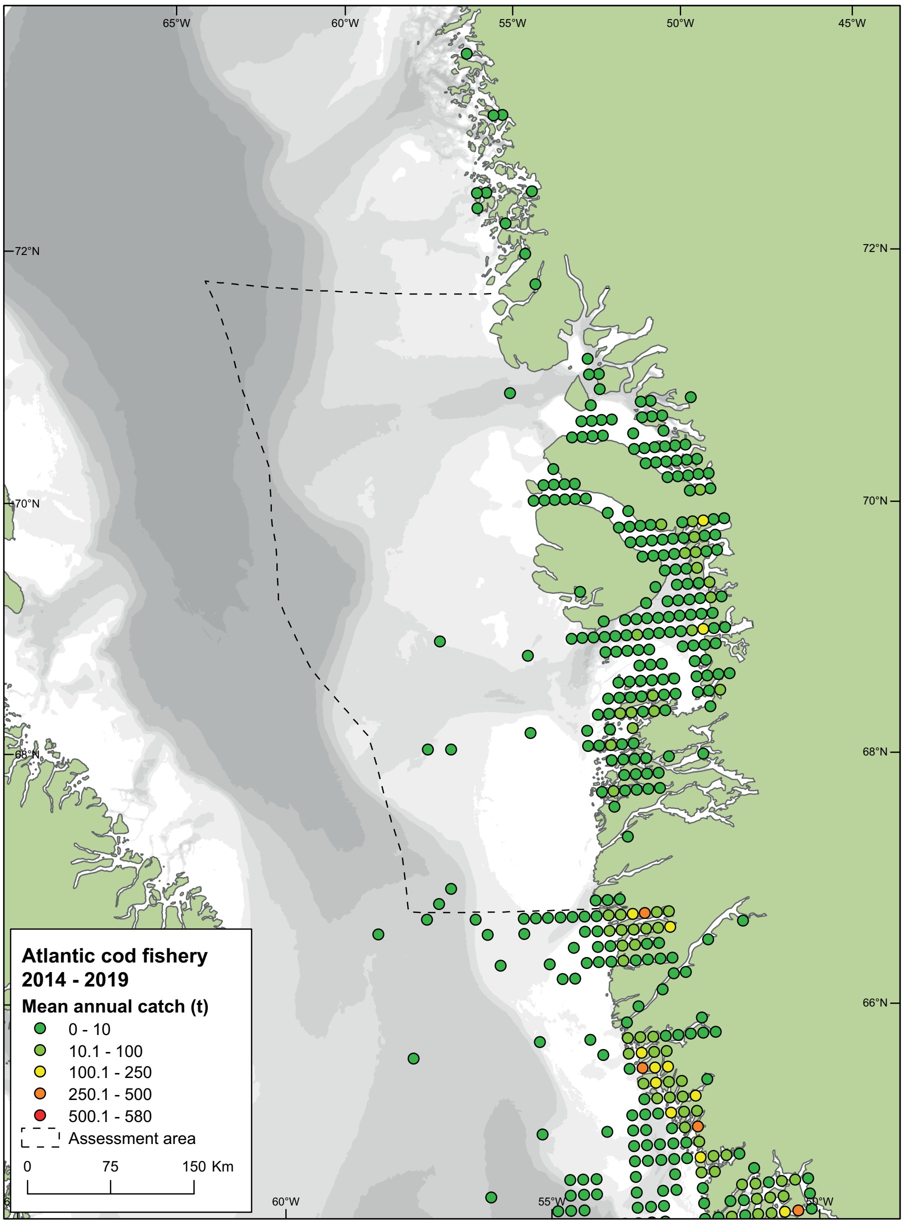


Figure 74. Distribution of lumpsucker catches in and adjacent to the assessment area, mean annual catch 2014-2019. Distribution based on the NAFO-grid.

Figure 75. Distribution of Atlantic cod catches in and adjacent to the assessment area, mean annual catch 2014-2019. Distribution based on the NAFO-grid.



Atlantic cod
This species is also fished on commercial basis in the assessment area, although the landings are relatively small (Figure 75). In 2019, the total catches in the assessment area were approx. 4500 t (Greenland Statistics 2020).

5.3.2 Subsistence and recreational fisheries and hunting

Lars M. Rasmussen (GINR) & Aqqalu Rosing-Asvid (GINR)

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. In the larger towns, however, subsistence hunting has gradually developed into recreational activities.

The income generated from subsistence hunting, i.e., the local sale of meat and skin, is still an important source of livelihood and the fish, birds and marine mammals also serve as important food supply for hunters and their relatives and in the northern areas as food for the sledge dogs (Bagoien et al. 2001). Many hunting products are also used for clothing, jewellery and art.

Many other species of fish are utilised on subsistence basis (some are also used on commercial basis, see above), such as: capelin, spotted wolffish, Greenland halibut, redfish, Atlantic cod, polar cod, Greenland cod and Greenland shark.

The species that will be most vulnerable to oil spills are those caught close to the shoreline: capelin, lumpsucker and Arctic char, and important areas in the assessment area for fisheries of these species were identified by the oil spill sensitivity mapping project covering West Greenland as far north as 72° N (Olsvig & Mosbech 2003, Mosbech et al. 2007a).

5.3.3 Bird hunting

Flemming Merkel (GINR)

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 (Link), 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 76). Within the assessment area the average number of murre catches 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 for the hunt, 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 and vary between species and region. For most species, the hunting season in the assessment area is from 1 September to 31 March. However, some species have a shorter season (e.g. thick-billed murre from 15 September to 15 November in the northern part of the assessment area and 1 November to 15 December in the southern part). In addition, there are daily

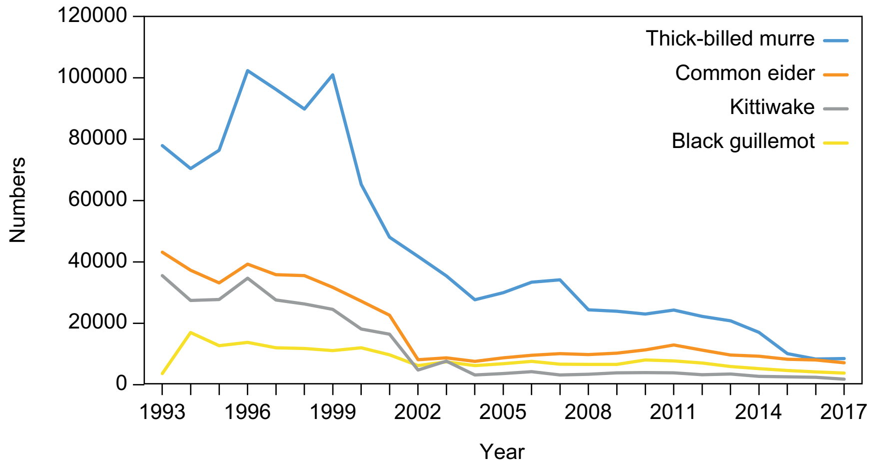


Fig. 76. Annual number of harvested thick-billed murre, common eider, black-legged kittiwake and black guillemot in the region between Sisimiut and Uummannaq (~ the assessment area) reported to the bag-record system in West Greenland (Piniarneq) in the period 1993-2017 (data from Piniarneq, APNN).

quotas for some of the most hunted species: eiders, thick-billed murre and kittiwake. These quotas vary between species, between different periods of the year and between occupational and recreational hunters.

5.3.4 Hunting of marine mammals

Tenna Boye (GINR), Fernando Ugarte (GINR), Malene Simon (GINR), Erik W. Born (GINR), Nynne H. Nielsen (GINR) & Mads Peter Heide-Jørgensen (GINR)

Only occupational hunters are allowed to take large whales, polar bears and walrus, while small whales and seals (as well as birds and land mammals), are accessible to recreational hunters also.

Minke whales, fin whales, bowhead whales and humpback whales are hunted in West Greenland and annual quotas were prior to 2019 set every 5 years by the IWC (The International Whaling Commission) (Table 13). From 2019, the quotas were set for a 7-year period. The Greenland government divides the quota among the different municipalities.

Polar bear hunting

Polar bears in the assessment area belong to the Baffin Bay population, which is shared and hunted by Greenland and Canada. During 1993-2005 (i.e. since the introduction of the Piniarneq catch reporting system, 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

Table 13. West Greenland quotas in 2020 for the five species of cetaceans regulated by quotas (APNN, https://naalakkersuisut.gl; GINR 2020).

Species	West Greenland quota	Quota in the assessment area*	Catch in the assessment area in 2019
Minke whale	164	Open	22
Fin whale	19	Open	
Humpback whale	10	5	3
Bowhead whale	2	2	0
Narwhal	410	245	231
White whale	340	200	94

*Included in West Greenland quota

Table 14. Polar bear catches and biological advice (GINR 2020). Catches are presented as the 3-year average and are combined removals from Greenland and Canada, including legal harvest, pouching and kills of defence of life and property. Only Baffin Bay bears are taken in the assessment area.

Population	Average yearly removals 2017 - 2019	Biological advice
Kane Basin	5	10
Baffin Bay	145	160
Davis Strait	58	No concern (mainly Canadian harvest)
East and Southwest Greenland	66	No advice, assessment ongoing

($r^2 = 0.353$, $p = 0.03$). By far most of the Greenlandic catch of polar bears from the Baffin Bay population takes place in Melville Bay, north of the assessment area. For instance, out of 76 polar bears caught in 2019, only 15 were caught in the assessment area, while 61 were caught in Melville Bay (APNN). Catches of polar bears in Baffin Bay and Kane Basin (further north, between Qaanaaq and Ellesmere Island) follow the advice of the Canada/Greenland Joint Commission on polar bears (Ugarte et al. 2020, GINR 2020). Table 14 shows the catches and the biological advice for the take of polar bears in Greenland in the period 2017- 2019. The catches in the three out of four populations were regarded as sustainable in 2020 (GINR 2020). However, export of polar bear products is forbidden, because there is no biological advice for the polar bears in East and Southwest Greenland (GINR 2020).

Hunting quotas are jointly managed by the Canada and Greenland governments (Joint Canada-Greenland commission on Baffin Bay and Kane Basin polar bears), and they are based on scientific advice and Traditional Ecological Knowledge. The joint 2018 quote was 80 bears, and of these 12 were allocated to the assessment area (Link).

Walrus hunting

Walruses taken in the assessment area belong to a stock shared with Canada. They are hunted in the West Greenland winter quarters until retreat of the pack ice (Born et al. 1994b, Born et al. 1995). Walruses from this stock are also hunted along the southeast coast of Baffin Island (Nunavut) mainly during the period May-November (COSEWIC 2006, Stewart 2008) – i.e. when they generally are absent from West Greenland. The Greenlandic catch is about twice as large as the Canadian, and the majority of walruses in Greenland are taken in or close to the assessment area. For instance, hunters from the assessment area took 44 out of 61 walruses reported from this stock in Greenland in 2019 (APNN).

Management advice for walruses is given by NAMMCO, and catches are considered sustainable (GINR 2020, Ugarte et al. 2020). Table 15 gives the advice for the entire population, while the quota in Greenland in 2020 was set at 74, distributed with 31 for Sisimiut and Maniitsoq, 19 for the central part of the assessment area and 24 in Upernavik, Uummannaq and Ilulissat (Link).

The majority of walruses are caught at Store Hellefiskebanke (Born et al. 2017, Garde et al. 2018). About ca. 68% of the catches reported for West Greenland during 2007-2018 (data from 2018 only partial) were taken in this area; ca. 8% were taken at Disko Bank and ca. 24% in the Upernavik area (Garde et al. 2018). During 2007-2018 the reported annual catch of walrus at Store Hellefiskebanke averaged 30.8 (range: 17-39/year). During the same period the annual catch averaged 3.8 (range: 1-7) at Disko Island and 8.5 (range: 4-13) in the Upernavik area (Garde et al. 2018).

Table 15. Walrus catches and biological advice (from GINR 2020). Catches are presented as the 3-year average of reported catches from Greenland and Canada. Only the Southern Baffin Island / West Greenland population is hunted in the assessment area.

Population	Average yearly removals 2017-2019	Biological advice
Northern Baffin Bay	51	79
Southern Baffin Island / West Greenland	86	100
East Greenland	7	17

Walruses used terrestrial haul-outs in the assessment area in the early 1900s (Chapter 3.8.2), and due to the reduction of sea ice and the increasing population size, this may occur again in the future. In this context it is relevant to note that all walruses hauled out on land are completely protected throughout all of Greenland (Anonymous 2006).

Seal hunting

Seals are important for both recreational and occupational hunters in the assessment area (Table 16). The skins are purchased and prepared for the international market by the tannery in Southwest Greenland, and the meat is used for consumption and also fed to the sledge dogs. In the period 2000-2008, more than half a million seal skins were traded in Greenland. However, in 2008-09 the market for seal skins collapsed and now it is difficult to sell them (Rosing-Asvid 2010). The temporal distribution of the catches is shown in Figure 77.

Harp seals are caught in high numbers (Table 16), 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, and are taken in low numbers then.

Hooded seal can also be caught throughout the year, but most catches occur 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-moulting seals migrate through the assessment area towards their foraging grounds in Davis Strait and Baffin Bay (Table 16).

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

Table 16. Mean annual catch of seals from the settlements in the area between Sisimiut and Uummannaq area (= most of the assessment area) in the period 2014–2018.

Species	Mean annual catch	Range
Harp seal	24,667	21,706-27,671
Ringed seal	6,506	5,852-10,205
Hooded seal	546	397-618
Bearded seal	293	216-352
Harbour seal	protected	–

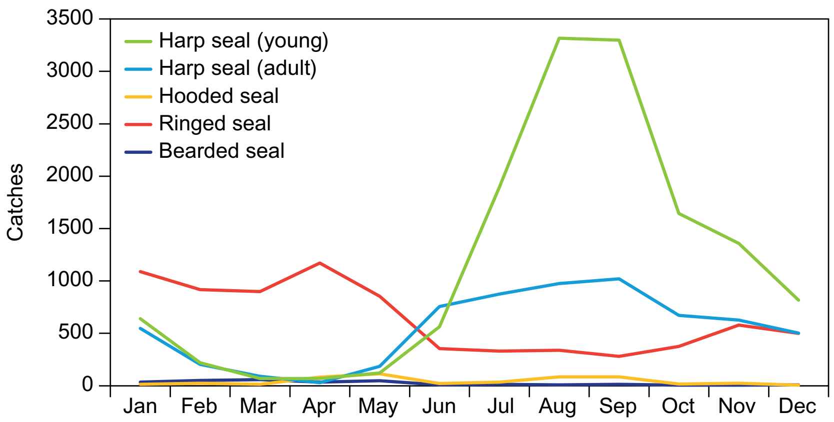


Figure 77. Development in catches of four species of seals through the year in the assessment area. Harp seal catches are distributed on adult and young seals.

which some have likely 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 Davis Strait and Baffin Bay pack ice when it approaches the coast during winter.

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

Since 1993, when the current hunting database was established, the number of hunters reporting catches of seals in the Baffin Bay and Davis Strait area has decreased (Merkel & Tremblay 2018).

Whale hunting

Quotas for large whales (fin, humpback, minke and bowhead whales) in Greenland are set by the International Whaling Commission (IWC). The Government of Greenland divides the quota among the municipalities, where after the municipalities divides their parts of the quota locally. Fin whales, bowhead whales and humpback whales can only be hunted using harpoon cannons and explosive penthrite grenades (Anonymous 2010). Due to a lack of boats equipped with harpoon cannons in the northernmost parts of West Greenland (as well as East Greenland), fin whales and humpback whales are normally taken in Disko Bay or further south. Bowhead whales are hunted only in Disko Bay.

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 17th-19th centuries and by the start of the 20th century the species had become rare in Greenland. In 1927 the species was protected. The population has recovered to the extent that a Greenland quota was approved by the IWC. Since 2008, it has been allowed to harvest two animals per year with the possibility of carrying over up to 2 whales from one year to the next (Table 13). The present quota is valid for the period 20019-2025. Between 2012 and 2019, only one bowhead whale (2015) has been taken in Greenland.

Minke whales have been hunted in West Greenland since the middle of the 20th 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.

The annual quota for minke whales in West Greenland in the period 2019-2025 is 164. 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 handheld harpoons and high-powered rifles. This type of hunt is called 'collective hunt' (Anonymous 2010). Figure 78 shows where minke whales were caught in the period 1991 to 2006.

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. 2007b).

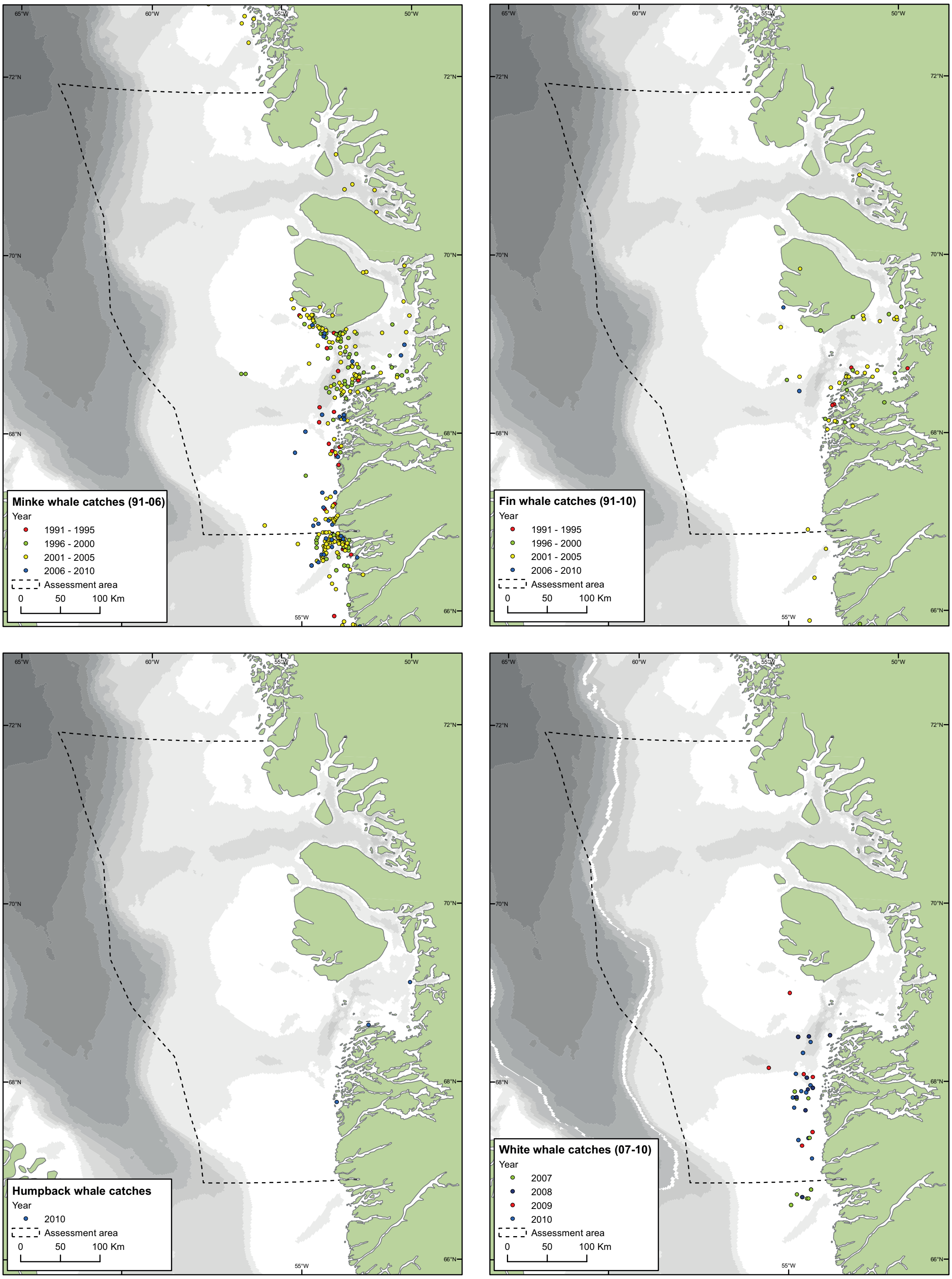


Figure 78. Minke whale, humpback whale, white whale and fin whale catches in West Greenland within varying time periods. For white whales, the figure shows only 7% of the reported catch. (data from APNN).

Greenlanders started catching fin whales from fishing boats equipped with harpoon cannons in 1948, but as early as 1924 there 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 the quota block 2019-2025 (Kapel & Petersen 1982, Caulfield 1997, Witting 2008). See also this link https://iwc.int/html_76. The average catch the whole of Greenland in 2016-18 was 8 fin whales per year (Ugarte et al. 2020). Figure 78 shows where fin whales were caught in the period 1991 to 2010.

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). Greenland begun catching humpback whales again in 2010 (Anonymous 2012). In 2018, the Scientific Committee of the IWC advised that a catch of 10 humpback whales per year for the quota block 2019-2025 is sustainable (https://iwc.int/html_76). Five out of the 10 humpback whales from the yearly quota can be taken within, or close to the assessment area. On average, 4 humpback whales were caught per year in West Greenland between 2016 and 2018 (Ugarte et al. 2020). Figure 78 shows where humpback whales were caught in 2010.

Narwhals and white whales are amongst the most important hunted species 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 (Anonymous 2011) and the southernmost distribution of regular catches in West Greenland are around Sisimiut and Maniitsoq.

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 were extirpated 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 1000 white whales often exceeded the catch of all other whale species combined (Heide-Jørgensen & Rosing-Asvid 2002).

As the number of white whales wintering off West Greenland declined, 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, quotas were established and nowadays the catches are considered sustainable, and the population seems to be increasing (Heide-Jørgensen et al. 2016, GINR 2020). In 2017-2019, a yearly average of 193 white whales were landed in West Greenland; a number considerably lower than the biological advice of 320 (GINR 2020). Figure 78 shows where white whales were caught in the period 2007 to 2010.

The recent history of narwhal hunting is similar to that of white whale, with catches that were considered unsustainable by the JCNB and NAMMCO at the end of the 20th century, leading to the introduction of quotas in 2004. However, in contrast with white whales, catches for some narwhal stocks are higher than the advice, and therefore it cannot be documented that hunting is sustainable in Greenland as a whole (GINR 2020). In the assessment area, catches can, by a small margin, be considered sustainable. In 2017-2019, catches in Uummannaq, at the northern part of the assessment area averaged 153 narwhals per year, compared to the advice of 154. In the Disko Bay area, catches for the same period averaged 97 narwhals per year, which is the same number as advised (GINR 2020).

Harbour porpoise, pilot whales and, to some extent white-beaked and white-sided 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 and white-sided dolphins and bottlenose whales were added in 2003. White-beaked and white-sided dolphins have the same name in Greenlandic, which make it impossible to differentiate between the two species in the reporting system. 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.

The data is entered into a large database administrated by the Ministry of Fisheries, Hunting and Agriculture. The data presented below are derived from this database. A partial validation of killer whale data from 1996 to 2007 showed that there are human mistakes in the reporting.

The average yearly reported catch of harbour porpoise in Greenland for the period 2015-2017 was 2275. This number is higher than the 1869 recommended by the scientific committee of NAMMCO (Ugarte et al. 2020). The proportion of catches taken by hunters resident in the assessment area has increased from 9% of the total catches of west Greenland in 1993-2004 to 24% in 2005-2018 (Figure 79a).

Due to their unpredictable occurrence, pilot whales, white-beaked and white-sided dolphins and killer whales are caught opportunistically, but with a general increase in catches over the past decade (Figure 79b). The North Atlantic Marin Mammal Commission (NAMMCO) has not assessed whether these catches are sustainable (GINR 2020, Ugarte et al. 2020). The occurrence of pilot whales 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 5 and 433. Average reported yearly catches in West Greenland in 2015–2017 were 254 pilot whales, half of which (55%) were by residents in the assessment area (Figure 79b).

In Greenland, white-beaked and white-sided dolphins are caught for subsistence. Annual catches of dolphins reported in West Greenland vary from 0 to 243, with a 2015–2017 average of 67, of which around 9% were from hunters resident in the assessment area (Figure 79c).

Killer whales are hunted partly for human consumption 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. There were 34 reported killer whale harvests by hunters from West Greenland in 2015–2017, of which 9 (26%) were from hunters from the assessment area. This number is probably an overestimation, as killer whale catch reports from 1996 to 2007 went through a process of validation, in which all hunters were contacted by phone or mail. A large proportion of the reports were false positives, where the hunter had reported other species as killer whales. Catches from 2008 onwards have not been validated, and therefore the newest numbers are probably too high and it is not possible to compare the development of the hunt.

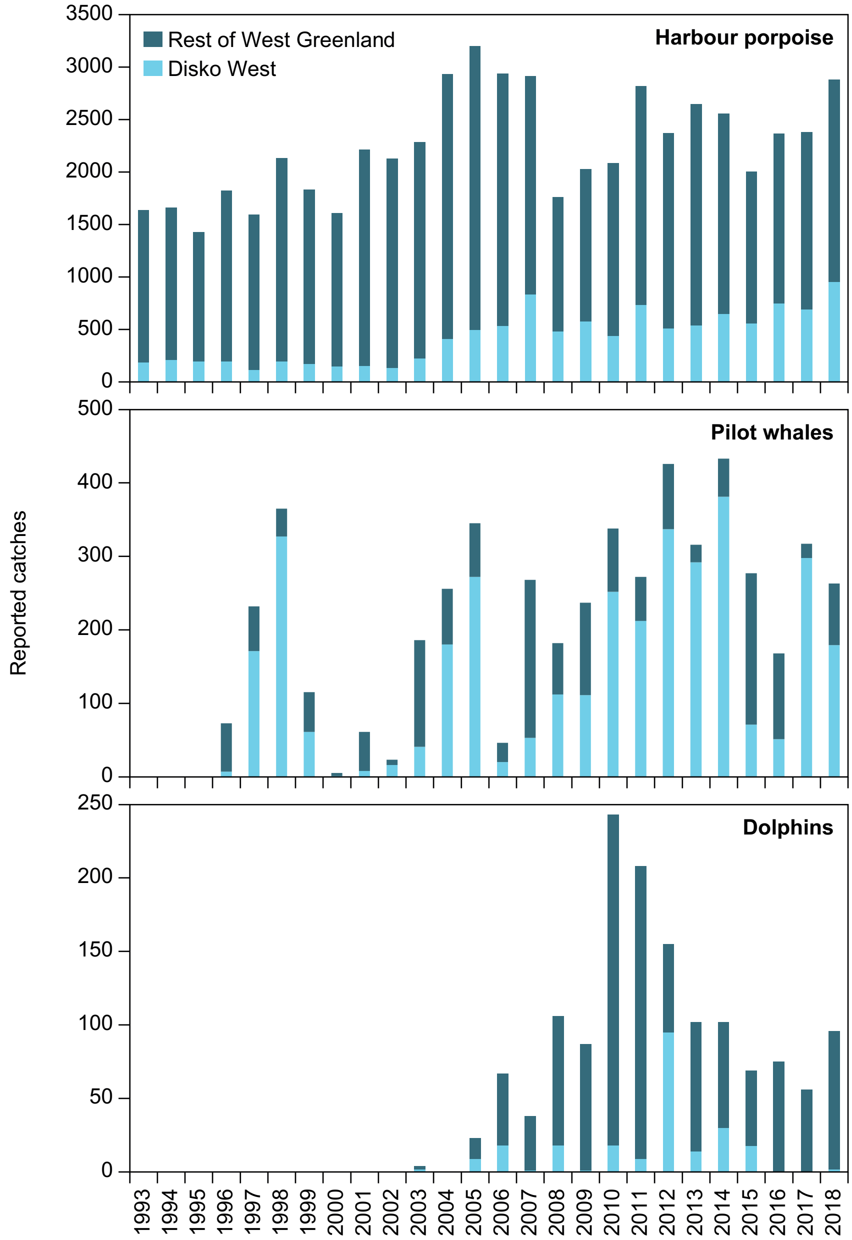


Figure 79. The catch of A) harbour porpoise, B) pilot whale and C) white-beaked and white-sided dolphin in the assessment area (grey bars) and the rest of West Greenland (blue bars).

Nevertheless, there seems to be an increase of catches north (Upernavik) and south (Cape Farewell) of the assessment area (APNN unpublished data).

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 diarrhoea to humans as well as dogs.

5.3.5 Tourism

David Boertmann (AU)

The tourist industry is one of three major sectors within the Greenland economy, and the industry has been increasing in importance both nationally and locally in the assessment area (Dawson et al. 2018). The National Strategy of Tourism 2008-2010 planned a 10% increase per year in the number of cruise ship tourists alone (Department of Industry 2007), but this was however, not achieved (Grønlands Selvstyre, without year).

The most important asset for the tourist industry is the unspoilt, authentic and pristine natural environment and the small settlements. 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 2019 were approximately 105,000 guests and approximately 265,000 'bed nights' (Statistics Greenland 2020). In the main tourist town Ilulissat, approximately 77,000 'bed nights' were recorded in 2019. The development is shown in Figure 80.

In addition, cruise ships brought until 2017 an increasing number of tourists to Greenland (Figure 81). 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 (e.g. Dawson et al. 2017).

A number of tourists also go to Greenland for outdoor leisure activities (mountaineering, kayaking, etc.) or scientific expeditions (natural history), but statistics on these tourists are not available.

Finally an increasing number of pleasure crafts (yachts and private boats) visits the assessment area either as primary destination or as transients en route to the North West Passage (Dawson et al. 2018).

Tourist activities

The activities are centered in the main town of the assessment area, Ilulissat. Here the great attraction is the UNESCO World Heritage Site – Ilulissat Icef-

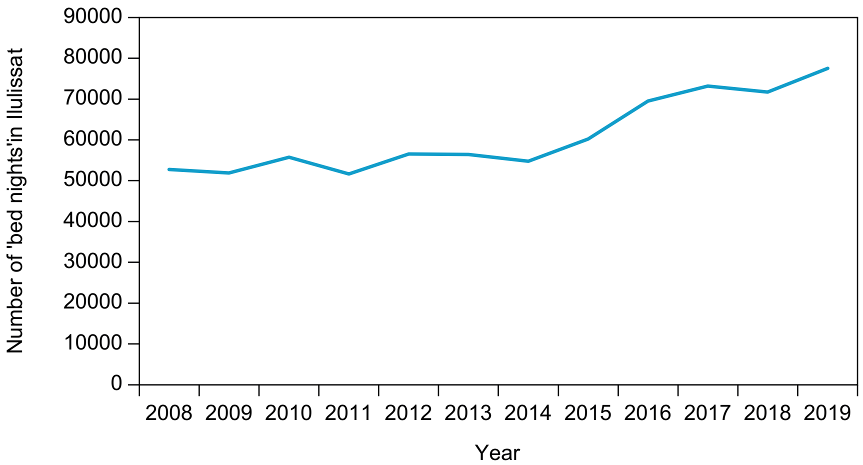


Figure 80. Development in number of "bed-nights" sold at hotels in Ilulissat (data from Greenland Statistics).

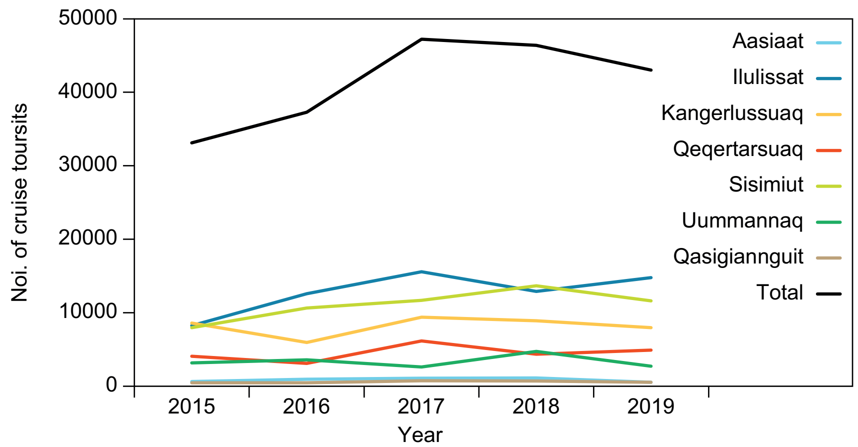


Figure 81. Development in number of cruise ship passengers in a number of towns in the assessment area (data from Greenland Statistics).

jord and there are several hotels in the town. The season starts for land based activities in early spring, when there are opportunities for dog sledding, but the main season is summer (July-August), when the cruise ships arrive and it is possible to sail from the towns to attractions such as archaeological sites, bird cliffs, whale habitats, glaciers, small settlements, hiking areas and areas with scenic views. In Ilulissat the following activities take place (Link):

- Whale watching cruises and wildlife exploring- summer and autumn,
- Jakobshavn Icefjord 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. In Ilulissat the passengers mainly visit the town: museums, art exhibitions and restaurants and explore the Isfjord,
- Skiing (cross country), mainly February to April,
- Hiking and mountaineering. Mainly spring and summer season.

Dawson et al. (2017) lists 33 different activity types that are advertised as being in offer in the Baffin Bay/Davis Strait region, including besides those mentioned above: Northern light watching, scuba diving, sport fishing etc.

Many of the tourist activities within the assessment area take place in the coastal zone and extensive oil activities in this area will probably impact on local tourist activity and the related industries.

5.4 Impacts of climate change in the Disko West and Davis Strait region

Anders Mosbech (AU) & Eva Friis Møller (AU)

With contributions from Kristin L. Laidre (GINR), Erik W. Born (GINR), Tenna Boye (GINR) & Martin Blicher (GINR)

The Arctic environment is rapidly shifting into a new state, driven by rising temperatures caused by increases in greenhouse gas concentrations in the atmosphere. It is assessed that Arctic ecosystems face significant change, stress and disruption (AMAP 2019). However, natural variability and model limitations make precise predictions of future change impossible, and it is difficult to separate the global climate change signal from the impact of multi-decadal poleward ocean heat anomalies on northern climate (Årthun et al. 2017). Recent assessments of climate change and the impact on the environment in the Arctic have been made by IPCC (Meridith et al. 2019), NOAA report cards (Link), AMAP (2017, 2018, 2019) and CAFF (2017).

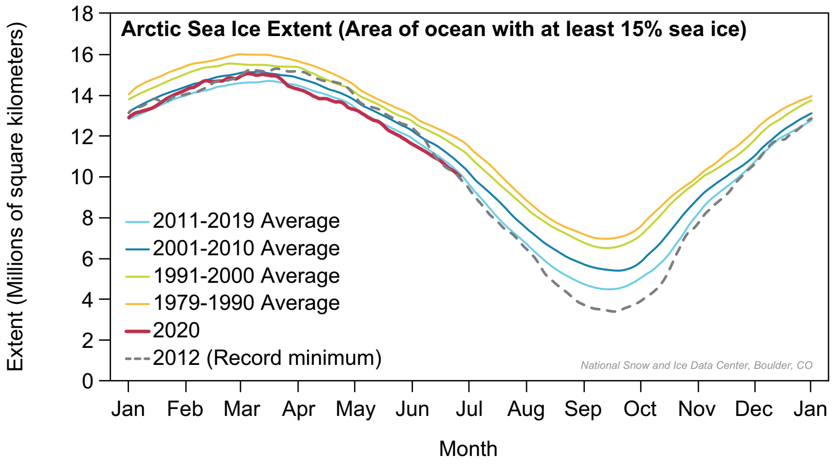
The AMAP *Arctic Climate Change Update 2019* supports the fundamental conclusions of the larger scientific reports and has been used extensively for the following general introduction together with the AMAP 2018a report *Adaptation Actions for a Changing Arctic – Perspectives from the Baffin Bay/Davis Strait (BBDS) region* which includes a regional review of climate change studies.

Observed and projected annual average warming in the Arctic continues to be more than twice the global mean, with higher increases in winter. Arctic annual surface air temperatures in 2014, 2015, 2016, 2017 and 2018 exceeded those of any year in the period 1900–2013.

5.4.1 Observed trends in Arctic Sea Ice

Sea ice is currently thinning and shrinking more rapidly than it has been projected by most models. Arctic winter sea ice maximums in 2015, 2016, 2017 and 2018 were at record low levels, and the 12 lowest minimum extents in the satellite record have all occurred in the last 12 years (Figure 82). Except for the coldest northern regions of the Arctic Ocean, the average number of days with sea ice cover in the Arctic declined at a rate of 10–20 days per decade over the period 1979–2013, with some areas seeing much larger declines (Figure 83). Sea ice extent has varied widely in recent years, but continues a long-term downward trend. A record low minimum sea ice extent occurred in 2012 (Figure 82) and a record low maximum sea ice extent occurred in 2016. Sea ice has gone through a transition from mostly thick multi-year sea ice to younger and thinner seasonal sea ice (Figure 84). Older ice that has survived multiple summers is rapidly disappearing; most sea ice in the Arctic is now 'first year' ice that grows in the autumn and winter but melts during the spring and summer (Figure 84). Sea ice thickness in the central Arctic Ocean has declined by 65% over the period 1975–2012. The volume of Arctic sea ice present in the month of September has declined by 75% since 1979 (Figure 85).

Figure 82. Sea-ice extent in the Arctic, average 1979-1990, 1991-2000, 2001-2010 and 2011-2020 in millions of square km. The minimum year 2012 also shown. Figure form US National Snow and Ice Data Center.



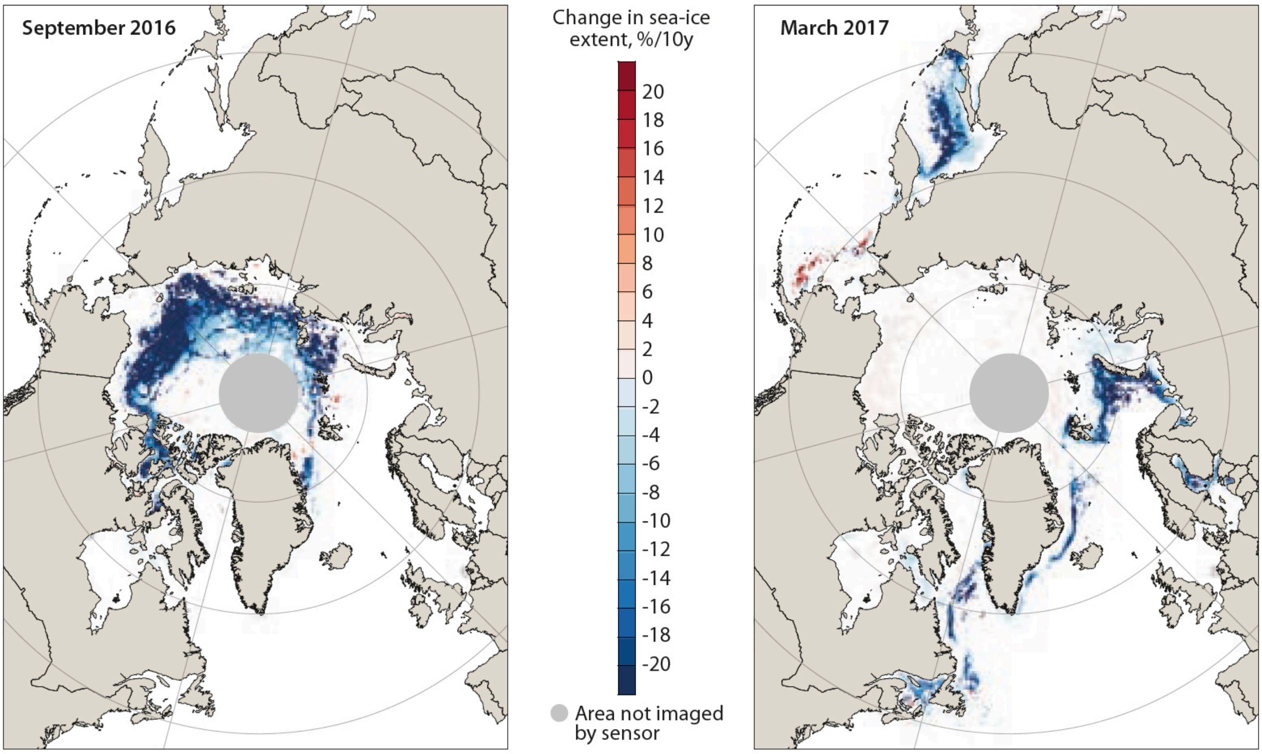


Figure 83. Linear trends in sea-ice extent (relative to the 1981-2010 average) for September 2016 and March 2017. Blue areas indicate loss of ice. Data source: NASA Team algorithm and the NSIDC Sea Ice Index (Fetterer et al. 2016).

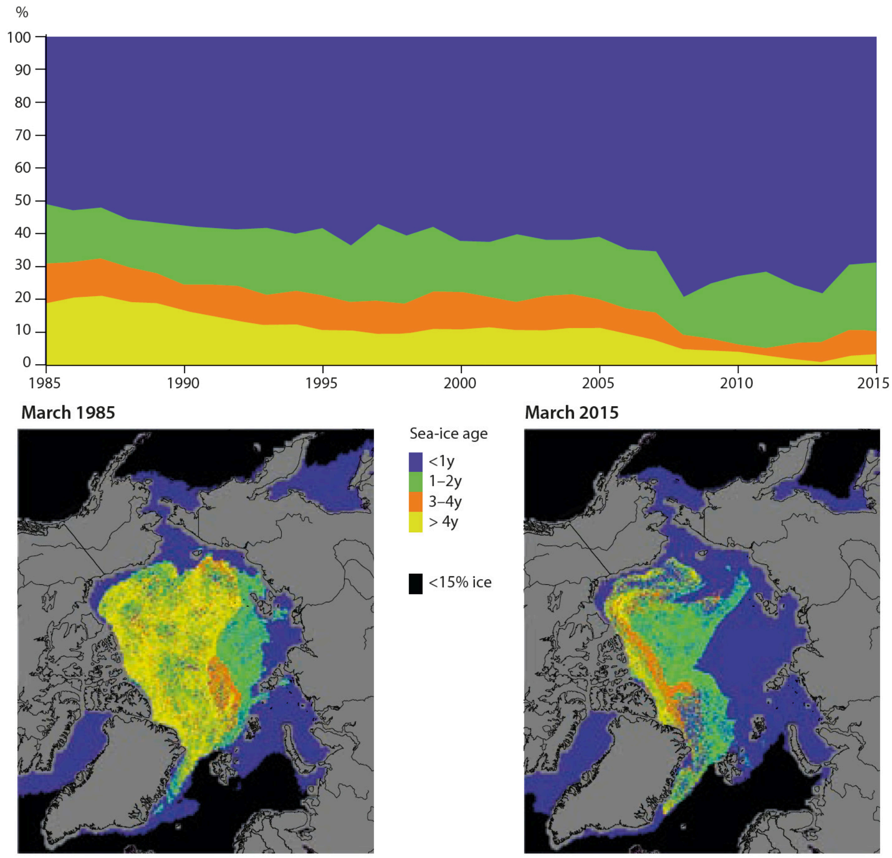


Figure 84. A time series of sea-ice age in March from 1985 to the present (upper panel) and maps of sea ice age in March 1985 and March 2015 (lower panel) (Perovich et al. 2015, Barber et al. 2017).

The reductions in sea ice are caused by a combination of atmospheric warming and the influx of warmer waters from the south. The coverage, extent, and thickness of multi-year sea ice reflect climate conditions over years to decades, making its loss an indicator of Arctic and global climate change. The later freeze-up of sea ice contributes to the rise in cold-season Arctic temperatures and affects the Arctic system's overall condition, which in turn can have far-reaching consequences for Arctic ecosystems.

The loss of sea ice has triggered shifts in the timing and intensity of marine algal blooms, with potential impacts throughout the food web including krill, fish, birds, and mammals in marine ecosystems. Areas experiencing double

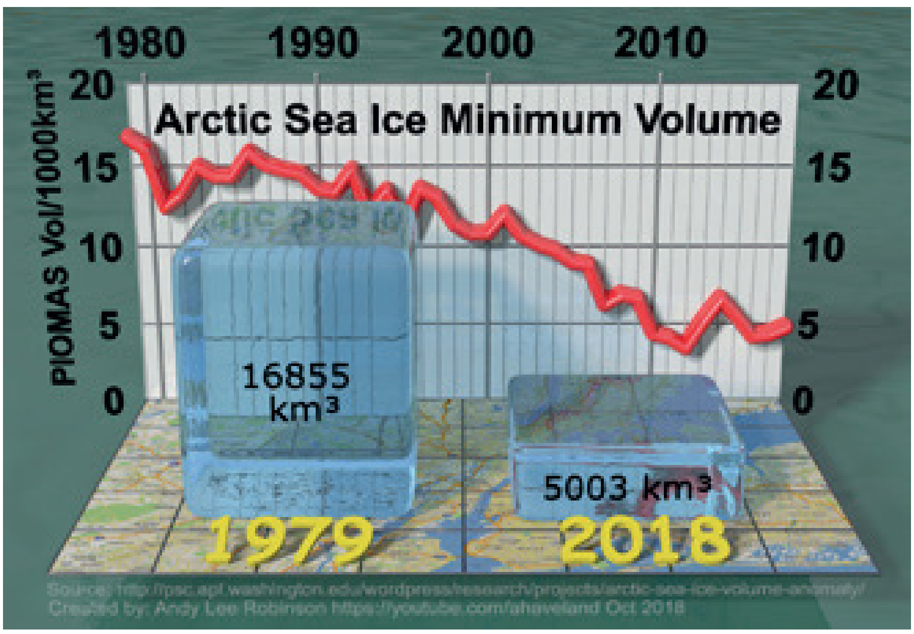


Figure 85. Arctic sea ice minimum volumes, 1979–2018. Visualization by Andy Lee Robinson using data from Pan-Arctic Ice Ocean Modelling and Assimilation System, University of Washington, Polar Science Center. Animated version available at https://www.youtube.com/watch?v=GZzEUJ86PCg

blooms (one in spring and one in autumn) have increased in regions with the greatest loss of sea ice. Sea ice loss also has direct impacts on species such as polar cod, ivory gull, whales, seals, and polar bears. The decline of sea ice in the Arctic appears to be linked to a loss of biodiversity in sea ice habitats, although observations also show that some species (e.g., a variety of whales, including killer whales, blue whales, fin whales and white whales) are expanding their ranges or are present during a longer portion of the year. The ranges of some marine fish species are shifting northward in response to warmer ocean waters, leading to changes in diet, altering predator-prey relationships, habitat uses and migration patterns.

5.4.2 Projections: What will happen in the coming decades

With the warming already committed in the climate system plus the additional warming expected from rising concentrations of greenhouse gases in the atmosphere, the Arctic will experience further significant changes during this century even if greenhouse gas emissions are stabilized globally at a level lower than today's. If emissions continue to increase, future changes in the Arctic would be even more substantial and long-lasting. The following description is based on updated climate projections in AMAP (2017, 2018 and 2019) using scenarios that depict plausible changes in future greenhouse gas emissions and concentrations over time.

Sea Ice

The Arctic is expected to be largely free of sea ice in late summer within the next few decades, possibly as early as the 2030s, although natural variability and other factors make it impossible to make precise predictions. Some models suggest that if global warming is stabilized at 1.5 °C, the probability of an ice-free summer occurring in any given year would be roughly 2 percent; at 2 °C, the probability would rise to 19–34 percent. The ice that appears in winter will be thinner, more salty, less rigid, and more mobile than today's sea ice. More open water is expected in winter, affecting temperature and the exchange of moisture between the atmosphere and ocean, leading to more extreme weather locally and at lower latitudes. See recent trends and projections from the assessment area in Figures 86 and 87.

Air temperature, and stratification and nutrients in the sea

Autumn and winter temperatures will increase by a regional average of 4 °C over the next 30 years – twice the warming projected for the Northern Hemisphere as a whole – with new record temperatures observed in some regions and years (Figure 88). The strongest warming is projected to occur during the cold season. Even several years of cold weather due to natural variations are unlikely to affect the long-term trend, and efforts to reduce greenhouse gas emissions will not affect projected temperatures until the latter half of this century. The warming climate will increase the amount of freshwater in the Arctic, with important implications for ecosystems and infrastructure.

Climate scenarios for the BBDS region forecast local summertime air temperature increases of 1 to 4 °C by 2030 and 1.5 to 10 °C by 2080 (relative to 1986–2005), corresponding to an average surface water warming of 0.2 °C per decade over the next 50 years (Langen et al. 2018). By 2080, total precipitation is expected to change by 10 to 70% during winter and by 0 to 35% during summer. In addition, there will be an increase in freshwater input to the surface from the melting Greenland Ice Sheet (Mankoff et al. 2019 & 2020). In combination, warming and freshening will increase the buoyancy of marine surface waters and this will cause a stronger vertical stratification which will tend

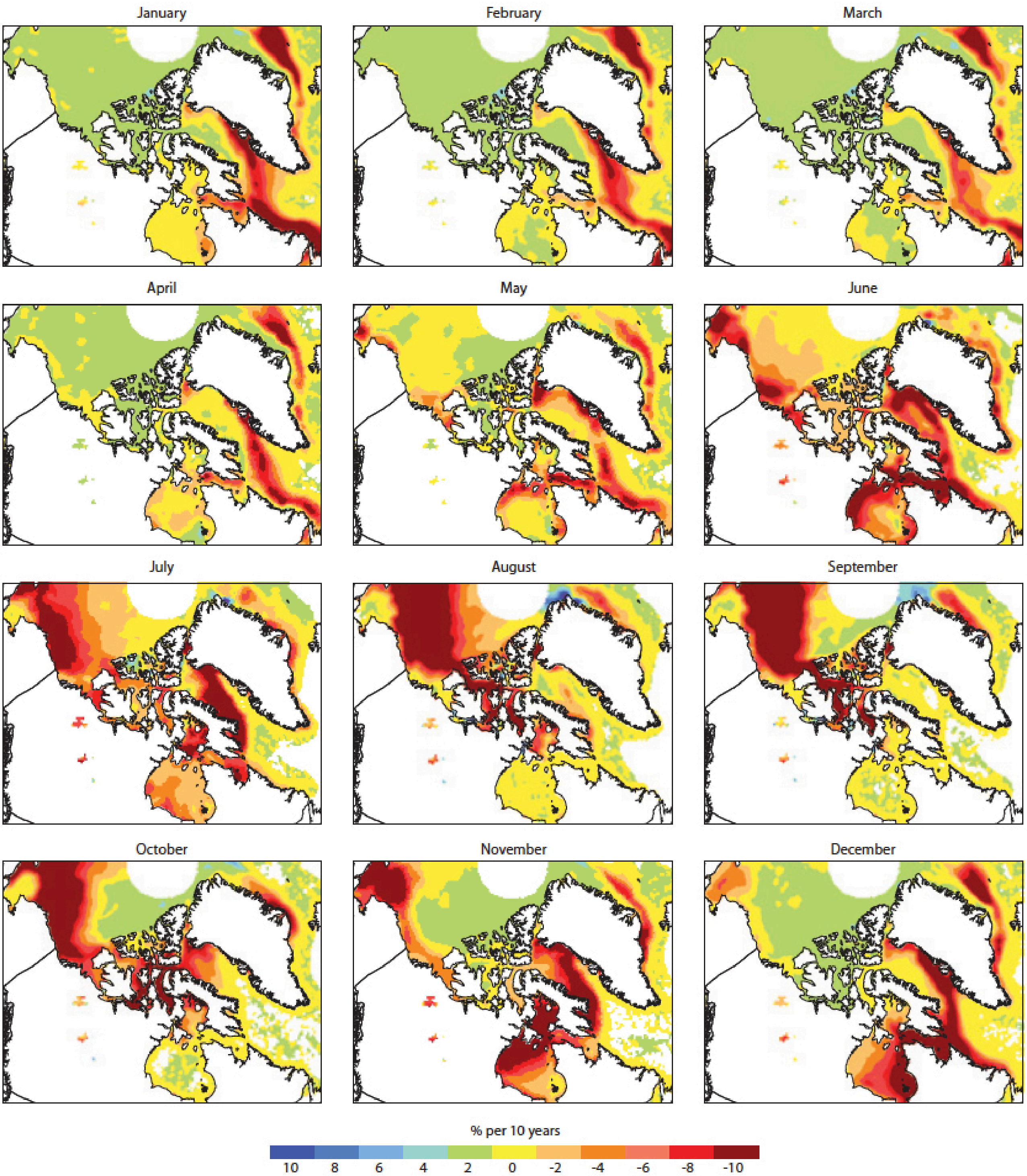


Figure 86. Trends in monthly average ice concentration (%) over the Canadian Arctic and adjacent waters, 1979–2012, expressed as percent change per decade (based on the passive microwave satellite data set of Cavalieri et al. (1996), updated to 2012) (From Langen et al. AACA: AMAP 2018).

to reduce the nutrient supply from deeper layers to the photic zone. Thus, while the reduced ice cover makes light conditions for a longer phytoplankton growing season a stronger stratification in the future may limit the nutrient supply and thus the total primary production (Tremblay et al. 2015). Still, recent studies show indications of a larger primary production and biomass with both a spring bloom and a summer/autumn bloom in the Baffin Bay (AMAP 2018a, Lewis et al. 2020) and see below.

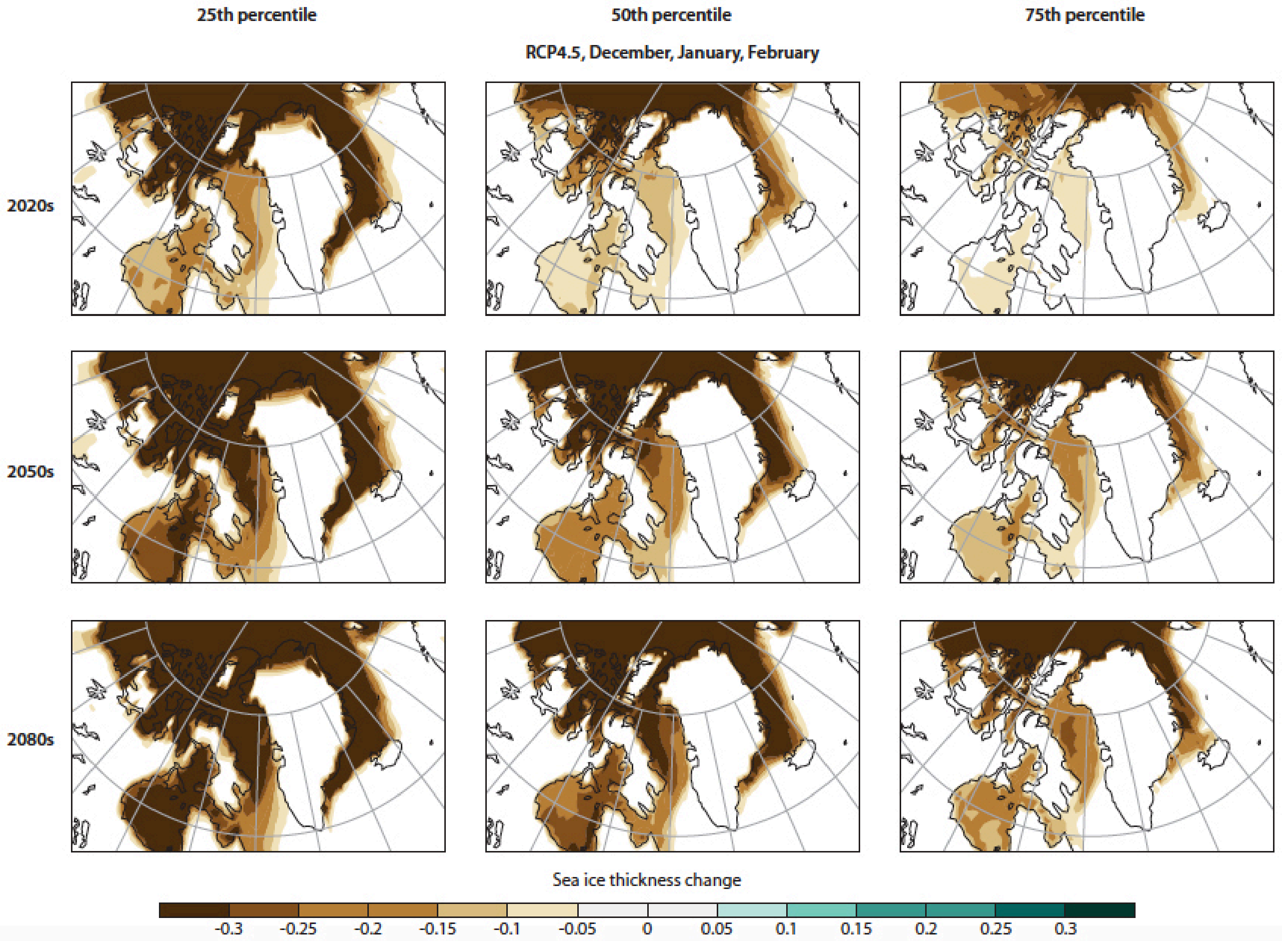


Figure 87. Projected change in winter (DJF) sea ice thickness (change in meters relative to the 1986–2005 average) for the RCP4.5 scenario, according to a 29-member CMIP5 multi-model simulation. Results are shown for three periods in the future: 2016–2035 (labelled 2020s), 2046–2065 (labelled 2050s) and 2081–2100 (labelled 2080s). The figures illustrate the 25th, 50th, and 75th percentile changes projected by the CMIP5 models (from Langen et al. 2018).

Acidification

The Arctic Ocean is continuing to remove carbon dioxide from the atmosphere and to acidify. In the Arctic Ocean, the area corrosive to organisms that form shells and skeletons with calcium carbonite expanded between the 1990s and 2010, with instances of extreme calcium carbonite under-saturation (IPCC 2019). Water with pCO_2 (partial pressure) substantially higher than the atmospheric values is exported from the Arctic Ocean to the North Atlantic both to the west and east of Greenland. The values are even higher than atmospheric values projected for the year 2100. There is a risk that with warmer climate the thawing of permafrost and increasing microbial activity will lead to more supply of organic matter and thus even higher pCO_2 in these waters (Swedish Agency for Marine and Water Management 2017). The resulting under-saturation of upper waters with respect to calcium carbonate is amplified by addition of freshwater from river runoff and sea ice melt, conditions that are also increasing with climate change and can cause areas corrosive to organisms that form shells and skeletons using calcium carbonite.

Populations and ecosystems

The rate and magnitude of climate changes projected for the Arctic will push some species out of their ranges, while other species may colonize new areas and the entire food web will change. See Table 17 for a summary of responses of Arctic marine organisms to climate change (for further info see CAFF 2017).

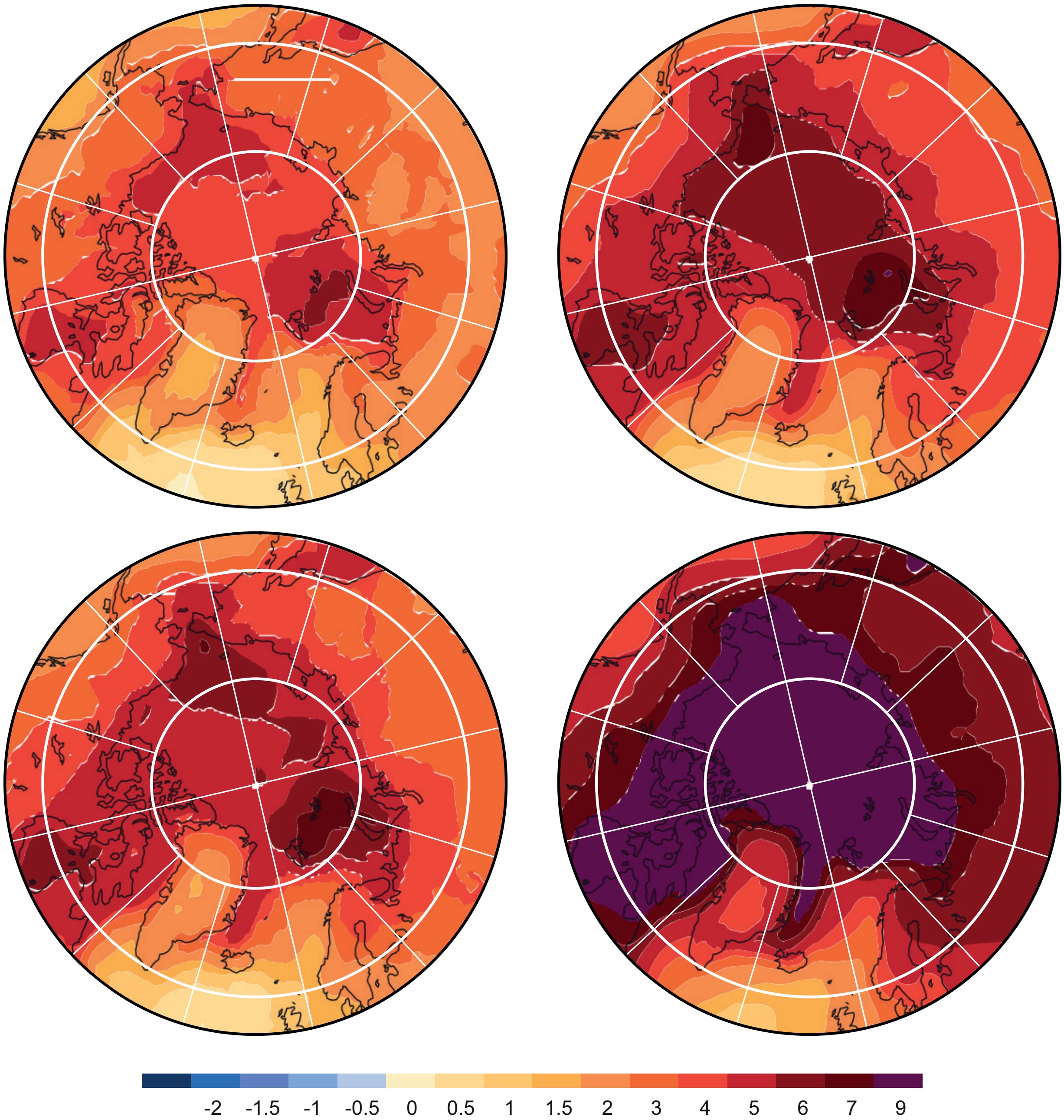


Figure 88. Projected changes in near-surface temperature (50th percentile), relative to 1986–2005, for December–February under the IPCC ‘intermediate’ RCP4.5 scenario (left panels) and the ‘worst case’ RCP8.5 scenario (right panels). Upper panels are for the decade of the 2050s, lower panels are for the 2080s (graphic courtesy of G. Flato, Environment and Climate Change Canada).

Table 17. Summary of responses of Arctic marine organisms to climate change (Wassmann et al. 2011).

Responses	Nature of changes
Range shift	Northward displacement of subarctic and temperate species, cross-Arctic transport of organisms from the Pacific to the Atlantic sectors
Abundance	Increased abundance and reproductive output of subarctic species, decline and reduced reproductive success of some Arctic species associated to the ice and species now used as prey by predators whose preferred prey have declined
Growth and condition	Increased growth of some subarctic species and primary producers, and reduced growth and condition of icebound, ice-associated, or ice-born animals
Behaviour and phenology	Anomalous behaviour of ice-bound, ice-associated, or ice-born animals with earlier spring phenological events and delayed fall events
Community and regime shifts	Changes in community structure due to range shifts of predators resulting in changes in the predator-prey linkages in the trophic network

Phytoplankton production may become less predictable and may increase due to the warmer waters and reductions in sea ice. In the assessment area there has been a slightly increasing trend in primary productivity and biomass in Baffin Bay and on the West Greenland Shelf (Tremblay & Sejr 2018, Lewis et al. 2020). The increase in Baffin Bay can be related to the longer growing season available with the reduction in sea ice. However sea ice is at present not considered the main limiting factor for productivity in the Disko West and eastern Davis Strait shelf areas, here the nutrient supply to the photic zone seems to be more important (Tremblay & Sejr 2018). The nutrient supply depends mainly on upwelling, stratification and mixing forces (Lewis et al. 2020).

Increasing numbers of southern species are moving into Arctic waters. In some cases, they may outcompete and prey on Arctic species, or offer a less nutritious food source for Arctic species. The boreal copepod *Calanus finmarchicus* is expanding north from the Atlantic and replacing its larger Arctic relatives *C. glacialis* and *C. hyperboreus* as documented in the Disko Bay area (Møller & Nielsen 2019). While this could be a threat to a high Arctic specialist like the little auk, which is depending on catching the large nutritious copepods one by one (Frandsen et al. 2014, Harding et al. 2009, Enstipp et al. 2018), the overall ecosystem response to changes in the species assemblage may be more resilient (Renaud et al. 2018).

A northward movement can be a fast response to the climate warming for mobile open water species, such as polar cod and capelin. While species linked to the sea bottom or shallow water, such as benthic invertebrates and some fish, may encounter problems finding suitable habitat if they move northward. Further, changes in climate may be too fast to allow for slow-growing and long-lived sessile organism like cold water corals to establish communities in suitable habitats further north because new habitats may become too warm during the decades it takes for coral gardens to establish. See Box 8 for a discussion of climate change effects on benthos in the Disko West and Davis Strait areas.

Fish

The important fish stocks in the region exhibit significant different trends. The Greenland halibut stock is considered stable; the northern shrimp stock is generally on a downward trend and the shrimp fishery is moving northward; while the Atlantic cod are slowly rebuilding the stock. Although the effect of warming is difficult to predict and there are both direct and indirect effects some experience from previous warm periods can be used (see e.g. Hovgård & Wieland 2008). Thus, it can be expected that the shrimp population will continue to decline in the region and finfish populations will increase. Most likely the ecosystem will shift from a shrimp dominated to a cod dominated ecosystem and thus reverse the ecosystem shift which took place under a cold period in the late 1980s and the early 1990s (Jacobsen et al. 2018). In addition to increasing Atlantic cod biomass in the Davis Strait and Disko West regions, the northern expansion of Atlantic cod is likely to continue into areas further north of Disko Bay. It is also expected that finfish species from warmer water like mackerel and herring will continue to become more abundant in the two assessment areas.

Seabirds

The marine food web will change on all trophic levels, and food resources could be lost for some species. Some species therefore have to move further around and expend more energy to feed, this may cause lower productivity and/or higher mortality and thus cause effects at the population level. An example could be the ice dependent ivory gull wintering in the marginal ice

Box 8 Benthic fauna and climate change

Martin Blicher (GINR)

Climate variability can also modify interactions between the pelagic and the benthic realm within the assessment area. Future fluctuations in zoobenthic communities will depend on the temperature tolerance of the present species and their adaptability. If further warming occurs, those species tolerating a wide temperature range will become more frequent, potentially causing changes in the zoobenthic community structure and functional characteristics, with consequences for the higher trophic levels. At the time being our knowledge about temperature tolerance and adaptability of benthic species in the assessment area is limited and it is not possible to make relevant predictions of changes in biogeography and species interactions. However, on a pan-Arctic scale, a recent study assessed the potential impact of climate change on benthic species distribution (presence only) under end-of-century ocean warming and acidification. Surprisingly, species distribution modelling predicted small mean habitat losses (0-11%) across taxonomic groups. The results also indicate that Arctic benthic species are not significantly more vulnerable than boreal or Arcto-boreal species, and that calcifying species are not significantly more vulnerable than non-calcifiers (Renaud et al. 2019). On a smaller geographical scale, and on single-species level, such general statements may, however, not be very relevant as impacts can still be significant. This is especially important if ecological key species are affected. In a review by Wassmann et al. (2011), 12 examples of changes in benthic communities are presented. Impacts of climate change included species-specific changes in growth, abundance and distribution ranges and community level changes in total species composition. Most of the examples found were geographically concentrated around Svalbard and the Bering Sea, where research efforts are highest. Nevertheless, they can be regarded as examples of changes occurring in many other marine Arctic ecosystems, including the assessment area. All in all, this suggest that more basic biological data and autecological studies of Arctic taxa are needed for improved projections of ecosystem responses to climate change, in combination with other stressors. Examples of that are given in a series of papers about intertidal blue mussels, *Mytilus* spp., in West Greenland (Thyrring et al. 2015a, Thyrring et al. 2015b, Thyrring et al. 2017a, Thyrring et al. 2017b, Thyrring et al. 2019). Studies of distribution, population dynamics, food preferences, freezing tolerance, physiological performance and resistance to chemical stress revealed a very robust genus with strong capabilities of physiological adaptation during adulthood, however vulnerability to temperature stress in the earliest life stage may control its distribution in the Arctic.

A future Arctic warming is also likely to result in increased freshwater run-off from rivers and glaciers. Besides a freshening of surface waters in near-shore areas, this will also lead to increased turbidity and inorganic sedimentation, with potential effects on the species composition of benthic communities in coastal areas (e.g. Wlodarska-Kowalczuk et al. 2004, Wlodarska-Kowalczuk et al. 2005, Pawłowska et al. 2011, Węsławski et al. 2011, Versteegh et al. 2012).

zone. Ivory gull population declines coincide with displacement and reduction in their sea ice feeding area; however, contaminants may also be a factor in the decline (Strøm et al. 2019).

Many of the coastal seabird species wintering in the Disko West and Davis Strait regions could be expected to be favoured by milder winters with reduced ice cover, since winter mortality most likely is an important factor regulating the populations of these species. For example, reduced ice means increased access to seabed feeding grounds for diving ducks. Species, which could benefit, include the great cormorant, common eider, mallard, long-tailed duck, harlequin duck, red-breasted merganser (Boertmann et al. 2020). However, while surveys during winter did confirm a range expansion towards north of red-breasted merganser, the general result was that the number of wintering marine birds did not seem to have increased in west Greenland between a survey in 1999 and a survey in 2017 (Merkel et al. 2019). The latter conclusion may be wrong if the wintering range has expanded north of the normal wintering area between Kap Farvel and Disko Bay, and thus outside the survey area. Local knowledge from Upernavik indicate that this may be the case for at least common eider (Merkel et al. 2019). For the breeding marine birds the non-Arctic lesser black-backed gull have increased significantly in the assessment area in recent decades (Boertmann 2008), while confounding effects and lack of data makes it difficult to assess the climate impact on other species (Merkel & Tremblay 2018). For example the common eider breeding population has increased since 2001, following a significant reduction in harvest (Merkel 2010), while the thick-billed murre population continue to decline in the region probably due to a combination of harvest and climate effects on food availability in the winter areas (Merkel et al. 2014, Descamp et al. 2017).

Marine mammals
Seals and the polar bears depend on sea ice for survival and reproduction and their populations may decline with changes in sea ice thickness and extent as well as changes in the timing of ice formation and melt.

Loss of sea ice have been demonstrated to impact the polar bears in the Baffin Bay area. 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, Stern & Laidre 2016). Mean sea-ice concentration in Baffin Bay in June-October declined from 22% to 12%. (Laidre et al. 2018b). Spring sea-ice retreat occurred two weeks earlier and fall sea-ice advance two weeks later in the 2000s. Also of note are the significant trends in loss of sea-ice on the banks of West Greenland in the Disko West area, which are an important spring foraging habitat for polar bears (SWG 2016). 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 et al. 2018b). This has translated to reduced geographic ranges, more time on land, reduced emigration, poorer body condition and reduced reproduction (Laidre et al., 2018a, b, 2020). Given the observed decrease in sea ice also in Davis Strait and the prediction of further future decreases it cannot be excluded that the occurrence of polar bears within the Davis Strait assessment area also will decrease in the future. Satellite telemetry data from the 1990s indicate that polar bears may occur in the Disko West assessment area from November-December until sometime in spring (May-June), depending on annual variability in sea ice cover. It is likely that the distribution and number of polar bears from the Davis Strait subpopulation that occur at the eastern edge of the Davis Strait pack ice to a certain extent are influenced by the location of the Davis Strait hooded seal whelping patch and unusual occurrence of harp seal concentrations.

On the main walrus wintering ground in West Greenland (Store Hellefiskebanke) the spring break-up of sea ice has occurred 7.6 days earlier per decade during 1979-2010 (Dietz et al. 2014). This change appears to have influenced the distribution of walruses to some extent – at least locally (Born et al. 2017).

Changes in the climate and ecosystem are also likely to have an effect on the distribution of whales in the assessment area. Ice-associated whales, such as the bowhead whale are expected to move northwards due to warming waters, and loss of their sea ice habitat (Chambault et al. 2018). On the West Greenland shelf north of Store Hellefiskebanke, white whales shifted their distribution westward, tracking the eastern edge of winter pack ice as it receded to the west in recent decades. Hansen et al. (2018) have documented a shift, or fluctuation, in the main distribution of Baleen whales. Minke, fin and humpback whales have apparently relocated their summering areas from West Greenland to East Greenland, where there have been a dramatic increase in a pelagic prey resource also supporting the increase in the summering mackerel stock.

Sea ice loss facilitates also human activities in the Arctic such as shipping and industrial development, and such activities has the potential to disrupt the habitats of ice associated marine mammal (Hauser et al. 2017).

5.4.3 Climate research facility

Both at Nuuk and at Qeqertarsuaq (Disko Bay) there are marine climate research facilities. Climate and the ecological climate response is monitored in the fjord and bay, respectively, as part of the Greenland Ecosystem Monitoring System (see https://g-e-m.dk/). Analyses of plankton times series shows that the interannual variation is high, particularly of the larger zooplankton that are influenced by large scale ocean circulation patterns (Arendt et al. 2012, Juul-Pedersen et al. 2015, Møller & Nielsen 2019). A recent focus has been on the impact of increased freshwater input and how upwelling in front of the marine terminating glaciers increase the primary production in the fjords (Meire et al. 2017, Hopwood et al. 2019). However, the GEM monitoring does not cover the offshore ecosystem.

5.4.4 Implications for monitoring, assessment and management of the ecosystem

The expected climatic changes in the assessment area will lead to significant ecological changes in the coming decades. The ecological changes will include changes in numbers and distribution of key species like the copepod *Calanus hyperboreus* and polar cod, and also iconic Arctic species of high conservation value like ivory gull, polar bear, narwhal and bowhead whale will be affected. Some of the areas that are identified as important habitats today, will most likely change status as different species assemblages with other habitat preferences move in, and the Arctic species may become dependent on new areas further north. It will therefore be a challenge to manage the ecosystem and protect the changing key habitats for biodiversity in the future, because these changes are impossible to predict with any detail, and the management relate to all the pressures of oil development, shipping and fishery and other human activities. To capture the dynamics of the changing system there will be a need for extensive monitoring and research feeding into an adaptive management system.

5.5 Cumulative impacts

David Boertmann (AU) & Anders Mosbech (AU)

Cumulative effects derive from the combined impacts from past, present and future human activities. Effects of a single activity can be insignificant but the cumulative effects – either from repeated activities or a combination of several activities – can be additive, synergistic or antagonistic (Ray 1994). They can originate from human activities (pressures) such as hunting and fishing, industry, shipping, tourism etc. and can be direct (such as the mortality from hunting) or indirect such as disturbance (e.g. Dawson et al. 2018, Christensen et al. 2018). Climate change is also often considered as a factor in this context (National Research Council 2003).

In the assessment area cumulative effects could, for instance, be the result of several seismic surveys carried out at the same time within a limited area. During a single survey many alternative habitats would still be available, but extensive activities in several licence blocks may, for example, exclude baleen whales from normally 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.

Another example is produced water: The oil concentration in the discharged produced water is usually low. However, the total amount of produced water from a single platform is considerable, and if several platforms are operating in the area the discharge may add up to substantial amounts.

Bio-accumulation is a concern when dealing with cumulative effects of produced water. The low concentrations of PAH, trace metals and radionuclides all have the potential to bio-accumulate in the fauna on the seafloor and in the water column and could, subsequently, be transferred to the higher levels of the food web, i.e. seabirds and marine mammals feeding on benthic organisms, plankton or fish (Lee et al. 2005).

Seabird hunting takes place in the assessment area, and the breeding population of thick-billed murre have been declining, mainly due to unsustainable harvest (Merkel et al. 2014, 2016). Tightened hunting regulations were introduced in 2001, but without effect on the negative population trend. The thick-billed murre rely on a high adult survival rate, giving the adult birds many seasons to reproduce. Extra mortality due to an oil spill or sub-lethal effects caused by contamination from oil and gas activities have the potential to be additive to the hunting impact and thereby enhance the population decline (Mosbech 2002).

In the assessment area there is substantial fishing activity on and especially at the edges of the banks where walruses occur (Born 2005). During the 2010-interview survey some of the walrus hunters living in West Greenland mentioned that walruses may also have changed distribution (i.e. occurring farther offshore) due to noise and other impacts from fisheries (trawling for shrimp and dredging for Icelandic scallop). The adverse effects were thought to be due to underwater noise and competition between walruses and fisheries for benthic resources, i.e. Icelandic scallop (Born et al. 2017).

Polar bears are also exposed to a multitude of impacts. Significant portions of the polar bear's range already are being developed and exploration is proposed for many other areas. With warming induced sea ice decline, previously inaccessible areas will be exposed to development and other forms of anthropogenic activities, e.g., trans-Arctic shipping and tourism (Dawson et al. 2018, Christensen et al. 2018). The direct effects of human activities, the increased potential for negative human-bear encounters, and the potential for increased local pollution are all concerns that must be understood if we are to understand and manage these impacts on the future for polar bears (Wiig et al. 2015).

The human pressures in the Arctic are still relatively few (Andersen et al. 2017a), and include in the assessment area: extensive commercial fishery for especially northern shrimp and Greenland halibut, shipping (extensive between the towns and settlements), tourism, exploration of mineral resources on land, subsistence hunting and fishing and long-range pollution. The climate-induced reduction in sea ice will facilitate shipping in the area and commercial fisheries will probably increase as well (Dawson et al. 2018, Christensen et al. 2018). These developments will add to the cumulative effects. Climate change is expected to be the largest pressure in the coming decades (Langen et al. 2018).

6 Review of oil and gas activities and their environmental impacts

David Boertmann (AU) & David Blockley (GINR)

6.1 Phases of oil and gas activities

Oil and gas project life cycles usually comprise several, to some degree overlapping, phases. These include exploration, appraisal, field development and production, and finally decommissioning. The main activities during exploration and appraisal are seismic surveys, exploration drilling and well testing. During field development, drilling continues (production wells, injection wells, delineation wells), and facilities for production, handling, refining and shipment including pipelines are constructed. Environmental safe production requires maintenance of equipment and facilities, waste management and environmental monitoring. Finally, during decommissioning, wells are plugged, all constructions and facilities are dismantled and removed, and the surrounding environment may be restored. But there will be some remains left on the seabed, such as cutting piles and drilling mud, which potentially can impact the surroundings for a long time. These phases occur over several decades and may happen simultaneously in a particular oil and gas region, with several projects in various stages of the oil and gass project life cycles. In the North Sea for example, oil exploration was initiated in the 1960s, the first well came on stream in 1975, production continues today and exploration still takes place, while decommissioning also has been initiated.

6.1.1 Exploration

In order for oil and gas deposits to be commercially viable, there need to be a source rock from which they originate, and reservoir rocks, where oil and gas leaching from the source rock are contained and concentrated. The purpose of exploration activities is, therefore, to ascertain if oil and gas may be present within rock layers beneath the ocean floor and identify the reservoirs from which they can be viably extracted. The main purpose of this phase is to survey large areas in order to determine likely formations that are known to be potential reservoirs of oil and gas and then to ascertain if such hydrocarbons actually occur. This is done by firstly using seismic surveys in order to detail the subsurface geology, and then drilling down through the seabed and underlying rock layers in order to be able to directly test for the presence of oil and gas. Sometimes geological cores are drilled (shallow coring) to obtain knowledge of the topmost subsurface layers.

In general, all activities related to oil exploration are temporary and will be terminated after a few years if no commercial discoveries have been made. An important aspect in relation to oil exploration in the assessment area is that the activities generally will be limited to the period when the sea is more or less free of ice, and drilling also has to be terminated leaving time for drilling a relief well before the ice stops activities. However, seismic surveys can and have been carried out with the aid of icebreakers in areas partially covered by ice, for example in the sea off Northeast Greenland.

Environmental impacts of exploration activities relate to:
- Noise from seismic surveys and drilling.
- Cuttings and drilling mud.
- Disposal of various substances including drilling chemicals, oil residues etc.
- Emissions to air.
- Placement of constructions.

Of these, the most significant impacts are noise and from disposal of cuttings and drilling mud. The other issues listed are much more significant during the later phases of the life cycle of an oil and gas field.

6.1.2 Appraisal

If promising amounts of oil or gas are located during the exploration, the commercial potential is appraised by establishing the size of the reservoir. This information is used to determine if an identified hydrocarbon resource is commercially viable to extract. The appraisal phase may involve further seismic surveys, but the focus will be on drilling of numerous wells to delimit the reservoir. Well logging and testing are other activities to provide data on the oil and gas bearing rocks, properties of the hydrocarbons, flow rate, temperatures and pressures in the well. During the appraisal phase, additional reserves may be identified that will require further seismic surveying and exploration drilling to determine the total quantities of oil or gas that might be extracted within the same project. This information will be used to determine the commercial viability of the project and the most appropriate production method. Appraisal may take several years to complete. If a reservoir is proved commercially viable, the operator may then proceed to development of the field.

6.1.3 Development and production

Field development includes also extensive seismic surveys and drilling activities (delineation wells, injection wells, etc.), and drilling will take place until the field is fully developed. Whilst drilling and seismic surveys will be at their peak during the early development of the field, both may continue throughout the production phase. Further wells may be drilled to inject reservoirs with gas or fluids (sea water with chemicals) in order to increase pressure and increase production rates and yields. Likewise, seismic surveys may continue at intervals over the life of the project in order to gain further knowledge about the behaviour of the reservoir.

How potential production will take place and be developed in West Greenland offshore areas is unknown. However, 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 such a production facility, crude oil subsequently has to be transported by shuttle tankers to a trans-shipment terminal in Northwest Europe or East USA/Canada.

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 oil and the production rate. Environmental impacts from routine activities during the development phase will mainly be related to:

- Establishment and placement of constructions including production facilities, welle and pipelines on the seabed and supporting infrastructure.
- Noise from facilities and transport.
- Produced water
- Other solid and fluid waste materials and their disposal.
- Emissions to air.

The major impacts during the production phase are from discharge of produced water and emissions to the atmosphere.

6.1.4 Decommissioning

Decommissioning is initiated when production is no longer economically viable. This phase of the project involves plugging of wells and removal of all infrastructure and facilities, which otherwise will remain in the environment for decades. The environmental impacts of the activities related to decommissioning typically relate to the large amounts of waste material which has to be disposed of or regenerated, and to the noise and disturbance at the sites and from traffic with ships, aircrafts and other vehicles needed to transport personnel, equipment and waste material. There is also the potential for the release of contaminants from the constructions themselves as well as from the immediate vicinity of the field where cuttings, drilling mud etc. may have accumulated over the decades of operation.

With many oil fields coming to the end of their life worldwide, there has been an increased focus on the environmental consequences of decommissioning of related infrastructure. In relation to the North Sea oil fields, this has been a source of much discussion and research, in particular regarding contaminants from the drill cuttings in the seabed (e.g. mercury) and on the constructions themselves e.g. as artificial reefs.

Typically, drill cuttings are disposed of to the sea bed and are deposited in a layer of sediment centimetres to meters deep in a radius around the wellhead. Depending on the type of chemicals used in the drill mud, as well as the composition of the rock being drilled, this sediment can contain elements that are harmful or toxic to marine life and which can accumulate in organisms.

The other emerging issue with regards to decommissioning is the physical removal of the constructions and how this will affect the ecosystems that have developed on them. Marine infrastructure associated with oil and gas can remain in situ for decades. In this time, they can develop complex ecosystems supporting a great diversity of biota on their submerged parts. By their nature, these are artificial reefs and so the ecosystem they support may not be analogous to that found on local natural benthos. Nonetheless, they can form important refuges for organisms that are subject to other anthropogenic impacts (e.g. bottom trawling) or provide connectivity between disparate populations and so prevent fragmentation of habitats. As such, there is an argument made that such infrastructure should be rendered safe and left in place. Such decisions need to consider whether the subsea constructions themselves can be abandoned in an environmentally safe way, what their value as habitat is and how their removal would affect the ecosystem locally and regionally.

The key lesson coming out of research on the decommissioning of North Sea oil and gas facilities is, that it needs to be planned at the time of development of the project, and not postponed until the field is near the end of its life. This will guide choices made in the development process as well as the type of monitoring and environmental data that needs to be collected throughout the production life. Cf. also the OSPAR-decision 98/3 on on the Disposal of Disused Offshore Installations (Link).

6.2 Environmental impacts from exploration and exploitation activities

6.2.1 Impact of underwater noise from seismic surveys

The purpose of seismic surveys is to obtain knowledge of the subsurface geology in order to locate and delineate oil and 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. These sound sources are some of the most powerful noise generators that derive from oil and gas exploration.

The sound source is an array of airguns (for example 28 airguns with a combined volume of 4330 in^3 = 71 l) that generate a powerful pulse (for example with a source level of 245 dB re 1 µPa peak) with 10-second intervals. Generally, sound absorption is much lower in water than in air, causing the strong noise created by seismic surveys to travel very long distances, potentially disturbing particularly marine mammals and fish (Kyhn et al. 2012). Regional seismic surveys (2D seismic) for locating reservoirs are characterised by widely spaced (over many kilometres) survey lines, while the more localised surveys (3D seismic) for identifying drill sites usually cover small areas with densely spaced (for example 500 m) lines. Rig site investigations, vertical seismic profiling and shallow geophysical investigations use comparatively much smaller sound sources than 2D seismic surveys. For example, during site surveys a single airgun (2.45 l = 150 in^3) may be applied.

The main environmental concerns relate to impacts on marine mammals and fish caused by noise generated during seismic operations including:

- Physical damage: injury to tissue and auditory damage (temporary or permanent) from the sound waves.
- Disturbance/displacement (behavioural impacts, including masking of underwater communication by marine mammals).

In Arctic waters, certain conditions must be considered. The water column is often stratified which causes refraction of sound waves. Therefore, a simple relationship between sound pressure levels and distance to source cannot be assumed. This makes it difficult to base impact assessments on simple transmission loss models (spherical or cylindrical spreading) or to apply results from assessments performed at southern latitudes to Arctic waters (Urick 1983). The sound pressure, for instance, might be significantly higher than expected in convergence zones far (> 50 km) from the sound source. This has been documented by means of acoustic tags attached to sperm whales, which recorded high sound pressure levels (160 dB re µPa, peak-peak) more than 10 km from a seismic array (Madsen et al. 2006).

Another issue rarely addressed is the fact that airgun arrays generate significant sound energy at frequencies many octaves higher than the frequencies of interest for geophysical studies. This increases concern regarding the potential impact particularly on toothed whales (Madsen et al. 2006).

In the following, potential impacts from seismic surveys on different ecosystem components are discussed and assessed.

Impact of seismic noise on zooplankton

Zooplankton (for example copepods such as *Calanus* and larvae of benthic crustaceans) and fish larvae and eggs (= ichthyoplankton) are unable to avoid the pressure wave from the airguns and the general impression is that they could be killed within a distance of up to 2 m, and sub-lethal injuries may occur within 5 m (Østby et al. 2003). A study in Australia indicated that adult and larval zooplankton could be killed up to 1.2 km from a relatively small seismic sound source (McCauley et al. 2017), but this remains to be verified. A more recent study of impacts on *Calanus* from Norway could not confirm this large mortality zone (Fields et al. 2019) and Pascoe & Innes (2018) also question the significance of the results.

The volume of water affected by a seismic survey is small compared to the non-affected volume and therefore population effects are considered to be limited, according to Norwegian and Canadian assessments (National Research Council 2003). However, some species have discrete spawning areas in certain periods of the year, where mortality on eggs and larvae could be more pronounced due to very high densities in the water column.

Impact of seismic noise on marine invertebrates

Regarding possible effects of seismic shooting on invertebrates, very little knowledge exists in general, and in different studies and reviews the need for research has been expressed as well as concern for long-term effects (Christian et al. 2003, DFO 2004, Chadwick 2005, Edmonds et al. 2016, Carroll et al. 2017). A Canadian review, for instance, emphasises the lack in information to evaluate the effects on crustaceans during their moult, a period when crustaceans are particularly vulnerable (DFO 2004).

A study has shown that the shrimp species *Palaemon serratus* is responsive to sounds ranging from 100 to 3000 Hz, the responsive organ being the statocyst (balance organ) in the basal segment of the antennule (Lovell et al. 2005). To date, behaviour of shrimps associated with noise impacts has not been demonstrated, but future research may reveal shrimp reactions to seismic sound pulses. A study on rock lobster (*Jasus edwardsii*) in Australia showed that a full scale seismic array damaged their statocysts on distances of 100-500 m, and this impaired the behaviour of the lobsters (Day et al. 2019).

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, Morris et al. 2018) did not find any short-term reduction in catchability. Morris et al. (2018) concluded that if seismic effects do exist, they are smaller than changes in catchability related to natural spatial and temporal variation.

An Australian study could not find evidence of seismic induced mortality among scallops, but could not exclude sub-lethal effects (Przeslawski et al. 2018).

When assessing environmental impacts in relation to oil and gas activities in the Barents Sea, impacts on northern shrimp and fishery of this resource were evaluated, and both the population and the fishery were considered relatively robust against impacts (Østby et al. 2003).

Impact of seismic noise on fish

Adult fish will generally avoid seismic sound waves, by seeking towards the bottom and, thus, avoid being directly harmed. Young Atlantic cod and redfish (30-50 mm long), are able to swim away from the lethal zone near the airguns (comprising a few meters) (Nakken 1992).

It has been estimated that adult fish react to an operating seismic array at distances of more than 30 km, and that intense avoidance behaviour can be expected within 1-5 km (see below). Norwegian studies measured declines in fish density at distances more than 10 km from sites of intensive seismic activity (3D). Effects on fish stocks may therefore occur if adult fish are scared away from localised spawning grounds during the spawning season. This concern is the reason behind a regulation of seismic activities in Norwegian waters, where time limits for seismic surveys can be introduced in individual licence blocks, where high spawning densities of fish occur (Olje- og Energidepartementet No year). 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- peak) down to 5-15 m distance sustained extensive ear damage, with no evidence of repair nearly 2 months after exposure (McCauley et al. 2003). It was estimated that a comparable exposure could be expected at ranges < 500 m from a large seismic array (44 l = 2685 in^3) (McCauley et al. 2003).

It appears that the avoidance behaviour of fish demonstrated in the open sea protects them from damage. In contrast to these results, marine fish and invertebrates monitored with a video camera in an inshore reef did not move away from airgun sounds with peak pressure levels as high as 218 dB (at 5.3 m relative to 1 µPa peak-peak) (Wardle et al. 2001). The reef fish showed involuntary startle reactions (C-starts), but did not swim away unless the explosion source was visible to the fish at a distance of only about 6 m. Despite a startle reaction displayed by each fish every time the gun was fired, continuous observation of fish in the vicinity of the reef using time-lapse video and tagged individuals did not reveal any sign of disorientation, and fish continued to behave normally in similarly quite large numbers before, during and after the gun firing sessions (Wardle et al. 2001). Another study performed during a full-scale seismic survey (2.5 days) also showed that seismic shooting had a moderate effect on the behaviour of the lesser sandeel (Hassel et al. 2004). However, no immediate lethal effect was observed on sandeel, neither in cage experiments nor in grab samples taken at night when sandeel were buried in the sediment (Hassel et al. 2004).

The studies described above indicate that behavioural and physiological reactions to seismic sounds among fish may vary between species, i.e. depending on whether they are territorial or pelagic, on their anatomy and physiology and on the seismic equipment being applied. Generalisations should therefore be made with caution.

A recent review (Slabbekoorn et al. 2019) concluded that there is "lack of insight into behavioural changes for free-ranging fish to actual seismic surveys and on lasting effects of behavioural changes in terms of time and energy budgets, missed feeding or mating opportunities, decreased performance in predator-prey interactions, and chronic stress effects on growth, development and reproduction." Moreover, they concluded that there is lack of insight into "whether any of these effects could have population-level consequences."

Impact of seismic noise on fisheries

Norwegian studies 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 (Engås et al. 1996). This occurred not only in the shooting area, but as far as 18 nautical miles away. The catches did not return to normal levels within 5 days after shooting (when the experiment was terminated), but it was assumed that the effect was short-term and catches would return to normal after the studies. The effect was more pronounced for large fish compared to smaller fish.

Impacts of 3D seismic survey on gillnet and longline fisheries were also studied in Norway, and the studies showed contradicting results (Løkkeborg et al. 2010): gillnet catches of Greenland halibut and redfish increased during seismic shooting and remained higher in the period after shooting. Longline catches of Greenland halibut, on the other hand, decreased. Saithe catches in gillnet showed a tendency to decrease (but not statistically significant) during the shooting, and 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, tusk and Atlantic halibut had not changed significantly. Catch rates of redfish and anglerfish seemed to increase, while catch rates of saithe and haddock caught in gillnet decreased and catches with other gear were not affected. The majority of the seismic surveys included in the analysis were 2D and scattered in time and space, for which reason major impacts on the fisheries were not expected. This substantial variation in catch rates (among species and fishing methods) was also found by an Australian review (Pascoe & Innes 2018).

Greenland halibut is very different from Atlantic cod and haddock with respect to anatomy, taxonomy and ecology. It has no swim bladder, which means its hearing abilities are reduced compared to fish with a swim bladder, in particular at higher frequencies. Thus, Greenland halibut is likely to be sensitive only 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 gillnet fishery and not trawling (Engås et al. 1996), thus the results cannot be applied to Greenland offshore fisheries.

In that study an increased catch of Greenland halibut were found in the gillnets. There are also other examples of this trend (Hirst & Rodhouse 2000, Bruce et al. 2018), which is most likely the result of changed behaviour (more moving around) of the fish.

In the review by Dalen et al. (2008) it was concluded that the results described by Engås et al. (1996) (mentioned above) cannot be applied to other fish species or to fisheries taking place at other water depths, such as the Greenland halibut fishery.

In summary, there is a risk of reduced catches of Greenland halibut in areas with intensive seismic activity, although reduced catches were not observed in West Greenland where seismic surveys in 2008 and 2009 overlapped with trawling grounds for Greenland halibut (F. Heilmann, Polar Seafood pers. comm.).

Impact of seismic noise on seabirds

Most research on the hearing of birds has focused on terrestrial species addressing how they perceive the environment, and how anthropogenic noise potentially influences their physiology, parent-offspring communication and behaviour. Seabirds are generally considered not to be sensitive to seismic surveys because they are highly mobile and therefore able to avoid the sound source from such surveys and so avoid direct harm. However, in inshore waters seismic surveys carried out near the coast may disturb congregations of breeding and moulting seabirds due to the presence of the vessel and the related activities.

From a few limited studies conducted to date, we know that marine birds hear surprisingly well both in air and underwater. Resent research suggest that the great cormorant is better at hearing underwater than expected, that they have anatomical and physiological adaptations for amphibious hearing and that their hearing thresholds are comparable to seals and toothed whales in the frequency band 1–4 kHz (Hansen et al. 2017, Larsen et al. 2020). No attempts have been made to assess possible impacts of exposure to airgun sounds when seabirds are in the water column, however, a new study on common murres found that this alcid species is vulnerable to underwater noise. The two birds tested showed consistent reactions to underwater broadband sound bursts from mid-frequency naval 53 C sonar signals (Hansen et al. 2020).

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, may therefore be temporary.

Impact of seismic noise on marine mammals

Responses of marine mammals to noise fall into three main categories: physiological, behavioural and acoustic (Nowacek et al. 2007). Physiological responses include hearing threshold shifts (reduced ability to hear) and physical damage in the ear. Behavioural responses include changes in surfacing, diving and movement patterns, and may result in displacement from the affected area or reduced feeding success. The acoustic response is based on the fact that low frequency sounds may effectively mask the calls of baleen whales. This may interfere with their social activities and/or navigation and feeding activities (Kyhn et al. 2019). Acoustic responses to masking by noise from seismic surveys and drilling include changes in type or timing of vocalisations. In addition, there may be indirect effects of noise as prey availability may change (scared away by the noise) (Gordon et al. 2003).

There is strong evidence of behavioural effects on marine mammals from seismic surveys (Compton et al. 2008). Mortality has not been documented but there is a potential for physical damage, primarily auditory damages. Under experimental conditions, temporary elevations in hearing threshold (TTS, temporary hearing loss) have been observed (Southall et al. 2007). Such temporarily reduced hearing ability is considered unimportant by Canadian researchers unless it develops into permanent threshold shift (PTS, permanent hearing loss) or occurs in combination with other threats normally avoided by acoustic means (DFO 2004). However, entanglement in fishing gear has been linked to hearing damage in a Canadian study (Todd et al. 1996).

The US National Marine Fisheries Service has adopted a sound pressure level of 180 dB re 1μPA (rms) or higher as a mitigation standard to protect whales from exposures considered capable of inducing temporary or permanent damage to their hearing (NMFS 2003, Miller et al. 2005a). This exposure criterion is poorly defined from a measuring standpoint and with little experimental support. Thus, Southall et al. (2007) proposed a reorganisation of exposure criteria, allowing more room for differences in sensitivity between different taxa and different sound types. They also implemented a dual criteria approach; 1/ maximum instantaneous sound pressure and 2/ total acoustic energy accumulated over the complete duration of exposure. These suggestions have led to controversial discussions, and it remains to be seen if and how they will be implemented in legislation in the USA and elsewhere.

Displacement is a behavioural response, and there are many documented cases of displacement from feeding grounds or migratory routes of marine mammals exposed to seismic sounds. The extent of displacement varies between species and 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 (McCauley et al. 2000). In the Beaufort Sea, autumn migrating bowhead whales avoid areas where the noise from exploratory drilling and seismic surveys exceeds 117-135 dB rms. They may avoid the seismic source by distances of up to 35 km (Reeves et al. 1984, Richardson et al. 1986, Ljungblad et al. 1988, Brewer et al. 1993, Hall et al. 1994, NMFS 2002, Gordon et al. 2003), although a Canadian study showed somewhat shorter distances (Miller et al. 2005a). 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. 2005a). In UK waters, StoneTasker (2006) described a significant reduction in marine mammal sightings at seismic surveys during periods of shooting compared with non-shooting periods, indicating that the marine mammals avoided the source.

In the Alaskan Beaufort Sea, it was shown that bowhead whales change their behaviour when exposed to low frequency sound from airgun arrays (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, Dunlop et al. 2017). Blackwell et al. (2015) showed that bowhead whales changed calling pattern when approached by a seismic sound source and became silent when sound exceeded a certain threshold.

Di Iorio & Clark (2010) documented that blue whales increase their calling rate during seismic surveys, probably as compensatory behaviour to the elevated ambient noise. A large group of fin whales stopped calling during a seismic survey (Clark & Gagnon 2006 quoted in OSPAR 2009), and fin whales have also been recorded to change the acoustic characteristics of their sounds (Castellote et al. 2010). On the other hand, Dunn & Hernandez (2009) tracked blue whales that were 42-90 km from operating airguns, and they were unable to detect changes in the behaviour of the whales at these distances.

In contrast, minke whales have been observed as close as 100 m from operating airgun arrays (DCE unpublished) – potentially close enough to sustain physical damage.

During a controlled exposure experiment in the Gulf of Mexico, sperm whale horizontal movements were not noticeably affected by a seismic survey, but foraging effort seemed to diminish when airguns were operating (Miller et al. 2015).

A tagged northern bottlenose whale was exposed to strong noise from naval sonar, and it showed strong behavioural reaction. The sound source was not directly comparable to a seismic airgun array except for the source level, but the study showed that this whale species is highly sensitive to acoustic disturbance (Miller et al. 2015).

Harbour porpoises exposed to seismic noise from a commercial 2D survey (7.7 l = 470 in^3 airgun, sound pressure level 165-172 dB re 1μPa and SEL of 145-151 dB re 1 $μPa^2 s^{-1}$) were displaced short-term at 5-10 km distance, but returned after a few hours and also showed habituation (Thompson et al. 2013).

The ecological significance of eventual displacement is generally unknown. If alternative areas are available, the impact will probably be low. The temporary character of seismic surveys also allows displaced marine mammals to return after the surveys.

In West Greenland waters, satellite tracked humpback whales utilised extensive areas and moved between widely spaced feeding grounds, presumably searching for their preferred prey (krill, sandeel and capelin) as prey availability shifted through the season (Heide-Jørgensen & Laidre 2007a). 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 sandeel (Heide-Jørgensen & Laidre 2007a). Similarly, a modelling study based on cetacean and prey surveys showed that rorquals (fin, sei, blue, minke and humpback whale) and krill aggregate in three high density areas on the West Greenland banks (Laidre et al. 2010b). Thus, displacement from such important feeding areas potentially reduce uptake of energy of these rorquals which are in West Greenland to feed before their southward migration.

The US National Marine Fisheries Service (US-NMFS) defines the distance around a seismic ship where the received sound level is 180 dB (re 1μPA) as the zone within which cetaceans are likely to be subject to behavioural disturbance (NMFS 2005). The corresponding distance in meters will depend on the source level of the airgun array and the salinity and temperature layers of the water but could typically be around 700 m. A few studies have observed lack of measurable behavioural changes in cetaceans exposed to the sound of seismic surveys taking place several kilometres away. For instance, Madsen et al. (2006) found no reaction of sperm whales to a distant seismic survey operating tens of kilometres away. Later, Dunn &Hernandez (2009) did not detect changes in the behaviour of blue whales that were 15-90 km from operating airguns. The authors estimated that the whales experienced sounds of less than 145 dB (re 1μPA) and concluded that while their study supports the current US-NMFS guidelines, further studies with more detailed observations are needed (Dunn & Hernandez 2009).

A behavioural effect widely discussed in relation to seismic surveys and whales is the masking effect of communication and echolocation sounds. There are, however, very few studies that document such effects (Clark et al. 2009, Castellote et al. 2010, 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 46).

Whether sound pressures could be high enough to mask biologically significant sounds is another uncertainty. Masking is more likely to occur from the continuous noise from drilling and ship propellers, as has been demonstrated for white whales and killer whales in Canada (Foote et al. 2004, Scheifele et al. 2005).

Owing to the low frequency of their phonation, baleen whales, followed by seals, are the marine mammals expected to be most affected by auditory masking from seismic surveys (Gordon et al. 2003, Clark et al. 2009).

Sperm whales showed diminished forage effort during air gun emission. It is not clear whether this was due to masking of echolocation sounds or to behavioural responses of the whales or the prey (Jochens et al. 2008).

Without beings specific about the mechanisms involved, the participants in the NAMMCO 'Symposium on Effects of Disturbance on Walrus, Beluga and Narwhal' considered oil and gas activities (i.e. shipping and seismic activities) to be significant risks to walrus in Greenland. The symposium suggested that potential negative impacts were displacement from habitat and sub-lethal effects. However, several data gaps were identified (hearing sensitivity of walruses, behavioural responses to shipping and seismic, unknown effects of oil spills) and it was suggested that mitigation of negative effects on walruses may include seasonal/location restrictions for critical times/areas (NAMMCO 2015).

Seals display considerable tolerance to underwater noise (Richardson et al. 1995), which is confirmed by a study in Arctic Canada, where ringed seals showed only limited avoidance to seismic operations (Miller et al. 2005b), and ringed seals can also adapt to industrial noise (Blackwell et al. 2004). Also Brendan et al. 2010 (and references therein) found that ringed seals were quite resilient toward noise and disturbances caused by oil activities, or at least the noise don't seem to have significant influence on their distribution and activity patterns. Nor do seismic operations in Arctic Canada, where they showed only little avoidance of the ships (Lee et al. 2005).

Walruses are much more sensitive to disturbance and noisy activities (especially when hauled out), and may be displaced from critical habitats by seismic activity.

A study carried out as a part of the *Strategic Environmental Study Program for Northeast Greenland*, the Strategic Environmental Impact Assessment for the Greenland Sea (Boertmann et al. 2020), addressed underwater noise and marine mammals. The effects of seismic noise on narwhals was studied in Scoresby Sound, and an initial analysis showed a cessation of foraging activity when seismic activity was within 15 km from the whales.

In a recent paper reviewing oil and gas exploration and exploitation impacts on marine mammals, more study results are described and discussed (Bröker 2019).

6.2.2 Impacts from exploration, appraisal and production drilling

During the exploration phase, one or more exploration wells are drilled to determine if a prospect exists and to gain further data on the subsurface conditions. If an oilor gas reservoir is encountered, the well is normally tested to see whether the reservoir is viable for production. Wells unsuitable for further development are sealed below the seabed and tested to ensure that they are fully secure before being abandoned. If an oil or gas reservoir is found, several appraisal wells are drilled in order to ascertain the size and configuration of the reserves. These are done in a similar way to previous exploration wells and, once complete, will be sealed below sea level and rendered safe. Production wells are drilled in order to extract oil or gas from the reservoir.

There may be several production wells drilled that are tied back to a single production facility, and additional wells may be drilled over the life of the project. The drilling process is functionally similar to that for exploration and appraisal, but as these wells are meant to last for the life of the project and used for extraction of oil or gas, they are more complex and will be drilled with a larger diameter bore, and be deeper and more extensive, including long sub-surface horizontal as well as vertical sections.

Offshore drilling takes place from Mobile Offshore Drilling Units (MODU) such as drill ships or semi-submersible platforms, both of which were used in West Greenland in 2010 and 2011. A drillship is a maritime vessel modified to include a drilling rig and special station-keeping equipment. The vessel is typically capable of operating in deep water. A semi-submersible platform is a particular type of floating vessel that is primarily supported on large pontoon-like constructions submerged below the sea surface. Most of the potential oil exploration areas in West Greenland waters, and also probably East Greenland, are too deep for using a third type of drilling platform, the jack-up rigs, which are built to stand on the seabed. In addition, jack-ups would be vulnerable to the collision risk from the drift ice and icebergs in the assessment area.

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

It is assumed that the drilling season in the waters of the assessment area will be limited to summer and autumn due to the presence of ice and harsh weather conditions during winter and spring. The potential drilling season is further shortened as a contingency to allow enough time to drill a relief well before ice prevents operations if a blowout does occur. During the drilling campaigns in 2010 and 2011 this period was two months.

There are two sources of noise from drilling units, the drilling process and the propellers/thrusters keeping the drill ship/rig in position (dynamic positioning). The noise is continuous in contrast to the pulses generated by seismic airguns and may potentially disturb marine mammals and acoustically sensitive fish (Schick & Urban 2000, Popper et al. 2004).

Generally, drillships generate more noise than a semi-submersible platform, which in turn produces more noise than a jack-up.

In order to assess possible effects of noise produced by a drillship, underwater noise was recorded in West Greenland in September 2010, and the emitted noise from the drill ship *Stena Forth* during operation was quantified. The measured noise levels were similar to those known from other drillships and were above those reported from semi-submersibles and drill rigs. The noise levels 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 sounds that are louder than the background noise levels at ranges of 16-38 km from the ship and was 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 their communication can be masked by this noise. Seals (especially bearded seal) and walrus also communicate when underwater. However, systematic studies on whales and possible impacts due to noise from drill rigs are limited. Whales are generally expected to be more tolerant to fixed noise sources than to noise from moving sources (Davis et al. 1990). In Alaskan waters, migrating bowhead whales avoided an area with a radius of 10 km around a drillship (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). Schick & Urban (2000) describe how bowhead whales, also in Alaska, avoided close proximity (up to 50 km) to oil rigs, which resulted in significant loss of summer habitats.

6.2.3 Drilling mud and cuttings

Drilling muds are used to optimise drilling operations, including cooling and lubricating the drill bit, transporting cuttings from the well bore to the surface, counterbalancing pressure in the well in order to prevent blowout, stabilising and sealing borehole wall, preventing sedimentation or corrosion etc. The muds are either water based (WBM's), oil based (OBM's) or based on synthetic fluids (SBM's). The drilling mud is circulated from the drill platform to the drill bit through a closed system allowing re-use of the mud and separation of the cuttings on the platform. Due to environmental concerns it is now standard that OBM's and SBM's are only used where the mud and the cuttings can be brought to land for treatment or can be deposited safely. After the drilling, water based muds (without harmful chemicals) and the cuttings are usually released to the sea in the vicinity of the well head. Although cuttings and mud can also be re-injected into old wells, this has not yet been possible in Greenland, and so direct discharge to the sea is more likely to become the method of choice in the assessment area as was the solution used in West Greenland in 2010 and 2011.

Discharge of drill cuttings and mud can affect marine fauna and flora in two ways. Firstly, the deposits can bury organisms living on the sea floor. Cutting piles can be cm to meters deep in a radius around the well head that can extend for tens to hundreds of metres depending on oceanographic conditions. In some cases, organisms will be able to move vertically or horizontally to prevent being buried, but this will not be universally true. The cutting pile may also be materially different from the pre-existing seabed and so may be an unsuitable habitat for local flora and fauna. Secondly, the drilling mud contains several chemicals to optimise the performance, and these chemicals may be toxic, bio-accumulative and slowly degradable, including: barite and bentonite, polymers, surfactants, emulsifying agents, pH adjusting chemicals, silicates, chemicals for removal of oxygen, sulphide and carbon dioxide, biocides, corrosion inhibitors, lubricants, inhibitors, etc. These chemicals can persist in the environment for some time and can be a source of secondary contamination by resuspension and dispersion of sediments and cuttings. In Greenland these problems are mitigated by applying the OSPAR regulation (HOCNF), see Chapter 7.3.1.

The strategic EIA of oil activities in the Lofoten-Barents Sea assessed that approx. 450 m^3 cuttings are produced and approx. 2000 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 which all was discharged and deposited on the seabed.

Until 1993, the practice in Norway was to dispose all the waste to the sea. However, due to environmental concerns, release of OBM was stopped then. Today, only WBM can be released to the seabed and only if the content of chemicals is approved, i.e. they only contain environmentally acceptable components. See also Chapter 7.3.1 about the Greenland mud strategy.

OBM's are still used in Norway, mainly for special drillings under difficult conditions, and afterwards cuttings and mud are either reinjected or transported to land for treatment at specialised facilities. According to the experiences from Norway, the environmental impacts on the seabed from OBM cuttings are widespread and long-term, (Davies et al. 1984, Neff 1987, Gray et al. 1990, Ray & Engelhardt 1992, Olsgard & Gray 1995, Breuer et al. 2004, Breuer et al. 2008). Benthic fauna is still impacted around old deposition sites, although regeneration has been relatively fast, and today impacts can rarely be traced to more than 500 m from the installations (Research Council of Norway 2012).

Synthetic muds (SBM) also lead to impacts on benthic fauna around a platform, though less pronounced than from OBM's (Jensen et al. 1999b). Ester-based cuttings have been shown to cause rather severe, but short-term, effects due to their rapid degradation which may result in oxygen depletion in the sediments. Olefin-based cuttings are also degraded fairly rapidly, but without causing oxygen deficiency and, hence, have more short-term and moderate effects on the fauna.

Studies in Norway conclude that the ban of release of OBM has considerably improved the environmental conditions on the seabed around the offshore installations (Renaud et al. 2007, Schaanning et al. 2008 and references therein), but there is still concern for long-term impacts due to the large amounts released, and due to the chemicals in the mud (Research Council of Norway 2012).

Even though the conditions on the seabed are improved by the use of WBM, there is a risk of moving the adverse effects from the seafloor to the water column where, for instance, suspension of particles gives some reason for concern (Research Council of Norway 2012). Biological effects from the particles in the water based mud have been observed on fish and bivalves, at least under laboratory conditions (Bechmann et al. 2006) and effects on plankton have also been described (Røe Utvik & Johnsen 1999, Jensen et al. 2006).

Cold-water corals, such as the reef-forming hard corals *Lophelia* (also known as *Desmophyllum*), and sponges are sensitive to suspended material in the water column (Freiwald et al. 2004, SFT 2008). However, research in Norway has shown that the *Lophelia* corals are not especially sensitive to sedimentation of cuttings (same sensitivity as to natural sedimentation), and they could remove a layer of up to 6 mm sediment. But where they were unable to remove the sediment layer, the underlying tissues would die (Larsson & Purser 2011). Also deep-sea sponges have been shown to be vulnerable to increased sedimentation and exposure of drill muds (Vad et al. 2018).

The deposition of cuttings on the seabed results in an increased reduction of species, individuals, abundance and biomass with the thickness of the cuttings layer, an effect not observed when using natural sediment (Trannum et al. 2010).

A modelling study on the shallow Store Hellefiskebanke off West Greenland (Wegeberg et al. 2016a) showed that 2000 t drilling mud and cuttings settled in 10 cm thick layer in a distance of 700 m from the well resulting in the extermination of seabed fauna, and a 2 cm thick layer would reach as far as 1600 m resulting in a reduction of 70% of the fauna. At larger depth the particles will disperse even further, but in a thinner layer.

A final environmental risk is impurities of the barite used in the drilling mud. These include mercury, lead and other heavy metals, and can be bio-available and enter the food web (Research Council of Norway 2012, Wegeberg & Gustavson 2019). In a Greenland context, especially mercury gives reason for concern, because the Arctic is a sink for long-transported mercury pollution (see Chapter 5.1). The mercury content in barite used for drilling in Greenland shall therefore be the lowest possible in accordance with the Minamata convention.

6.2.4 Produced water discharge

During production, several by-products and waste products are generated, and they need to be treated or disposed of in one way or the other. Produced water is by far the largest '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 peaked in 2007 with 190 million m^3/year and has since then stabilised at a level of around 160 million m^3/year (Norsk olje & gass 2014) and was in 2015 148 million m^3 (Beyer 2019). Produced water contains low concentrations of oil and chemicals from the reservoir or added during the production process. Some of these chemicals may be harmful to the environment, by being for example toxic, radioactive, or by containing heavy metals, having hormone disruptive effects, or some may act as nutrients that influence primary production (Lee et al. 2005, Beyer et al. 2019). Some of the chemicals are persistent and have the potential to bio-accumulate. Moreover, the produced water is the major source of of oil pollution from normal operations, in Norway for instance up to 88%. See also Lee & Neff (2011) and Beyer et al. (2019) for a summaries of the chemical composition of produced water.

Produced water is usually discharged to the sea after a cleaning process that reduces the concentrations of oil to levels accepted by the authorities (a maximum of 30 mg/l is set by OSPAR, which also has set targets for reducing the total amount of dispersed oil in the produced water). For the North Sea there are also restrictions on the total amount that may be discharged over specified periods (in the UK for instance 1 tonne in any 12-hour period from a well). By applying best available practice (BAT), Norwegian operators have committed themselves to further reduce these levels, and in 2017 the average content was 12.1 mg/l (Norsk olje & gass 2018). Although the concentrations of oil in produced water are on average low, oil sheen may occur on the water surface where the water is discharged, especially in calm weather. This gives reason for concern because sheen is sufficient to impact the plumage of seabirds (Fraser et al. 2006, Fritt-Rasmussen et al. 2016).

Due to the dilution effects, discharges of produced water and chemicals to the water column appear to have acute effects on marine organisms only in the immediate vicinity of the installations and that the effects further away are low. However, long-term effects of the release of produced water are unknown (Rye et al. 2003) and, therefore, in high need to be studied (for example as initiated by the Research Council of Norway in 2012, see also Beyer et al.

2019). Several uncertainties have been expressed concerning, for example, the hormone-disrupting alkylphenols and radioactive components with respect to toxic concentrations, nutrients, bio-accumulation, etc. (Meier et al. 2002, Rye et al. 2003, Armsworthy et al. 2005).

Norwegian studies reviewed by the Research Council of Norway (2012) concluded that produced water does have effects on fish and invertebrates, including damage to genes and disrupted reproduction. The concentrations of produced water used for the experiments were similar to concentrations in the sea very close to release sites, indicating that the effects will occur only locally. Beyer et al. (2019) in a review of environmental effects of produced water in the Barents Sea did not find any studies that could prove any significant effects on fish population and community levels, and the effects on pelagic organisms were limited to a small impact zone up to a few km downstream the discharge point.

In a test of effects of PAH (from oil), Atlantic cod or blue mussels were positioned at various distances (0-5000 m) and different directions from offshore oil platforms in Norway; in addition, two reference locations were used, both 8000 m away from the respective platforms. PAH tissue residues measured in blue mussels ranged between 0-40 ng/g ww, depending on the distance to the oil rigs. PAH bile metabolites in cod confirmed exposure to effluents, but levels were low compared to those found in cod from coastal waters (Hylland et al. 2008). The biological effects found in the blue mussels reflect exposure gradients and that the mussels were affected by components in the produced water.

Furthermore, a study of exposure and bio-accumulation of PAH's in Atlantic cod and haddock in the marine environment off Norway used a sampling station far from production sites as reference. However, it became clear that even at this reference site effects from PAH's on the fish could be measured. This result suggests that there is a significant background pollution from the oil production in the North Sea (also far from the production sites), for example from produced water, disposed drilling mud and accidental spills (Balk et al. 2011). However, it cannot be precluded that the examined fish specimens were exposed locally and subsequently moved away from the sources (Bakke et al. 2013).

In yet another study in Norway, genotoxic potential of water-soluble oil components on Atlantic cod has been documented (Holth et al. 2009).

Nutrient concentrations can be high in produced water (for example ammonia up to 40 mg/l). When released to the environment, nutrients may act as fertiliser (Rivkin et al. 2000), but it is not known to which degree they will impact the sea around release sites.

The release of produced water into areas with ice gives reason for concern since there is a risk of accumulation of oil just below the ice, where degradation and evaporation etc. are slow. Sensitive organism living near and in the sea ice ecosystem, including eggs and larvae of polar cod, could be exposed (AMAP 2010).

6.2.5 Other discharged substances

Besides produced water, discharges of oil components and different chemicals occur in relation to deck drainage, cooling water, ballast water, displacement waters, bilge water, cement slurry and testing of blowout preventers etc. Similarly, sewage and sanitary waste water will be released to the sea. The handling and extent of such releases are regulated by the OSPAR convention, and these standards must be applied to minimise impacts in case of production in the assessment area.

Ballast water from ships poses a special biological problem, i.e. the risk of introduction of non-native and invasive species (also termed as Aquatic Nuisance Species – ANS) to the local ecosystem (Anonymous 2003). This is generally considered as a severe threat to marine biodiversity. Blooms of toxic algae in Norway, for instance, have been attributed to the release of ballast water from ships. There are also many examples of introduced species that have reduced stocks and fisheries (for example the comb jelly *Mnemiopsis* in the Black Sea (Kideys 2002)).

At present, the Arctic Ocean is the least affected area by non-native invasive species as shown by Molnar et al. (2008) and CAFF (2013). 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 (Ware et al. 2016).

6.2.6 Air emissions

Emissions to the air occur during all phases of oil and gas development, including seismic surveys and exploration drilling, although the major releases occur during development and production (e.g. Olaguer 2017). 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 gases (CO_2, CH_4), NOx, volatile organic compounds (VOC) and SO_2. In particular, the production activities create large amounts of CO_2; e.g., the emission of CO_2 from the large Norwegian Statfjord field was almost 1.5 million t in 2003 (Statoil 2004), and the total emissions of CO_2 equivalents from all the oil and gas activities on the Norwegian continental shelf was in 2017 13.6 million t. The drilling of the three exploration wells in 2010 in the Disko West area resulted in the emission of 105,000 t CO_2. Moreover, is it important to remember, that possible produced oil, when combusted, also contributes to the global increase of CO_2 in the atmosphere.

Emissions of SO_2 and NO_x contribute, among other effects, to the acidification of precipitation and may thus impact nutrient-poor vegetation types inland far from the release sites. The large Norwegian field Statfjord emitted almost 4000 t NO_x in 1999. In the Norwegian strategic EIA on oil and gas activities in the Lofoten-Barents Sea area it was concluded that NO_x emissions, even from a large-scale scenario, would have insignificant impact on the vegetation on land. It was, however, also stated that there was no knowledge about tolerable depositions of NO_x and SO_2 in Arctic habitats, where nutrient-poor habitats are widespread (Anonymous 2003). This lack of knowledge also applies to the terrestrial environment bordering the assessment area.

Finally, emission of black carbon (BC) from combustion a matter of particular concern in the Arctic, because the black particles reduce the albedo on snow and ice surfaces and, thus, increase the melting.

6.2.7 Infrastructure construction

The development of an oil or gas field requires a large amount of physical infrastructure to support it, such as buildings, rigs, pipelines, storing tanks and roads. Construction activities cause a number disturbances to the environment including transport of materials by land, sea and air, waste and pollution generation, damage or removal of natural habitats, and the introduction of new and novel habitats. Although there may be some support facilities built on land during exploration and appraisal phases, it is only likely to happen if there are no existing service facilities that can support the project. Construction of subsea, surface and land-based infrastructure will likely be at its peak during early development, with some continuing intermittently through the life of the project (e.g. for maintenance or building further subsea pumps and pipes). Most of the disturbances related to the construction of facilities will, therefore, be at the beginning of the development of a field, although the most persistent disturbance will be the presence of the constructions themselves.

In the ocean, infrastructure related to oil and gas extraction can be extensive and is completely novel to the natural environment. Pipelines can stretch for hundreds of kilometres, wellheads are a substantial subtidal reef environment, and platforms provide a unique subtidal environment in areas previously devoid of them. Subsea constructions in a soft bottom environment will be substrate for hard bottom organisms and thereby act as artificial reefs. Wellheads, pipelines and other subsea constructions as well as the legs of jack-ups all have potential to destroy important habitats on the seafloor. These include sponge gardens (e.g. Kazanidis et al. 2018) and cold-water corals which are considered as particularly sensitive (OSPAR, Link, Campbell & Simms 2009). Cold-water coral have been located in West Greenland waters, but their distribution is unknown.

The presence of constructions as well as the noise associated with their construction and operation may have disturbance effects, in particular for marine mammals that may avoid areas where constructions are built and, hence, alter migration and distribution patterns. Most vulnerable in this respect are walrus, narwhal and bowhead whale.

Illumination and flaring attract birds during the night (Wiese et al. 2001). In Greenland, this particularly relates to the two eider duck species. Under certain weather conditions (for example fog and snowy weather) during winter nights, eiders are attracted to the lights on ships (Merkel & Johansen 2011). Occasionally hundreds of eiders are killed on a single ship; not only are eiders killed, but these birds are so heavy that they damage ship antennae and other structures (Boertmann et al. 2006, Merkel & Johansen 2011).

A related problem is known from the North Sea, where millions of passerine birds migrate at night during autumn and spring. Under certain weather conditions large numbers of passerine birds are attracted to light from illumination and flaring, and many die from exhaustion or collision (Bourne 1979, Jones 1980). It has been shown that the attraction of birds can be mitigated by changing the illumination to colours not attracting birds, for example green (Poot et al. 2008).

How polar bears will be affected by human activities related to oil and gas development are not well known (Vongraven et al. 2012).

Placement of constructions will affect fisheries due to exclusion (safety) zones, although the areas are small compared to the total fishable area. In the Lofoten-Barents Sea area, the effects of exclusion zones on the fisheries are generally estimated as being low, except in areas where very localised and intensive fishery activities 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 established during the construction phase. Experience from the North Sea indicates that large ships will trawl across subsea constructions and pipelines, while small ships often choose to avoid the crossing of such constructions (Anonymous 2003).

Another effect of the exclusion zones is that they act as sanctuaries, and in combination with the artificial reefs created by the subsea constructions attract fish and, in the North Sea, even seals.

6.2.8 Disturbance from ships and aircrafts

One of the more significant sources of noise during the life cycle of an oil or gas field is ships and helicopters used for intensive transport operations (Overrein 2002).

Depending on the set-up, supply vessels might sail between offshore exploration or production facilities and coastal harbours. Whilst for the exploration phase activities are expected to peak in summer, it could be year-round at the production stage. During production, shuttle tankers could sail between crude oil terminals and the trans-shipment facilities on a regular basis, even in winter and then assisted by icebreakers. The loudest noise levels from shipping activity result from large icebreakers, particularly when operating in ramming mode. Peak noise levels may then exceed the ambient noise level up to 300 km from the sailing route (Davis et al. 1990).

Helicopters produce strong noise that can scare and displace marine mammals as well as birds (Patenaude et al. 2002, Frederiksen et al. 2017). Particularly walruses hauled out on ice or land are sensitive to this activity. As walruses have a narrow foraging niche restricted to the shallow parts of the shelf and activities in these areas may displace the walruses to suboptimal feeding grounds.

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

An environmental impact assessment of shipping along the Northern Sea Route (*i.e.* the Northeast Passage) concluded that the walrus populations could be negatively impacted by disturbance from ship traffic and oil spills (Wiig et al. 1996), and NAMMCO (2015) also indicated that shipping could displace walruses from their habitats.

Seabird concentrations are also sensitive to helicopter flyovers. The most sensitive species is the thick-billed murre at breeding sites. These birds will often abandon their nests for long periods of time, and when scared off from their breeding ledges they may push eggs or small chicks off the ledge on steep cliffs, resulting in a failed breeding attempt (Overrein 2002). Also, concentrations of feeding birds can be sensitive, as they may lose feeding time due to the disturbance.

6.3 Environmental impacts from oil spills

6.3.1 Likelihood of oil spills

In relation to oil drilling in the Barents Sea, it has been calculated that, at a global scale, a blowout ranging between 10,000 and 50,000 t would occur once every 4600 years (small-scale development scenario) and once every 1700 years in an intensive development scenario (Anonymous 2003). The likelihood of a large oil spill from a tanker ship accident is generally estimated to be higher than for an oil spill due to a blowout (Anonymous 2003). Another study estimated that the probability of a deep water blowout in the Greenland part of the Labrador Sea would be one blowout for every 8488 exploration wells drilled, although the data base was meagre (Acona 2012).

Drilling in deep waters[6] and ultra-deep waters[7] increases the risk for a long lasting oil spill, due to the high pressures encountered in the well and due to the difficulties of operating in such deep waters. The water depth was among the many factors contributing to how long time it took (almost three months) to cap the *Macondo*-well (*Deepwater Horizon*) in 2010 (Graham et al. 2011).

6.3.2 The fate and behaviour of spilled oil

Previous experience with spilled oil in the marine environment gained in other parts of the world shows that fate and behaviour of the oil vary considerably, depending on the physical and chemical properties of the oil (light oil or heavy oil), how it is released (surface or subsea, instantaneous or continuous) and on the sea conditions (for example temperature, ice, wind, waves and currents).

Simulations of oil spill trajectories in the assessment area was modelled by DMI (Nielsen et al. 2008) and by SINTEF (Johansen 2008) – see Chapter 8.4.

General knowledge on the potential fate and degradation of spilled oil relevant for the Greenland marine environments has been reviewed by Pritchard & Karlson (2002), Vergeynst et al. 2018 and Wegeberg et al. 2018. Behaviour of potential offshore oil spills in West Greenland with special regard to the potential for clean-up was evaluated by Ross (1992).

6.3.3 Surface spills

Oil released to the sea surface will usually spread rapidly (depending on oil type), resulting in a thin slick (often about 0.1 mm thick in the first day). Wind-driven surface currents move the oil at approx. 3% of the wind speed

6 > 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).

7 > 5000 feet ≈ 1524 m according to US authorities (cf. Graham et al. 2011).

(Kim et al. 2014). Wind also causes turbulence in the surface water layer, breaking up the oil slick into patches. As a result, some of the oil will be dispersed in the upper water column and it usually will stay in the upper 10 m (Johansen et al. 2003). Oil on the surface interacts with the water to form emulsions, both oil-in-water and water-in-oil, and these expand the volume of hazardous substances on the surface.

Low temperature and the presence of sea ice can hamper the dispersal process considerably, and the complexity of an oil spill in ice-covered waters can be much larger than in open water.

The oil spill simulations performed so far in Greenland have generally addressed the drift of oil on the sea surface (except the Statoil simulations (Skognes 1999) and simulations at Store Hellefiskebanke (Wegeberg et al. 2016a), both West Greenland). Depending on the density of the spilled oil, it may also sink to the seabed, and oil adhering to sediment particles in the water column (Hjermann et al. 2007) may also end up there. Sediment particles are found in many Greenland waters where the turbid melt water from glaciers can disperse widely into the open sea.

6.3.4 Subsurface spills

Blowouts from a platform initially typically cause a surface spill, but may start or continue as a subsurface spill if the riser from the wellhead collapses. The risk of such a collapse is increased in deeper water. The oil in a subsurface blowout may float to the surface or remain in the water column for a longer period of time where it typically will be dispersed into small droplets. Oil type, oil/gas ratio, temperature, and water depth are factors influencing the fate of oil from a subsea blowout, i.e. whether it remains in the water column as a dispersed plume or float to the surface. As the potential oil type and oil/gas ratio is unknown for the assessment area, it is too early to predict the behaviour of possible spilt oil. The oil in the DMI models of subsurface spills in West Greenland, for instance, quickly floated to the surface (Nielsen et al. 2006), while a SINTEF model estimated that oil would not reach the surface at all, but rather form a subsea plume at a depth of 300-500 m (Johansen et al. 2003).

The *Deepwater Horizon* oil spill in the Mexican Gulf in 2010 was unusual in size and duration, but in many ways similar to the *Ixtoc* blowout in 1979, also in the Mexican Gulf. It revealed new and not yet described ways spilled oil could be distributed in the environment, although this probably also happened during the *Ixtoc* spill (Jernelöv 2010). The unusual dispersion of the oil was mainly caused by the spill site on the seabed at more than 1500 m water depth. Dispersants were applied at the wellhead and subsea plumes of dispersed and dissolved oil were formed in different depths and moved long distances with the water currents (Diercks et al. 2010a, Thibodeaux et al. 2011).

From studies of deep-water blowout events, Johansen et al. (2001) predicted that a substantial fraction of the released oil and gas will be suspended in pelagic plumes, even in the absence of added dispersal agents. The fate of oil in deep water is likely to differ strongly from that of surface oil because processes such as evaporative loss and photo-oxidation do not take place (Joye & MacDonald 2010). Microbial oxidation and perhaps sedimentation on the seabed is the primary fate expected of oil suspended in the deep sea (Joye & MacDonald 2010). In the Gulf of Mexico, natural oil seeps contribute to the marine environment with an estimated 140,000 t oil annually (Kvenvolden

& Cooper 2003), so there is an intrinsic potential for microbial degradation (presence of the relevant microorganisms). Bio-degradation rates faster than expected in the deep plumes at 5 °C have been reported in accordance with this hypothesis (Hazen et al. 2010) and later studies also support that indigenous oil-degrading bacteria were enriched (Montagna et al. 2013).

Microbial degradation of oil, however, may cause oxygen depletion, if oxygen is not replenished by photosynthesis, as is the case for surface waters, or advection in deep water, (Joye & MacDonald 2010). Oxygen depletion was not a serious problem during the *Deepwater Horizon* spill (Lubchenco et al. 2012).

The amount of spilled oil from the *Deepwater Horizon* disaster has been estimated at 780,000 m^3, making it the largest recorded peace-time spill. Moreover, at least 250,000 t of natural gas was discharged. Unexpectedly, approx. 50% of the oil and all of the natural gas was sequestered in deep waters (Joye 2015). The fate of the oil was estimated by McNutt et al. (2012): Burned 5%, skimmed constituted 20%, chemically dispersed 16%, naturally dispersed 16%, evaporated or dissolved 23% and the remaining 22% may have settled on the seabed or at coastlines.

Dispersants were added at the wellhead, and these probably contributed to the formation of a huge plume of dispersed and dissolved oil in depth between 900 and 1200 m (Hazen et al. 2010, Valentine et al. 2010, Lubchenco et al. 2012), although a later study questioned the effects of the dispersant (Paris et al. 2018). It was estimated that 2-15% of the spilled oil from this plume settled on the seafloor transported as Marine Oil Snow (MOS), a pathway not observed before (Daly et al. 2016, Passow & Ziervogel 2016, Short 2017, Brakstad et al. 2018a). MOS is a combination of marine snow (mainly mucus from planktonic organisms) and oil, which settles on the seafloor, and at *Deepwater Horizon* formed a loose floc layer up to 1.2 cm thick Chanton et al. (2015), (Passow & Ziervogel 2016) estimated that up to 24,000 km^2 seafloor was contaminated by MOS.

Although many studies of environmental impacts of the *Deepwater Horizon* oil spill have been published and compiled by Beyer et al. (2016), a Norwegian review concluded that it is difficult to use the environmental consequences to predict what would happen in a similar spill situation in Norway (Trannum & Bakke 2012). This conclusion certainly also applies to the assessment area, which in contrast to the subtropical environment of the Gulf of Mexico is Arctic.

6.3.5 Oil spill in ice-covered waters

An oil spill in ice-covered waters will usually cover a smaller area than a spill in open waters due to ice floes restricting the spreading and the roughness of the subsurface of the ice, at least as long as the ice does not move. This also means that very high oil concentrations may occur and persist for prolonged periods below the ice. Fauna there or in leads and cracks may therefore risk exposure to highly toxic hydrocarbon levels. In dynamic drift ice oil will tend to concentrate between floes and move with the drifting floes (Wegeberg et al. 2018).

Oil spilled in more or less ice-covered waters is usually not exposed to the same weathering processes as in ice-free waters (Word 2013). Temperatures are low, wave action is reduced, and the total surface of the oil is reduced due to the ice limiting the dispersal of the oil slick which in turn conditions lower evaporation, natural dispersion and emulsification. Dampening effects of ice reduce the mixing energy needed for dispersant applications. Spilled oil moves with the ice, where the speed of the drifting ice influences film thickness (faster = thinner) and area distribution. The rate of emulsification and natural dispersion usually decreases with increasing ice coverage, but ice-ice interactions can also induce emulsification. The oil film thickness increases with increasing ice coverage, but there is limited knowledge of oil-ice interactions (Word 2013).

Oil can be built into the ice during freezing, because oil will accumulate in the interface between ice and water, where the ice grows downwards (Faksness 2008).

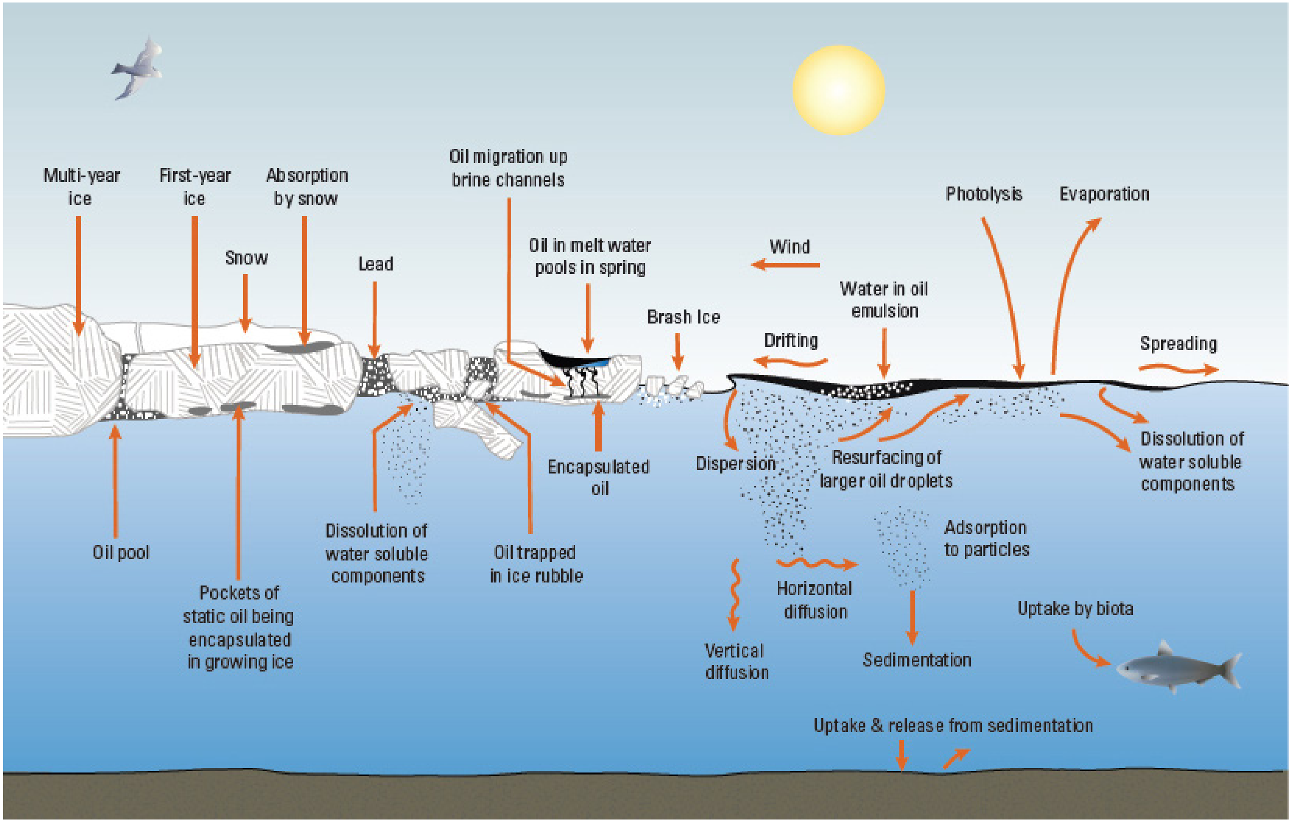
Spilled oil moves with the ice – on the water surface between floes, below the ice and build into the ice – where the speed of the drifting ice influences film thickness (faster = thinner) and area distribution. The rate of emulsification and natural dispersion usually decreases with increasing ice coverage, but ice-ice interactions can also induce emulsification. The oil film thickness increases with increasing ice coverage, but there is limited knowledge of oil-ice interactions (Word 2013).

Spilled oil can float between broken ice, accumulate under the ice, be submerged and can also accumulate in melt ponds on the surface of the ice. The ice itself can encapsulate oil as the water begins to freeze, and can be released into the water during the melting season in a relatively un-weathered condition and far from the spill site (Wegeberg et al. 2017). See Figure 89.

The oil can migrate vertically in the ice through small brine channels and can be released on top of the ice when the ice melts in spring (see Chapter 6.3.5).

These particular oil-ice interactions imply that the oil will retain much of its potential toxicity upon release from the ice, and/or toxicity of oil components may be increased due to the photo-oxidation processes (Word 2013), which also have to be taken into consideration when making toxicological assessments.

Figure 89. Environmental processes that affect oil behaviour and weathering in open water and in ice. SOURCE: National Research Council (2014).



6.3.6 Dissolution of oil and toxicity

The amount and concentrations of oil in the water column from a surface oil spill depends on dispersion, evaporation, oxidation, dissolution, biodegradation and emulsification of the oil. These processes are facilitated or hampered by climatic factors such as wind, temperature, presence of ice etc.

Different physical processes, for example wind and waves, produce oil/water emulsions, where oil is dispersed via oil droplets both horizontally and vertically. The horizontal drift depends on wind, water currents, waves and turbulent diffusion processes. The vertical transport of oil in the water column is driven by water currents, oil buoyancy and turbulence from waves. The process of dissolution of oil in the seawater is of particular interest, as it increases the bio-availability of the oil components. Fractions of the total oil present in the aqueous phase following a period of mixing are a water-soluble fraction (WSF) and a water-accommodated fraction (WAF). The difference between these two fractions of dissolved oil is that WAF contain micro-emulsions of fine droplets, while WSF is a true solution (Singer et al. 2000, Kang et al. 2014).

The water soluble fraction (WSF) is a multi-compound fraction that is bio-available and toxic to aquatic organisms (Melbye et al. 2009, Salaberria et al. 2014). The typical oil compounds in WSF from fresh oils include phenols, naphthalenes, 2-3 ring PAH's and so-called NSO compounds (highly polar compounds with nitrogen, sulphur, and oxygen atoms in their structures) (Word 2013). Melbye et al. (2009) showed that the main contributor to toxicity of the WSF was one of the most polar fractions, (besides the naphthalenes, PAH's, and alkylated phenols), which contained a large number of cyclic and aromatic sulfoxide compounds and low amounts of benzothiophenes.

The water soluble fraction (WSF) can leak from oil encapsulated in ice. Controlled field experiments with oil encapsulated in first-year ice for up to 5 months have been performed in Svalbard, Norway (Faksness & Brandvik 2005). The results showed that the concentration of water-soluble components in the ice decreases with ice depth, but that the components could be quantified even in the bottom ice core. A concentration gradient as a function of time was also observed, indicating migration of water-soluble components through the porous ice and out into the water through the brine channels. The concentration of water-soluble components in the bottom 20 cm ice core was reduced from 30 ppb to 6 ppb in the experimental period. Although the concentrations were low, the exposure time was long (nearly four months). This might indicate that the ice fauna could be exposed to a substantial dose of toxic water-soluble components and, at least in laboratory experiments with sea ice amphipods, sub-lethal effects have been demonstrated (Camus & Olsen 2008, Olsen et al. 2008). Leakage of water-soluble components to the ice is of special interest, because of a high bio-availability to marine organisms, relevant both in connection with accidental oil spills and release of produced water.

6.3.7 PAH's in the environment

Among the many compounds found in oil, the polycyclic aromatic hydrocarbons (PAH's) are regarded as the substances that have the most serious long-term environmental effects in relation to toxicity and bio-accumulation.

For further information see also Chapters 5.1.2 and 6.3.8.

Experience from the *Deepwater Horizon* blowout

Boehm et al. (2011) reported the results of analyses for total petroleum hydrocarbons (TPH) and total polycyclic aromatic hydrocarbons (TPAH) in water column samples collected in the vicinity of the spill from the *Deepwater Horizon* incident in the Gulf of Mexico. They were sampled during the 3-month release period (May through mid-July) and in a 3 month period after the well was capped. Overall, during the release, concentrations of TPAH's in water samples ranged from not detected (ND) to 146,000 µg/l (ppb), and 85% of all samples had TPAH concentrations of < 0.1 ppb, essentially at or near background levels. Concentrations attenuated rapidly with distance from the wellhead and were generally lower than 1 ppb 24-32 km away, in one direction out to 65 km.

In another study, PAH concentrations associated with acute toxicity were located in discrete depth layers between 1000 and 1400 m, extending at least as far as 13 km from the wellhead (Diercks et al. 2010b).

A baseline study of sediment PAH concentrations following the blowout conducted within several months after the accident showed that PAH's ranged from 0.01 to 0.070 µg/g dw (ppm) which, according to international sedimentary quality guidelines (ERL-ERM), indicated a low probability of harmful effects to benthic organisms (Botello et al. 2015). Chemical analysis of sediments sampled during repeated surveys between June 2010 and June 2012 to test for selected PAH's as indicators of contamination due to the spill showed that PAH's in samples from the continental slope in May 2011 were highest near the well site, and were reduced in samples taken one year later. PAH's from continental shelf sediments during the spill (June 2010) ranged from 10 to 165 ng/g (ppb) (Snyder et al. 2014).

Boehm et al. (2011) also reported other substances from water column samples near the *Deepwater Horizon* blowout. Total petroleum hydrocarbons (TPH) ranged from not detected to 6130 mg/l (ppm) and BTEX (Benzene, Toluene, Ethylbenzene and Xylene) were measured for the most part at values < 0.1 ppb, though higher values >100 ppb were encountered especially near the well. The TPAH, TPH and BTEX concentrations decreased rapidly after the well was closed on 15 July 2010 (Boehm et al. 2011).

6.3.8 Oil spill effects in the environment

The effects of an oil spill on organisms in the marine environment can be divided into two: the effects due to the physical contact (for example of smothering bird plumage and fish eggs) and the toxic effects due to skin contact (adsorbtion), ingestion or inhalation.

Exposure to oil also involve indirect effects, as oil in the environment may interfere with other environmental stressors, both natural and anthropogenic, or it may impact food resources for species not directly affected by the oil. Such effects are also important to consider and assess when effects of oil pollution are evaluated (Whitehead 2013).

If sufficiently many individuals are affected, effects on the population level may be the result and this in turn may induce further changes in the food web and ecosystems.

Oil spill impact on primary production

There are very few studies on the effect of oil spills on primary production. Following the *Deepwater Horizon* spill, a reduction in chlorophyll *a* concentrations (indicator of primary production) between 2011 and 2014 in an 96,000 km^2 large area which was hit by surface oil could be measured by remote sensing (Li et al. 2019). It was even more evident in the much smaller area (7000 km^2) suffering the most severe impacts. It was however, not possible to determine the exact mechanisms behind this reduction (Li et al. 2019). Lemcke et al. (2018) also showed that primary production of microalgae may be inhibited on increasing concentrations of oil and that the effect was enhanced by pre-exposure of the oil to sunlight (phototoxic effect).

Subsurface oil spills at least, may therefore have the potential to impact primary production at a large scale and localised primary production hotspots may be particularly vulnerable.

Effects on copepods

Copepods are very important in the food web, as they represent one of the most important groups in terms of energy transfer to upper trophic levels (See Chapter 3.2). Among the large copepods, the *Calanus* species *C. hyperboreus* and *C. glacialis* are dominant throughout the Arctic region (Word 2013). They are perennial and hibernate near the sea floor on great depth for ascending to surface waters in spring Copepods can be affected by the toxic oil components from the WAF and the WSF in the water below a surface oil spill. Recent exposure experiments with *Calanus* spp. showed that PAH's can accumulate in these organisms and cause effects such as lowered reproductive output, reduced grazing and increased mortality rate (Grenvald et al. 2012, Hansen et al. 2013a, Nørregaard et al. 2015, Toxværd et al. 2018). A recent study showed strong delayed effects on faecal production, egg production and high sensitivity to oil contamination (Toxværd et al. 2018), effects which may be the result of a subsurface spill affecting hibernating *Calanus* in deep waters.

Other studies also showed toxic effects of pyrene (PAH) on reproduction and food uptake among *Calanus* species (Jensen et al. 2008b) and on survival of females, feeding status, and nucleic acid content in *Microsetella* spp. from Western Greenland (Hjorth & Dahllöf 2008). The pyrene concentrations applied were, however, difficult to compare to actual spill situations. Toxic effects of combined temperature changes and PAH exposure on pellet production, egg production and hatching of *C. finmarchicus* and *C. glacialis* have also been demonstrated (Hjorth & Nielsen 2011). Effects from both naturally dispersed and chemically dispersed oil, such as increased mortality and decreased filtration rates in filter feeding copepods *C. finmarchicus* have also been demonstrated, with only slight differences between the treatments (Hansen et al. 2012).

Comparison of acute toxicity, expressed as mortality of herbivorous copepods (*Acartia tonsa*) and growth inhibition of a primary producer (*Skeletonema costatum*) of WAF's from non-weathered and naturally weathered oil, shows a general decrease in effect as a function of weathering degree (Faksness et al. 2015) and of increased effects with increasing WAF concentrations (Lemcke et al. 2018).

Finally, it has been shown that there is a significant inverse correlation between the size and the sensitivity to crude oil exposure for sub-tropical marine copepods (Jiang et al. 2012) – smaller species are more sensitive. This may be related to the higher surface to volume ratio of small organisms. Whether this applies to the Arctic species is not known.

However, given the usually restricted vertical distribution of these components in the surface layer and the wider depth distribution of the copepods, this is not likely to cause major population effects. This was also the conclusion of a study of the potential effects of oil spills on copepods in the Barents Sea (Melle et al. 2001): populations were distributed over such large areas that a single surface oil spill would only impact a minor part and not pose a threat to the populations.

As these Arctic copepods are lipid-rich (up to more than 50% of their dry weight) they can bio-accumulate oil compounds from oil-polluted waters, and thereby facilitate transfer of oil up in the food web to fish, birds and whales, which feed on these copepods and also to their offspring (Agersted et al. 2018, Gustavson et al. 2019). Moreover, other studies indicate that the timing of the migration to the surface waters in spring may be delayed (Skottene et al. 2019).

Microzooplankton is an important element in the food web, and a recent study showed high sensitivity to chemically dispersed crude oil exposure (Almeda et al. 2014). Increased mortality of microzooplankton may result in indirect effects of oil spills on copepods, through disruption of the trophic web and, consequently, in the structure and dynamics of the planktonic communities.

A subsurface spill, such as the *Deepwater Horizon* spill, where huge subsea plumes of dispersed oil were found at different depths, may impact copepod populations to a much higher degree than a surface spill. However, studies of zooplankton assemblage structure in the northern Gulf of Mexico following the *Deepwater Horizon* spill showed a surprising response among some taxa, including copepods, namely that they had higher densities during the oil spill year. This may be related to the increased microbial production based on the input of carbon and perhaps also on reduced predator populations. Variations in assemblage structure were observed, but they were weak and recovery of the zooplankton community was rapid (Carassou et al. 2014). An exposure study following the *Deepwater Horizon* spill on meiobenthic copepods showed reduced abundance, both on exposure to oil and to oil with added dispersant (Elarbaoui et al. 2015).

Oil spill impact on fish and shrimp and their larvae

Effects on adult fish and shrimp: Oil may injure fish through direct or indirect pathways and effects can be acute and/or chronic. Due to dispersion and dilution of oil in open waters and avoidance behaviour of many fish, adult fish populations may not be exposed to lethal concentrations of oil. Adult fish may, however, be exposed to oil compounds from the sediment and dietary sources, especially if prey organisms do not possess an efficient metabolising system to clear them from oil compounds. This is especially a risk in sheltered coastal areas such as bays and fjords, where concentrations of oil compounds can result in high fish mortality.

A series of studies on fish, reviewed by Hylland (2006), have shown a causality between exposure to PAH's from oil and (1) increased content of bile metabolites, (2) induced hepatic cytochrome P-4501A, (3) elevated concentrations of DNA adducts in liver, and (4) increased prevalence of neoplasia (cancer) in liver. Studies of biological responses in fish from different coastal sites in the Gulf of Mexico following the *Deepwater Horizon* spill, linked oil exposure to such sub-lethal effects, despite very low concentrations of hydrocarbons remaining in water and tissues (Whitehead et al. 2012).

A review of the available literature addressing the responses of estuarine fish to the *Deepwater Horizon* spill (Fodrie et al. 2014), documented that effects at the individual level were widespread, but failed to detect effects at the population level.

Adult northern shrimp live at and near the seabed in relatively deep waters (100-600 m), where oil concentrations from a potential surface spill will be very low, if detectable at all. No effects were seen on the shrimp stocks (same species as in Greenland) in Prince William Sound in Alaska after the large oil spill from *Exxon Valdez* in 1989 (Armstrong et al. 1995). A subsea blowout creating high concentrations in the water column may, on the other hand, hit northern shrimp stocks such as those in West Greenland. How shrimp stocks respond to such an impact is unknown. However, surprising results were found in Barataria Bay, one of the places hardest hit by the *Deepwater Horizon* spill. Here shrimp numbers actually increased the year after the spill due to reasons not yet known (Cornwall 2015).

Sub-lethal effects on penaeid shrimps (another family of shrimps than the northern shrimp) have been shown through exposure to oil components. These included cytological and histological damage to the hepatopancreas, the main detoxifying organ in shrimp (Sreeram & Menon 2005).

Fish and shrimp larvae: Fish/shrimp eggs, embryos or larvae are vulnerable to direct contact with oil (Pasparakis et al. 2019). The adverse effects are due to, e.g., ingestion and dermal absorption of toxic oil components, smothering of gas- and ion-exchange surfaces, or the loss of the epithelial mucus that protects fish from infections. Early life-history stages (for example embryos, larvae, juveniles) are often highly susceptible to physiological stressors. Exposure of zebrafish embryos to seven non-alkylated PAH's caused direct effects on cardiac conduction, which had secondary consequences for late stages of heart and kidney development, neural tube structure and formation of the craniofacial skeleton. Additionally, pyrene, a four-ring PAH, induced anaemia, peripheral vascular defects and neuronal cell death (Incardona et al. 2014). It has also been shown that environmentally realistic exposure (1–15 µg/l total PAH) to WAF's of field-collected *Deepwater Horizon* spill oil samples caused specific dose-dependent defects in cardiac function in embryos of three pelagic fish: bluefin tuna, yellowfin tuna and an amberjack (Incardona et al. 2014).

Exposure studies with embryos and eggs of pacific herring have shown that even low aqueous concentrations of oil components cause effects such as genetic damage, physical deformities, yolk sac oedema, reduced mitotic activity, lower hatching weight, premature hatching, malformations of the heart, mortality, decreased size and inhibited swimming (Kocan et al. 1996, Carls et al. 1999, Incardona et al. 2015).

Another study on an Arctic key species – the capelin – exposed fertilized eggs to different kinds WAF in concentrations similar to concentrations found at spill sites (Tairova et al. 2019). This experiment also found elevated mortality among the eggs, and developmental effects on the hatched larvae. Two studies also on capelin (Beirão et al. 2018, 2019) showed that embryos and sperm cells were harmed by exposure to chemically dispersed oil and by the dispersant alone. Capelin that spawn in Greenland use the subtidal part of the coasts, where eggs can be continuously exposed to oil sequestered in the sediments (slow release stressor) (Culbertson et al. 2008). Another key species – the polar cod – has also been shown to be susceptible to oil in the water in the early life stages (Nahrgang et al. 2016).

Juvenile penaeid shrimps showed reduced growth rates after exposure to sub-lethal concentrations of oil components following the *Deepwater Horizon* spill (Rozas et al. 2014).

Theoretically, impacts on fish and shrimp larvae may be significant and reduce the annual recruitment strength with some effect on subsequent populations and related fisheries for a number of years. However, such effects are extremely difficult to identify/filter out from natural variability, and they have never been documented after spills. Yet, the crash of the pacific herring stock in Prince William Sound four years after the oil spill may likely be a function mainly of impacts from very low oil concentrations in the water of the spawning grounds (Incardona et al. 2015).

Moreover, species with distinct spawning concentrations and where eggs and larvae concentrate in the upper part of the water column may be particularly vulnerable as eggs and larvae may be exposed to toxic oil concentrations from a surface spill (e.g. Johansen 2003).

Based on oil spill simulations for different scenarios and different toxicities of the WSF, the individual oil exposure and population mortality on cod egg and larvae has been modelled (Johansen et al. 2003). The population impact is, to a large degree, dependent on whether there is a match or a mismatch between high oil concentrations in the water column (which will only occur for a short period after the spill when the oil is fresh) and the highest egg and larvae concentrations (which will also only be present for weeks or a few months, and only be concentrated in surface water in calm weather). For combinations of unfavourable circumstances and using the PNEC (Predicted No Effect Concentration) with a 10 x safety factor, there could be losses in the region of 5% and, in some cases, up to 15% for a blowout lasting less than 2 weeks, while very long-lasting blowouts could give losses of eggs and larvae in excess of 25%. A 20% loss in recruitment to the cod population is estimated to cause a 15% loss in the cod spawning biomass and to take approx. eight years to recover fully (Figure 90).

However, Hjermann et al. (2007) reviewed the impact assessment of the Barents Sea stock of Atlantic cod, herring and capelin by Johansen et al. (2003) and suggested improvements by emphasising oceanographic and ecological variation more in the modelling. They also concluded that it is not possible to assess long-term effects of oil spills due to variation in the ecosystem. At

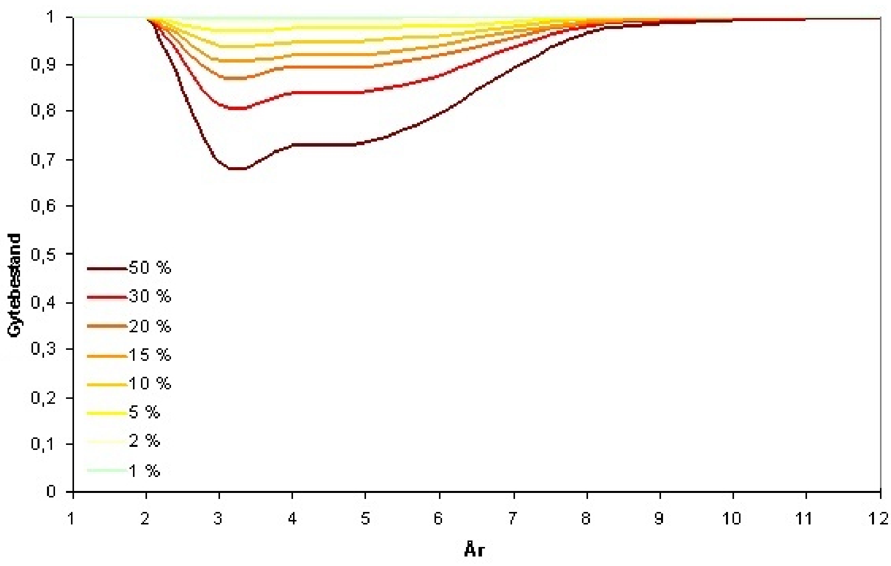


Figure 90. Estimated reduction and recovery in Barents Sea cod spawning biomass following large losses of egg and larvae due to large 'worst case' oil spills. The lines shows results for different degrees of losses. Gydebestand = spawning stock, År = year. Sources: Anonymous (2003b), Johansen et al. (2003).

best, ecological modelling can give quantitative indications of the possible outcomes of oil spills in the ecosystem context. Qualitatively, modelling can assess at which places and times an oil spill may be expected to have the most significant long-term effects.

Oil spill impacts on benthic flora

From different studies and monitoring of oil spill on the coastline and the effects on its biota, it has been shown that the natural removal and effects depend on oil type, and that clean-up efforts also may influence on the recovery of these habitats (Boitsov et al. 2012, Shigenaka 2014, Wegeberg et al. 2020, Gustavson et al. submitted). The oil type also determine the impact on the marine vegetation with respect to smother and/or eco-toxicological effects (Wegeberg et al. 2020).

A study aiming to mimic self-cleaning of rocky shore tidal levels in Greenland, showed that natural oil-removal along Arctic rocky-shorelines depends on position within the tidal zone as well as the physical and chemical properties of the oil. Ample exposure to water and wave-wash increases oil-removal rate and efficiency, and a lighter crude oil (North Sea Naphthenic Crude) was removed more readily than a heavy fuel oil (IFO180) (Gustavson et al. submitted).

Furthermore, experiments have shown that the effects and response of the tidal macro-algae *Fucus distichus* to oiling under high Arctic conditions, i.e. self-cleaning potential by seawater wash and photosynthetic activity, depended highly on the oil type. Oiling experiment with four oil types (ANS, Grane, IFO30 and MGO) on *F. distichus* tips showed that oil removal half-times ranged between 0.8 - 4.5 days, indicating that oiling of macro-algae with the tested oils was short-term. However, Grane oil mostly inhibited photosynthetic activity whereas oil from ANS, IFO30 and MGO stimulated it within the experimental period (14 days), but the photosynthetic activity of *F. distichus* continued to be affected (inhibited or stimulated), even after oil on the tip surface was washed off. Hence, long-term response remains unknown (Wegeberg et al. 2020). Initial stimulation of photosynthetic activity is explained by presence of growth regulating compounds in the oil acting as micronutrients (Wegeberg et al. 2020).

After the *Exxon Valdez* oil spill in 1989 in Alaska, the macroalgae cover in the littoral zone (mainly *Fucus gardneri*) was lost. It has taken many years to fully re-establish these areas, and some areas were still considered as recovering in 2010 (NOAA 2010). Strong fluctuations in the cover were observed during the recovery phase, and they may be a result of the interactions between grazers and the macroalgae, as was the case after the *Torrey Canyon* accident at the coast of Cornwall, UK (Hawkins et al. 2002). Regarding Prince William Sound, the fluctuations were considered as a result of homogeneity of the recovering *Fucus* population (for example genetics, size and age), which made it more vulnerable to natural environmental impacts (for example no adult *Fucus* plants to protect and assure recruitment), thus resulting in a longer time span to restore *Fucus* population heterogeneity (Driskell et al. 2001). Later studies (Shigenaka 2014) indicate that also the natural variation caused by the Pacific Decadal Oscillation played a role.

In contrast, no major effects were observed in a study on impact of crude and chemically dispersed oil on shallow sublittoral macroalgae at northern Baffin Island (BIOS project), which was conducted by Cross et al. (1987). It was discussed that it might be due to a similar lack of impact on the herbivores as well as the vegetative mode of reproduction in the dominant macroalgal species, and hence the impact from oil compounds may be isolated to the sexual reproduction.

The conditions of the *Exxon Valdez* accident and the BIOS project differed from one another. The oil types and state of weathering were different (Sergy & Blackall 1987). The BIOS studies on macroalgae were conducted in the upper sublittoral and not in the littoral zone, where the most dramatic impacts were observed in connection with the *Exxon Valdez* oil spill (Dean & Jewett 2001), and cleaning of the shoreline added to the impacts of the oil contamination in Prince William Sound.

After the *Exxon Valdez* oil spill, adult *Fucus* plants were coated with oil, but did not necessarily die. Part of the clean-up effort involved high-pressure washing of shores with large volumes of hot water. This treatment caused almost total mortality of adult *Fucus* and probably scalded much of the rock surface and, thereby, *Fucus*-germlings. In the long term (3-4 years), though, no significant difference was observed on *Fucus* dynamics at oiled and unwashed vs. oiled and washed sites (Driskell et al. 2001). Use of dispersants in cleaning up oil spills may increase recovery time of the treated shores. For example extended recovery times were recorded on shores badly affected by dispersants after the *Torrey Canyon* spill in South England (Hawkins et al. 2002).

Effects of oil spill response methods, dispersants and dispersed oil has also been studied on kelp species from the shallow sublittoral under high Arctic conditions in the assessment area in 2019 (S. Wegeberg, unpubl. data). Although analyses and data processing are still on-going, observations during the experiments suggested that *Laminaria solidungula* seemed more negatively affected than *Saccharina latissima* by, especially, dispersants but also by a mixture of oil and dispersants.

How the common oil spill PAH pyrene might affect natural algae and bacteria communities in Arctic sediment was studied near Sisimiut (just south of the assessment area) using microcosms. Benthic microalgae were especially sensitive to pyrene, and increased toxicity was found at high levels of UV light already at low pyrene concentrations (Petersen & Dahllöf 2007, Petersen et al. 2008). The pronounced pyrene effects caused algal death and release of organic matter, which in turn stimulated bacterial degradation.

Antarctic benthic diatom communities were exposed to oil and showed significant declines up to 80% and significant effects on community composition even after 5 years (Polmear et al. 2015).

Another more subtle way oil spill can impact algae is by oil components interfering with the sex pheromone reaction, as observed in the life history of *Fucus vesiculosus* (Derenbach & Gereck 1980), but the effects in a spill situation are unknown.

Finally a review of studies of phototoxicity of oils, dispersant and dispersed oils on algae and aquatic plants (Lewis & Pryor 2013) showed that effect varied by as much as six orders of magnitude due to experimental diversity. This indicates that results of experimental studies should be interpreted with caution. In a study quoted above, where the effects of oil components on primary production was studied phototoxic effects were also demonstrated (Lemcke et al. (2018).

Oil spill impacts on benthic fauna

Bottom-living organisms (benthos) are generally very sensitive to oil spills and high hydrocarbon concentrations in the water. They are often sessile – and thus cannot escape the oil. Also, many species have a slow growth and a long lifespan making population recovery very slow.

The sensitivity of many benthic species has been studied in the laboratory, and a range of sub-lethal effects have been demonstrated from exposures not necessarily comparable to actual oil spill situations (Camus et al. 2002a, 2002b, 2003, Olsen et al. 2007, Bach et al. 2009, Hannam et al. 2009, 2010, 2010, Vad et al. 2020). Effects occur especially in shallow water (< 50 m), where toxic concentrations can reach the seafloor. In such areas, intensive mortality has been recorded following an oil spill, for example among crustaceans and molluscs (McCay et al. 2003b, 2003a, Short 2017).

Oil may also sink to the seafloor as tar balls, which happened after the *Prestige* oil spill off northern Spain in 2002. No effects on the benthos were detected (Serrano et al. 2006), but the possibility of an impact is apparent. Another study of a benthic community monitored a series of stations beginning in 2002 following the *Prestige* oil spill, and showed that the original biodiversity decreased in the studied area with a loss of 16 species – from 57 in 2002 (before the spill) to 41 species in 2004. Five years later, the benthic communities had recovered, although a new composition among the macrofauna species was observed (Castège et al. 2014).

Sinking of oil may also be facilitated by sediment particles (such as in meltwater from glaciers) or as oil contaminated marine snow (MOS) in relation to subsurface spills.

After the *Deepwater Horizon* spill, a study found "severe" and "moderate" reductions in fauna abundance and diversity, respectively, in an area covering 148 km^2 around the wellhead (Montagna et al. 2013). The effects were correlated to content of total petroleum hydrocarbons (TPH), total polycyclic aromatic hydrocarbons (TPAH) contents and distance to the wellhead. Moreover, the authors of this study estimated that recovery rates would be slow, in the order of decades or longer. For example detrimental effects on deep-water corals were documented below the subsea plume of dispersed oil (White et al. 2012, Fisher et al. 2014). These corals was impacted by oil contaminated marine snow (MOS) (Girard et al. 2018). An experiment showed that survival rates of benthic species impacted by MOS were reduced by up to 80% (van Eenennaam et al. 2018). McClain et al. (2019) concluded based on surveys of the seabed in 2017, that there were continued impacts on deep sea megafauna.

Studies on and experiments with oil contaminations in benthic communities have shown that impacts for example occur on species composition, behaviour of the affected species, and vertical distribution in the sediments (including bioturbation activity) (Baguley et al. 2015, Ferrando et al. 2015, Gilbert et al. 2015, Vad et al. 2020). Studies of these aspects are therefore necessary in order to estimate real (structural and functional) and long-term effects of oil contamination on benthic communities (Gilbert et al. 2015).

Oil spill impacts on ice habitats

High oil concentrations may occur and persist for prolonged periods below the ice after an oil spill. Flora and fauna there or in leads and cracks may therefore risk exposure to highly toxic hydrocarbon levels. The water-soluble components released from encapsulated oil may be transported through the brine channels, thereby exposing sea ice microbes in the brine and the underlying water to toxic water-soluble components for a potentially prolonged period of time (Word 2013).

At least in laboratory experiments with sea ice amphipods, sub-lethal effects of exposure to the water soluble fraction (WSF) have been demonstrated on sea ice fauna (Camus & Olsen 2008, Olsen et al. 2008).

As described above, polar cod is probably sensitive to oil spills in ice due to the spawning behaviour. In experiments, both in the laboratory and in the field, polar cod have been exposed to PAH's and crude oil, and several sub-lethal effects were demonstrated. Moreover, polar cod seems to be a suitable indicator species to monitor pollution effects caused by oil (Nahrgang et al. 2009, Christiansen et al. 2010, Jonsson et al. 2010).

The question is how sensitive the ice-associated ecosystem is to oil spills. The available knowledge is very limited (Camus & Dahle 2007, AMAP 2010), and the flora and fauna (at least in areas dominated by first-year ice) are very resilient as the communities has to re-establish each season when new ice is formed. But as indicated above, polar cod could be particularly sensitive due to the fact that their eggs stay for a long period just below the ice, where oil also will accumulate (AMAP 2010).

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). A status report from NOAA's post spill monitoring programs (Shigenaka 2014) concluded that although the coastlines were difficult to clean, their recovery generally was rapid and lasted up to 4 years depending on how the shores were treated after the spill.

Many of the populations living in this habitat in Prince William Sound have since recovered, for example the sea otter population was declared as recovered in 2013 (Ballachey et al. 2014). But certain populations of other affected species were still under recovery and as late as in 2014, the pigeon guillemot (a close relative to the black guillemot in Greenland) and pacific herring were assessed as 'not recovered' (EVOS 2014a, b, Shigenaka 2014). However, natural variability may contribute to the slow recovery (Wiens 2013).

A much smaller spill (600 m^3) with diesel fuel in Antarctica in 1989 (*Bahia Paraiso*) also resulted in effects in the intertidal zone (Sweet et al. 2015), where macro-algae, birds, and invertebrates were fouled. But in general both the temporal and spatial effects in the environment were limited, and less than two years after the spill most locations had returned to background conditions. This rapid recovery was primarily due to the volatile nature of the spilled oil (Sweet et al. 2015).

In coastal areas, oil can also be buried or absorbed as subsurface oil residues (SSOR). This was the case in Prince William Sound, where oil was buried in gravel or absorbed in peat. Some of the buried oil was sealed from the atmosphere and was still in 2014 a source for continued (chronic) exposure (Shigenaka 2014), although the bio-availability of this oil is disputed (Page et al. 2013).

Almost 30 years after the spill, Nixon & Michel (2018) estimated that 227 t of oil were still present along 11.4 km shoreline in the areas affected by the Exxon Valdez oil spill.

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, e.g., geese. During the *Braer*-spill in the Shetland Islands, spray with oil was carried by wind and impacted fields and grasslands high above, but close to, the coast.

The oil spill from *Deepwater Horizon* also impacted on salt march flora and fauna along the coasts, where effects could be detected at least 6.5 years after the spill (Lin et al. 2016, Fleeger et al. 2019).

Oil spill impacts on seabirds

It is well documented that birds are extremely vulnerable to oil spills in the marine environment (Schreiber & Burger 2002), and particularly birds that rest on and dive from the sea surface, such as auks, seaducks, cormorants and divers (loons), are highly exposed to floating oil and sheens. This particular vulnerability is attributable to their plumage. Oil makes the feathers stick together, destroying the insulation and buoyancy properties of the plumage (Fritt-Rasmussen et al. 2016) and sheens as thin as 0.1µ may damage the microstructure of the feathers (Morandin & o'Hara 2014). Oiled seabirds readily die from hypothermia, starvation or drowning. Birds may also ingest oil when cleaning their plumage and by feeding on oil-contaminated food. Oil in this way has both sub-lethal and more long-term effects. However, the main cause of seabird losses following an oil spill is direct oiling of the plumage.

Many seabird species aggregate in small and limited areas for certain periods of their life cycles. Even small oil spills in such areas may cause very high mortalities among the birds present. The high concentrations of seabirds found at coasts, for example breeding colonies, in moulting areas or in offshore waters at important feeding areas (see Chapter 3.7) are particularly vulnerable.

After the *Deepwater Horizon* spill, bird mortality was estimated 600,000 to 800,000. Most affected were gulls, terns, pelicans and gannets; especially the local breeding population of laughing gulls was reduced (Haney et al. 2014a, b). The toll after *Exxon Valdez* was estimated to 650,000 birds (Piatt & Ford 1996), while a much lesser oil spill (350-500 m^3) in Danish waters with very high concentrations of birds resulted in 35,000 collected and euthanized birds (Clausager 1979), which probably represented only a fraction of the killed birds.

Oiled birds that have drifted ashore are often the focus of the media when oil spills occur. This, as a minimum, documents the individual suffering, but the question in an ecological context is how the populations are affected. This can only be demonstrated by extensive studies of the natural dynamics of the affected populations and the surrounding ecosystem (Figure 91).

The seabirds most vulnerable to oil spill impacts are those with low reproductive capacity and a correspondingly high average lifespan (low population turnover). Such a life strategy is found among auks, fulmars and many seaducks. Thick-billed murres (an auk), for example, do not breed before they are 4-5 years of age and a successful pair only raises one chick per year. This very low annual reproductive output is counterbalanced by a very long expected life span of 15-20 years or more. Such seabird populations are, therefore, particularly vulnerable to the additional adult mortality caused, for example, by an oil spill (e.g. Wegeberg et al. 2016a).

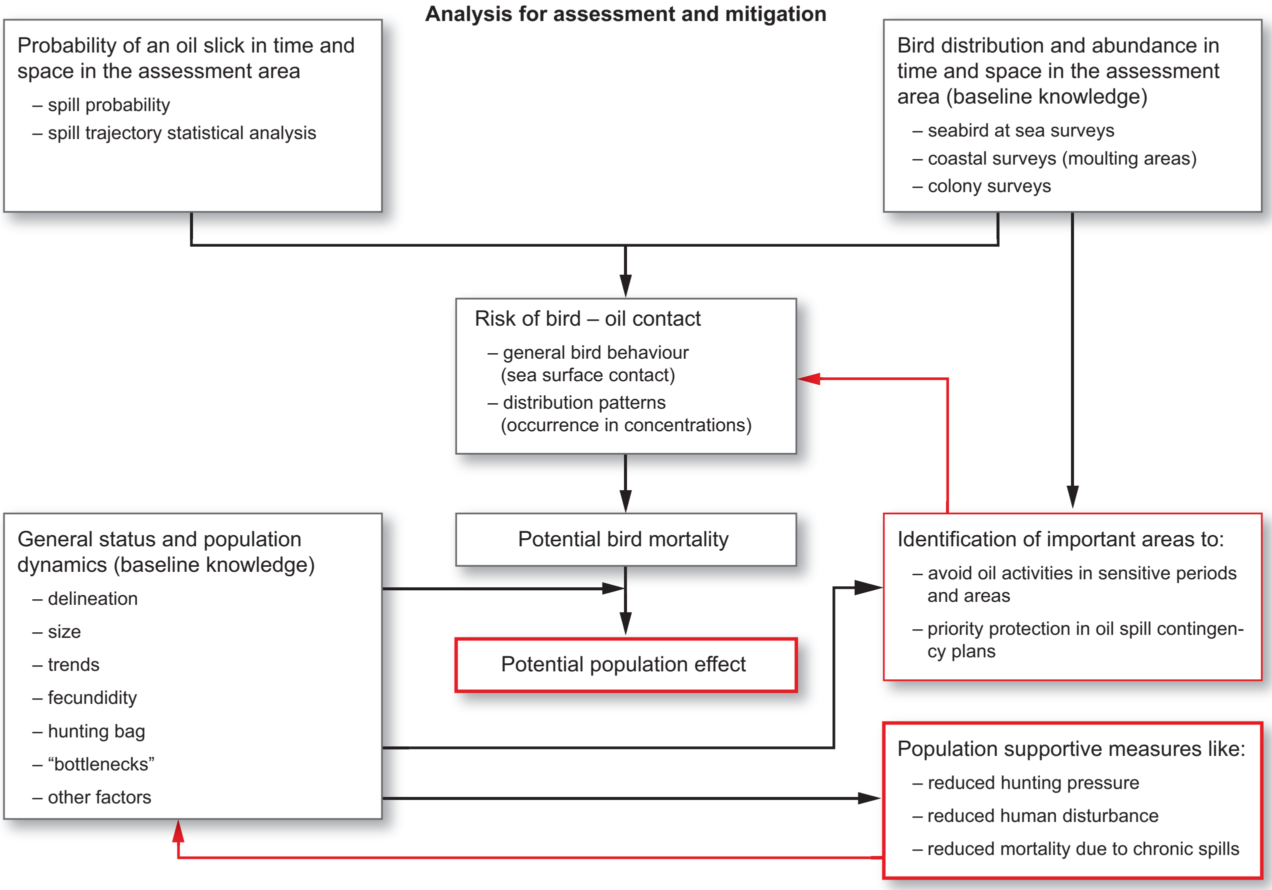


Figure 91. Basic principles of assessing the vulnerability of seabird populations to oil spills. Black lines indicate main effects on bird populations, red lines indicate effect of potential mitigative measures. Indirect effects not included for simplicity (based on Mosbech 1997).

Should a breeding colony of birds be completely wiped out by an oil spill, it must be re-colonised from neighbouring colonies. Re-colonisation is dependent on the proximity, size and productivity of these colonies. If the numbers of birds in neighbouring colonies are declining, for example due to hunting, there will be no or only few birds available for re-colonisation of an abandoned site (cumulative effect). Moreover, many seabirds are philopatric to their breeding site or where they were hatched, contributing to a slow recovery potential of an impacted site.

Oil spill impacts on marine mammals

Marine mammals are relatively robust and can generally survive short periods of fouling and contact with oil. However, there are exceptions, such as polar bears and seal pups, for which even short-term exposure can be lethal (Geraci & St. Aubin 1990). See details below.

It is difficult to assess mortality of marine mammals after an oil spill because carcasses are rarely found in a condition suitable for necropsies. Nevertheless, increased mortality of killer whales, sea otters and harbour seals exposed to the oil from the *Exxon Valdez* event in Prince William Sound was evident (e.g. Spraker et al. 1994, Matkin et al. 2008, Esler et al. 2016).

Marine mammals in the water need to breathe at the surface. Inhalation of vapours of Volatile Organic Compounds (VOC's) from an oil spill is therefore a potential hazard. Some of the marine mammal mortality after the *Exxon Valdez*-spill has been ascribed to this kind of exposure. The loss of killer whales was probably related to inhalation of VOC's from the spill (Matkin et al. 2008) (see details below), and the death of harbour seals was also related to VOC's (Spraker et al. 1994). In periods with ice-coverage when oil can fill the spaces between the ice floes, the risk of inhalation of toxic VOC's may be even higher because marine mammals are forced to surface in these confined ice-free spaces.

Seals and walrus

The effects of oil on seals were reviewed by St. Aubin (1990). Adult seals are vulnerable to oil spills because oil can damage the fur, produce skin irritation and seriously affect the eyes as well as the mucous membranes that surround the eyes and line the oral cavity, respiratory surfaces, and anal and urogenital orifices. Moreover oil is toxic if ingested or inhaled

Seal pups are more vulnerable than adult seals (St. Aubin 1990 and references therein). Effects of oil on the pups is likely to be more severe because pups are sessile during the weaning period and therefore cannot move away from oil spills. The pups are insulated by a thick coat of woolly hair (lanugo hair), and oil reduce 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 identify its pup. In this respect the ringed seal may be more vulnerable due til the relatively long lactations period (from April to mid-May), compared to the other seals.

Although the sensory abilities of seals should allow them to detect oil spills through sight and smell, seals have been observed swimming in the midst of oil slicks (St. Aubin 1990).

Oil spills in ice pose a special threat to seals and walrus if they are forced to surface in leads and cracks covered with oil, where they may inhale VOC from the oil and also become smothered. Harbour seals found dead shortly after the *Exxon Valdez* oil spill had evidence of brain lesions caused by VOC exposure, and many of these seals were disoriented and lethargic ('solvent syndrome') over a period of time before they died (Spraker et al. 1994).

The bearded seals which feed on benthic organisms may also be exposed to oil contaminated food, with sub-lethal effects as a result.

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

- Due to the high level of gregariousness in walruses, an oil spill will likely affect several individuals.
- Their pronounced thigmotactic behaviour (i.e. when in a group walruses keep close body contact) on ice and on land makes it likely that oil-fouled walruses will rub oil onto the skin or into the eyes of other individuals.
- Walruses tend to inhabit coastal areas and areas of relatively loose pack ice. Spilled oil is likely to accumulate in just such areas (Griffiths et al. 1987). Walruses therefore have a high risk of being fouled not only in the water but also when they haul out.
- Because they are benthic feeders, walruses may be more likely to ingest petroleum hydrocarbons than most other pinnipeds. Benthic invertebrates are known to accumulate petroleum hydrocarbons from food, sediments and the surrounding water (Richardson et al. 1989a).

- . Furthermore, sub-lethal effects on the behaviour, physiology, and productivity of benthic molluscs may result from exposure to petroleum products (Clark & Finley 1977). The implications for walruses may be serious since contaminants in their food are certain to build up in their own tissue. Also, if oil contamination were to reduce the biomass or productivity of the invertebrate communities that sustain walruses there would evidently be some secondary impact on the walruses themselves.
- Walruses are stenophagous (i.e. they have a narrow feeding niche) and depend on access to mollusc banks in shallow water. Oil spills in certain feeding areas could force walruses to seek alternative food or relocate to other feeding areas. It cannot be assumed that alternative types of food or feeding areas are actually available; thus, such an oil spill scenario could prove detrimental to the walruses.

But there is no information available on how walruses react to direct oiling.

Whales

There are several reports of whales that have repeatedly moved directly into oil slicks (e.g. Harvey & Dalheim 1994, Smultea & Wursig 1995, Anonymous 2003, Matkin et al. 2008). Whales are therefore probably not able to detect oil and probably do not avoid oil-contaminated waters (Goodale 1981, Harvey & Dalheim 1994, Anonymous 2003).

If whales have direct contact with oil slicks, immediate contact with the oil is through the skin and perhaps the eyes. Physical contact with oil may injure eye tissue and, toxic effects and injuries in the gastrointestinal tract have been described after ingestion (Albert 1981, Braithwaite et al. 1983, St. Aubin 1990, Werth 2001). Not much is known about the toxic effects of oil on whale skin, but the oil is likely to adhere and possibly stay for a long time on the skin, and may be toxic.

Baleen whales feed by filtration through the baleen plates. Spilled oil fouling the baleen plates may affect filtration, but this issue has not been studied so far. Any oil related effect on the baleen likely depends on factors such as the physio-chemical characteristics of the oil and the water temperature (Werth 2001).

The possible effect of oil spills on killer whales has been described by Matkin et al. (2008). They monitored the demographics and group composition of killer whales from Prince Williams Sound 5 years prior to and 16 years after the 1989 *Exxon Valdez* oil spill. Two of the killer whale groups did not avoid the oil and they were reduced by up to 41% in the year following the spill. After 16 years, one group had not recovered at all and the other recovered at rates lower than expected (Esler et al. 2016).

After the *Deepwater Horizon* spill in the Gulf of Mexico, increased mortality and many sub-lethal effects have been described in bottlenose dolphins in oil affected areas (Litz et al. 2014, Schwacke et al. 2014, 2015b, Venn-Watson et al. 2015a, Graham et al. 2017, Mullin et al. 2017).

Polar bear

Polar bears are very sensitive to oiling, as they are dependent on the insulation properties of their fur, and also because they are likely to succumb after ingestion of oil (Durner & Amstrup 2000) which they will do as part of their grooming behaviour (Øritsland et al. 1981, Geraci & St. Aubin 1990, Isaksen et al. 1998).

Polar bears may become exposed to spilled oil, especially when crossing open waters between ice floes or if the oil accumulate on the ice surface (Aars et al. 2007) (see Chapter 3.8.1). They moreover tend to feed along ice edges where oil spills would accumulate.

A model study of potential effects of oil spills on polar bears in the Beaufort Sea under different ice conditions indicated that there was a high probability that a low number of bears would be affected and a very low probability that a large number would be affected (Amstrup et al. 2006). Another model study (Wilson et al. 2018) carried out in the Chukchi Sea also showed that polar bears would be exposed to spilled oil: In one area in a worst case situation up to 38% of the population would be exposed to medium densities of oil and 13% to high densities 76 day after the spill occurred. In another area these proportions were lower.

Although the biological threats and impacts of oil and gas activities on polar bears are reasonably well understood (Stirling 1988, 1990, Amstrup et al. 2006), mitigation and response plans are currently lacking.

Long-term environmental effects of oil spills

The long-term effects of the *Exxon Valdez* oil spill in Prince William Sound in 1989 persisted longer than anticipated and many effects were, and still are, difficult to explain. Particularly the pacific herring stock has not recovered since the spill (Aderhold et al. 2018, Rice & Peterson 2018). Some of the delayed effects derive from oil sequestered in sediments in the intertidal zone, where it formed subsurface reservoirs of oil (SSOR) protected from loss and weathering (Nixon & Michel 2018). The oil was sufficiently bio-available to induce chronic biological exposure and caused long-term impacts at the population level of harlequin duck. At oiled coasts they had lower survival, their mortality rate was higher, their body mass was smaller and they showed a decline in population density as compared to un-oiled shores (Peterson et al. 2003). These effects decreased over time and in 2014 the harlequin duck population was declared 'recovered' (EVOS 2014c, Esler et al. 2017). The SSOR are now considered as not bio-available unless disturbed, and are expected to persist for further decades (Lindeberg et al. 2018, Nixon & Michel 2018).

The effects of the 1989 oil spill are still under study, and the focus has changed from a single species to an ecosystem approach (Rice & Peterson 2018).

Long-term effects were also seen 17 months after the *Prestige* oil spill off northern Spain in November 2002. Increased PAH levels were found in both adult gulls and their nestlings, indicating not only exposure from the residual oil in the environment, but also that contaminants were incorporated into the food web, as nestlings could only have been exposed to contaminated organisms through their diet (for example fishes and crustaceans) (Alonso-Alvarez et al. 2007, Pérez et al. 2008).

Another important finding of the long-term monitoring of the *Exxon Valdez* oil spill is that natural environmental variability should be considered when evaluating how populations have been disturbed and how they are recovering (Wiens 2013, Shigenaka 2014, Esler et al. 2016).

6.3.9 Oil spill impacts on some human activities

Oil spill impacts on fisheries

Tainting (unpleasant smell or taste) of fish flesh is a severe problem related to oil spills. Fish exposed even to very low concentrations of oil in the water, in their food or in the sediment where they live may be tainted, leaving them useless for human consumption (GESAMP 1993, Challenger & Mauseth 2011). The problem is most pronounced in shallow waters where high oil concentrations can persist for longer periods. Flatfish and bottom-living invertebrates are particularly exposed. Tainting has, however, not been recorded in flatfish after oil spills in deeper offshore waters where degradation, dispersion and dilution reduce oil concentrations. Tainting also occurs in fish living where oil-contaminated drill cuttings have been disposed of.

A very important issue in this context is the reputational damage an oil spill would cause on fish products from oil spill affected areas. To avoid even the risk of marketing contaminated products, it will be necessary to suspend fishery activities in an affected area (Rice et al. 1996, Challenger & Mauseth 2011, Graham et al. 2011).

Strict regulation and control of the fisheries in contaminated areas will be necessary to ensure the quality of the fish from these areas.

Suspension of fisheries would usually last for some weeks in offshore areas, and longer in coastal waters. The coastal fishery was banned for four months after the *Braer* incident off the Shetland Islands in 1993 and for nine months after the *Exxon Valdez* incident in Alaska in 1989 (Rice et al. 1996). However, some mussel and lobster fishing grounds were closed for more than 18 and 20 months, respectively, after the *Braer* incident (Law & Moffat 2011). During the *Deepwater Horizon* spill starting in April 2010, 230,000 km^2 were closed for both commercial and recreational fishing; in September 2010 approx. 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). In the Prince William Sound both commercial fishery and subsistence harvest and fishery were still considered as 'recovering' in 2010, 21 years after the oil spill in 1989 (NOAA 2010).

A recent paper by Pascoe & Innes (2018) reviews the potential oil spill economic impacts on fisheries.

Oil spill impacts on tourism

The tourism industry will be sensitive to a large oil spill hitting the coasts. Tourists travelling to Greenland to encounter the pristine, unspoilt Arctic wilderness will most likely avoid oil-contaminated areas. In this context it is notable that recreation and tourism industries still were considered to be 'recovering' from the effects of the *Exxon Valdez* oil spill in 1989 in Alaska as late as in 2010 (NOAA 2010).

7 Assessment

David Boertmann (AU) & Anders Mosbech (AU)

This chapter gives an overview of potential environmental impacts from oil and gas activities and their effects on the VEC's in the Disko West assessment area.

The assessments presented here are based on our present knowledge on the distribution and abundance of the different organisms and their sensitivity to and threshold levels toward human activities, noise and pollution in relation to oil exploration. However, the Arctic is increasingly affected by climate change – a process that accelerate – so the conclusions and assessments presented here may not apply to future conditions. Furthermore, an increase in knowledge from further investigations may also contribute to future adjustments of assessments and conclusions.

At present, we do not know much about the adaptive capacity of important species in the assessment area and how their sensitivity to human impacts might change under changing environmental conditions. Changes in habitat availability and quality forced by climate change, e.g. reduced sea ice coverage, is ongoing, with consequences for the local fauna (e.g. Langen et al. 2018). This affects the distribution patterns and living conditions for many species with implications for the food web and also the human activities. Northward range expansion of fish targeted by commercial fisheries could, for example, result in increased fishing activities in the assessment area.

7.1 Potential environmental impacts from oil and gas activities in the assessment area

See Chapter 6 for a review of the specific activities which may impact the ecosystem in the assessment area and the review in Wegeberg et al. (2017). Table 18 summarize the impacts and their potential significance.

7.1.1 Impacts from seismic noise

The most noise-sensitive species in the assessment area are narwhal, white whale, bowhead whale and walrus. Potential areas for seismic surveys will overlap with the range of these species, but there will generally be no temporal overlap as these species occur when ice is present and therefore outside the seismic survey season. However, late in the season (October/November) there could be a risk for overlap with migrating narwhal and white whale routes, and some kind of displacement of routes may be expected in case of spatial overlap.

Other whale species, such as blue, fin, humpback and minke whale occur in the assessment area when seismic surveys can be carried out, and their habitats will potentially overlap with exploration areas. There will therefore be a risk for displacement of individuals of these whales from important feeding grounds. The studies of Heide-Jørgensen & Laidre (2007) indicated that the whales have alternative feeding grounds, making them less sensitive to displacement.

It is unknown to which degree seismic noise may affect seabirds in the assessment area. It has recently been shown that cormorants and murres have a good hearing of underwater sound (Larsen et al. 2020, Hansen et al. 2020), but noth-

Table 18. Overview of the assessment and the impacts described in this report. Main activities and their impacts shown. Pot. = potential. *Spatial extend:* Local refer to the near surroundings of the source and the project area. Regional refer to the region in which the activity takes place, in this case the assessment area. *Duration:* Short-term refer to a definite period, of up to a few years before the impacted elements have recovered. In this case typical for impacts caused by exploration activities. Long-term is longer than that and often much more. In the case of the Exxon Valdez impacts more than 25 years, but also the lifetime of a production field and potentially indefinite (irreversible impact). *Significance of impact:* Low will recover shortly after the activity and without permanent ecological consequences (reversible impacts). Medium are localised impacts, which may take a long time to recover, but due to their limited extend the ecological consequences are limited. High are when e.g. populations are reduced and their recovery is delayed and also when background levels and exposure limits for pollutants are exceeded. Extreme are when the ecosystem is impacted including the ecosystem services, which the local population benefits from.

Impact	Activity/ source	Effect	Project phase	Spatial extend	Duration	Vulnerable VEC	Signifi-cance	Remark
Underwater noise	Seismic surveys, shipping, drilling	Displacement of marine mammals and fish	Exploration	Regional	Short-term	Narwhal, bowhead whale, white whale, walrus, fishery	Pot. high	Potential population impacts if key foraging areas or spawning areas are abandoned. Fishery may be temporarily affected. Risk for cumulative effects in case of multiple surveys.
			Production	Local	Long-term			
Drilling mud and cuttings, release to seabed and water column	Drilling from ships and platforms	Sedimentation, suspended material in water column, toxic chemichals	All	Local	Long-term	Seabed organisms	Pot. medium	Risk for cumulative effects in case of multiple drillings
Produced water	Production platforms	Contamination	Production	Regional	Long-term	Polar cod egg and larvae and primary production hotspots	Pot. high	
Invasive species	Ships	Replacement of native species, food web disruption	All	Regional	Long-term	The ecosystem	Pot. medium	
Sewage and waste water	Rigs and ships	Eutrophication, chemical pollution	Exploration	Local	Short-term	The ecosystem	Low	Risk for cumulative effects in case of multiple platforms
			Production	Local/ regional	Long-term	The ecosystem	Pot. medium	
Emissions to atmosphere	Fuel combustion	Climate change	Exploration	Global	Long-term	The Arctic ecosystem		
			Production	Global	Long-term			
Installations and infrastructure	Facilities on- and offshore	Habitat loss, novel habitats, aestetics	Exploration	Local	Short-term	Rare and species with localized distribution, VME's	Low	VME's, Arctic char rivers, rare and localised vegetation, trawl fishery are examples of vulnerable VEC's
			Production	Local	Long-term		Pot. high	
Transportation	Ships, aircrafts, helicopters	Disturbance/ displacement of wildlife	Exploration	Local	Short-term	Walrus, seabird concentrations	Low	
			Production	Regional	Long-term		Pot. high	
Prescense of people	Primarily at shore-based facilities	Disturbing/displacement of wildlife	Exploration	Local	Short-term	Moulting geese, seabird breeding colonies, caribou	Low	
			Production	Local	Long-term		Pot. high	
Large oil spill	Accidents with ships, rigs, pipelines, blowouts at surface or seabed	Oil smoothering, intoxication, direct mortality, sublethal effects	Drilling and transport	Regional	Long-term	The entire ecosystem, particularly vulnerable are seabirds, seabed communities and fish spawning in shallow water	Pot. extreme	

ing is known about response to underwater noise. However, the presence of seismic ships may have a disturbance effect, in general similar to other shipping activities. Feeding, moulting and autumn concentrations of seabirds could be at risk of being displaced by such a survey. Most of these may find alternative feeding grounds, but thick-billed murres on swimming migration (while flightless) may be more vulnerable. They seem however to be very dispersed (Box 5).

Fish eggs and larvae can be impacted by seismic surveys at close distance. But concentrations in Greenland waters are generally low in the upper 10 m and most fish species spawn in a dispersed manner in winter or spring. When the seismic surveys takes place, the eggs and larvae of fish (ichtyoplankton) will be dispersed both vertically and horizontally. It is therefore most likely that impacts of seismic activity (even 3D) on zoo- and ichtyoplankton, and thus on fish recruitment, will be negligible in the assessment area. However, sandeel is a summer spawner and concentrations of egg and larvae may be at risk of being impacted. But no knowledge is at hand to evaluate this risk.

The offshore fishery for Greenland halibut may encounter reduced catches for a period during and after intensive seismic shooting, due to a displacement of the fish. Local fishery companies operating west of Disko did not observe

Table 19. Summary of potential impacts from a single seismic survey on VECs in the Disko West assessment area. Displacement indicates spatial movement of animals away from an impact, and is classified as none, short term, long term or permanent. Sublethal effects include all notable fitness-related impacts, except those that cause immediate mortality of adult individuals. Sublethal effects and direct mortality are classified as none, insignificant, minor, moderate, major or potential. Dashes (–) are used when it is not relevant to discuss the described effect. Several surveys, either simultaneous or consecutive, have the potential to give more pronounced cumulative impacts. (L) = local extent, (R) = regional extend.

			Potential impacts – worst case with current regulation			
VEC	**Overlap**	**Risk of impact on critical habitats**	**Displacement 2D**	**Displacement 3D**	**Sublethal effects**	**Direct mortality**
Prim. production	small	no	–	–	–	–
Zooplankton	small	low	–	–	insignificant	insignificant
Benthic fauna	no	no	–	–	–	–
Benthic flora	no	no	–	–	–	–
Ice flora and fauna	no	no	–	–	–	–
Greenland halibut	pot. large	low	short term (L)	short term (L)	none	none
Arctic char	no	no	–	–	–	–
Polar cod	small	no	short term (L)	short term (L)	none	none
Sandeel	large	yes	short term (R)	short term (R)	potential	none
Fish egg and larvae	small	low	–	–	insignificant	insignificant
Seabirds	small	no	–	–	–	–
Walrus	no	no	–	–	–	–
Ringed seal	small	no	short term (L)	short term (L)	–	–
Bearded seal	small	no	short term (L)	short term (L)	–	–
Narwhal	no	no	–	–	–	–
White whale	no	no	–	–	–	–
Bowhead whale	no	no	–	–	–	–
Baleen whales (summer)	pot. large	no	short term (R)	short term (L)	potential	–
Toothed whales (summer)	pot. large	no	short term (R)	short term (L)	potential	–
Polar bear	no	no	–	–	–t	–
Comm. fisheries	pot. large	high	short term (L)	short term (L)	–	–
Hunting	small	no	short term (L)	short term (L)	–	–
Tourism	small	no	–	–	–	–

reduced catches in periods when simultaneous fishery and seismic surveys took place in the same areas in the 2000s (Boertmann et al. 2013).

Table 19 provide an overview of potential impacts from a single seismic survey in the assessment area, and Chapter 6.2.1 summarize available evidence on how far from seismic surveys different whale species may be affected.

7.1.2 Impacts of noise from exploration drilling rigs

High levels of underwater noise are generated during drilling, mainly from the propellers/thrusters securing the position of floating rigs (Chapter 6.2). The most vulnerable species (in respect to continuous noise) in the assessment area are narwhal, white whale, bowhead whale and walrus. If drilling rigs are placed in areas where these species occur, displacement of these species from critical habitats is a risk. However, there will be no or only a very short temporal overlap between the occurrence of these species and the drilling activities, as all these species occur in winter and spring, when ice is present. The other whale species are less vulnerable, but if several rigs operate in the region, there is a high risk for cumulative effects for example displacement from important habitats.

Exploration activities are temporary and, consequently, displacement of marine mammals caused by noise from drilling rigs is also temporary. However, exploration may take several years, and in an area with many license blocks, exploration may last for decades resulting in extensive cumulative impacts, which potentially may displace the whales permanently.

Table 20 gives an overview of potential impacts of noise and discharge from a single exploration drilling in the assessment area.

7.1.3 Impacts of drilling muds and cuttings

Drilling muds and cuttings are expected to be discharged to the sea during both exploration and exploitation drilling. Physical impacts of the sediment load are expected on the benthic communities near the release sites (Table 20, Chapter 6.2.3), while effects from the offshore chemicals will be low as far as current regulation is applied.

The most vulnerable VEC's in this respect will be the coral and sponge gardens which to some extend probably are the same areas as are identified as important benthic habitat vulnerable to trawling using the FAO criterias (FAO 2008) (see Chapter 3.4).

7.1.4 Impacts of other discharges and emissions

Besides drilling mud and cuttings the discharges from production facilities causing most reason for environmental concern relates to produced water and the substances it carries (See Chapter 6.2.4). Effects of produced water in the assessment area are difficult to evaluate but, for example, polar cod, and especially their egg concentrations below ice, could be exposed and impacted. Plankton production hotspots could also be of concern in relation to release of production water.

Another risk is the release of non-native and invasive species from ballast water and ship hulls, a risk which will increase with increasing sea water temperatures.

Table 20. Overview of potential impacts of noise and discharges from a single exploration drilling on different VEC's in the Disko West assessment area. This assessment assumes the application of current (2020) mitigation guidelines, see text for details and Table 19 for explanation.

VEC	Overlap	Risk of impact on critical habitats	Potential impacts – worst case		
			Displacement	Sublethal effects	Direct mortality
Prim. production	neglig.	no	–	insignificant	insignificant
Zooplankton	neglig.	no	–	insignificant	insignificant
Benthic fauna	small	yes	no	minor (L)	minor (L)
Greenland halibut	minor	no	no	insignificant	no
Arctic char	no	no	no	no	no
Polar cod	neglig.	no	no	no	no
Sandeel	small	yes	short term (L)	yes	no
Fish egg and larvae	neglig.	no	no	insignificant	insignificant
Seabirds	neglig.	no	short term (L)	insignificant	no
Walrus	no	no	no	no	no
Bearded seal	small	no	short term (L)	no	no
Ringed seal	small	no	short term (L)	no	no
Narwhal	no	no	no	no	no
White whale	no	no	no	no	no
Bowhead whale	no	no	no	no	no
Baleen whales (summer)	small	yes	short term (L)	no	no
Toothed whales (summer)	small	yes	short term (L)	no	no
Polar bear	no	no	no	no	no
Comm. fisheries	small	yes	short term (L)	–	–
Hunting	small	no	short term (L)	–	–

Sewage and sanitary wastewater will be released from rigs and ships. Such releases will be regulated according to the OSPAR convention, and environmental impacts of these discharges in the assessment area are expected to be minor, at least from a single drilling rig or production facility, but accumulated releases from many facilities and/or over long time periods could be of concern.

Finally, emissions from production activities to the atmosphere will be substantial and contribute significantly to Greenland's total contribution of greenhouse gases. The CO_2 emission from the Statfjord field in Norway, for example, was in 2003 (Chapter 6.2.6) almost three times the total current Greenland CO_2 emission, which in 2017 was 573,800 t (Nielsen et al. 2019). Such amounts will have a significant impact on the Greenland greenhouse gas emissions in relation to the Kyoto Protocol (to the United Nations Framework Convention on Climate Change, UNFCCC), although Greenland has a territorial reservation, i.e. no international reduction commitments in relation to the Paris Agreement. Although outside the scope of this assessment, the produced oil, when combusted, will contribute even more. Other emission to the atmosphere of concern in the Arctic are black carbon (BC) and SO_2 that will be emitted from all platforms and vessels supporting the operations. It is however, difficult to evaluate effects of these emissions in the assessment area.

7.1.5 Impacts from constructions and presence of infrastructure

Placement of constructions have both biological and aesthetic impacts. The biological impacts include disturbance and permanent displacement of particularly marine mammals and seabirds from critical habitats, and habitat loss is also an important issue to consider in this context, both on land and on the seabed.

A particular sensitive area in this respect is the shallow (< 50 m) parts of Store Hellefiskebanke where king eiders, walrus and bearded seals concentrate in winter and feed from the rich benthic communities (Box 4, Christensen et al. 2016, Wegeberg et al. 2016a).

A specific assessment of the impact of subsea constructions in the assessment area must wait until locations for oil exploration and production are known and site-specific EIAs and studies have been carried out.

Light attraction of eiders (Chapter 6.2.7) will be a problem in winter in the assessment area, while attraction of night-migrating passerines as observed in the North Sea (Bourne 1979) may occur, although to a much lesser degree than in the North Sea (Chapter 6.2.7), as the bird migration over the Davis Strait/ Baffin Bay is much smaller. Concern for night-time migrating little auks has been expressed in relation to platforms off Newfoundland (Fraser et al. 2006) and may also apply to the assessment area in the migrating periods in spring and autumn. However, the studies in 2009 and tracking studies of birds from Thule indicate that the majority of the little auks stay and move at least in the autumn to the west of the assessment area (Chapter 3.7).

Placement of constructions may affect both the shrimp and the Greenland halibut fisheries due to exclusion (safety) zones around installations. Especially in areas with intensive fishery, reduced catches may be expected due to these zones (OED 2006).

Placement of constructions onshore or in coastal habitats may give other types of environmental impacts in the assessment area:

- Habitat loss, for example rivers with spawning and wintering Arctic char can easily be obstructed, resulting in the loss of a local population. Infrastructure facilities may be constructed/placed in habitats for unique coastal flora and fauna.
- Traditional hunting grounds may be reduced in importance, if hunted species are displaced by the activities.
- Aesthetic aspects must be considered in a landscape conservation context when dealing with onshore activities. The risk of spoiling pristine wilderness, an important asset for the local tourist industry, is high.

All such impacts should be countered by thorough background studies combined with authority regulation.

The strategic environmental impact assessment of oil activities on Disko and Nuussuaq (Wegeberg & Boertmann 2016) describes the different environmental issues related to onshore activities.

7.1.6 Impacts from transportation

Ships and helicopters are widely used in the Greenland environment today. But the level of these activities will increase significantly, both in relation to exploration activities and to development of one or more oil fields.

Offshore (and onshore) facilities will involve access from the air, most notably helicopter flights between platforms and land-based facilities. Helicopters are very noisy and have a high potential for disturbing birds and marine mammals over a range of many kilometers. In the assessment area walrus, narwhal, white whale and bird concentrations such as breeding thick-billed murres and moulting seaducks will be particularly vulnerable to this activity. The result will in worst case be displacement while reduced time to forage will be more likely.

Especially the walruses wintering in the assessment area seems to be vulnerable to shipping and fishery activities: Local hunters have experienced that that walruses have changed distribution (i.e. occurring farther offshore) due to noise and other impacts (competition between walruses and fisheries for benthic resources, *i.e.* Icelandic scallop) from fisheries (Born et al. 2017).

An evaluation of shipping in Davis Strait/Baffin Bay in relation to a mining project considered the increased activity, including winter time shipping as posing a high risk for disturbing the walruses at Store Hellefiskebanke including displacement from their feeding grounds (NAMMCO 2019). As they have few alternative feeding areas in winter, the loss of walrus habitat on Store Hellefiskebanke through disturbance could be a risk for the population.

Increase in shipping in the assessment area will result in more disturbance of wildlife from noise pollution as well as raise the potential for ship strikes of large whales. The risk of oil spills will also increase (Christensen et al. 2015). The shipping moreover contributes to air emissions and discharges to the ocean (see above). However, ice will limit the shipping in the period, when vulnerable species, such as walrus, white whale and narwhal are present, contributing to limit the overlap and the potential impacts.

7.2 Potential impacts from accidental oil spills

7.2.1 Oil spills

Large oil spills are the most harmful incidents to the marine environment in relation to oil and gas exploration and exploitation (AMAP 2010a). The probability of such an incident is low, and the global trend in spilled amounts of oil is decreasing (Schmidt-Etkin 2011). Nevertheless, the risk is evident and the environmental impacts from a large spill can be severe and long-lasting, particularly in an Arctic environment such as the assessment area, where the risk is increased mainly because of the presence of icebergs and winter ice.

Several factors also increase the potential for severe impacts of a large oil spill in the assessment area. Owing to the specific Arctic conditions (particularly low temperatures), the degradation of oil is reduced, thus prolonging potential accumulation in the environment and organism as well as the exposure to toxic substances. Harsh weather conditions and occurrence of sea ice may influence the distribution and fate of oil and especially in winter hinder an effective oil spill response or even make it impossible.

According to the AMAP oil and gas assessment, tankers are the primary potential source for spills (AMAP 2010a). Tanker accidents can cause large spills while minor spills can occur in connection with offshore bunkering. Another potential source in the assessment area will be a blowout during drilling which, in contrast to a tanker spill, is continuous and may last for days, weeks or even months. The blowout from the *Deepwater Horizon* disaster, for instance, lasted 87 days before it was stopped by the drilling of a relief-well.

7.2.2 Environmental impacts of oil spills in the assessment area

A large oil spill in the assessment area has the potential to severely impact the ecology of the region. Effects will be long-lasting, and potentially longer than in Prince William Sound due to the Arctic conditions. Local populations of seabirds, marine mammals and seabed communities will most likely suffer from increased mortality and reduced populations, and if oil is hitting the coastal regions, hunting and fishing there will be impacted.

The winter ice in the assessment area is dynamic and moves with the surface currents, and will probably, if oil is spilled in the ice or just before the ice is formed, contribute to spreading the oil. Moreover, spilled oil in an almost unweathered condition may be released from the melting sea ice to open waters far from the spill site.

A report from DCE assessing oil spill impacts and particularly the fate of dispersed oil on Store Hellefiskebanke and Disko Bay (Wegeberg et al. 2016a):

- showed that dispersed oil from spills located on Store Hellefiskebanke and close to the coast at the northern part of the bank may stay on the bank, beach on nearby coasts or spread into Disko Bay,
- assessed that oil spill from a well head at the seabed would not cause stronger effects than a blowout at the surface because the oil would be transported to the sea surface at a fast rate,
- concluded that lethal and sub-lethal concentrations of dispersed oil would reach a depth of app. 7 m offshore and 15 m in coastal areas,
- assessed that burning residues from in situ burning may pose a risk of more direct effects on the benthos if they sink, as mats of partly burned oil accumulate on the sea bed. Environmental effects of these residues on benthos and, in particular, demersal fish has only been sporadic elucidated,
- assessed that protected coasts, may have very limited self-cleaning potential, why there is risk of preserving oil for example buried in the beach sediment or between boulders and in crevices. Such oil may pose a source of continuous contamination to the environment as was the case after the *Exxon Valdez* accident in 1989,
- assessed that the toxic effects of oil components may be transmitted through the food web causing cascading effects.

Plankton and primary production and oil spills

Special attention should be given to the implication of oil spills in connection with fronts in the assessment area, particularly during the spring bloom. Fronts between different water masses, upwelling areas and the marginal ice zone are examples, where high surface concentrations of phytoplankton and zooplankton, including fish larvae, can be expected.

The most sensitive season for primary production and plankton in the assessment area – i.e. where an oil spill can be expected to have the most severe ecological consequences – is April to June, when high biological activity of the pelagic food web of phytoplankton, copepods and fish larvae is concentrated in the surface layers. The spring bloom is trailing the receeding ice edge, and if oil is caught in the marginal zone large areas can be impacted. But also the autumn/winter time can be sensitive in case of a subsurface spill like the spill from *Deepwater Horizon* (see Chapter 6.3.1), because hibernating *Calanus* (ecological key species) in deep waters may be exposed.

The model study carried out in the Store Hellefiskebanke showed that there is risk of effects from dispersed oil (1000 t per 24 hours) on the organisms in the water column (Wegeberg et al. 2016a, ClimateLab 2014b, c, d): The vertical distribution of toxic oil concentrations reaches the upper part of the water column (down to app. 10 m), which also is occupied by a high fraction of the plankton (mainly down to 50 m). Hence, there is an overlap between the zones with toxic concentrations (acute lethal and sub-lethal) and high density of plankton. This overlap is estimated to potentially cover 0.4–3% of Store Hellefiskebanke's surface area for lethal concentrations and 7–30% for sub-lethal concentrations. Besides the toxic concentrations of oil components, dispersal of oil may result in oil droplets which can be perceived as food items and taken up by copepods. This may pose a risk, especially during summer, when the copepods are feeding and lead to accumulation of oil components in these organisms. However, dispersal of oil during winter time may not pose the same risk, as the copepods do not feed during this season.

Compared to the Lofoten-Barents Sea-area, there is less knowledge available on concentrations of fish eggs and larvae in Greenland. However, the highly localised spawning areas for Atlantic cod with high concentrations of eggs and larvae for a whole stock near the surface as seen in the Lofoten-Barents Sea have not been reported from the assessment area. The overall picture here is that fish larvae are widespread and found in low concentrations, although patches holding relatively high concentrations may occur. Another factor of importance is the vertical distribution of eggs and larvae. Eggs of Atlantic cod are concentrated in the upper 10 m of the water column, whereas larvae of shrimp and Greenland halibut also are found in deeper waters and therefore would be less exposed to harmful oil concentrations from a surface oil spill. This suggests that impacts on recruitment to Greenland halibut will most likely be insignificant in the assessment area. However, a subsea blowout with the properties and quantities of the *Deepwater Horizon* spill in 2010, where huge plumes of dispersed oil was sequestered in the water column, may expose eggs and larvae over much larger areas and depth ranges and potentially impact the recruitment and stock size of bottom-living species.

Polar cod eggs accumulate just below the ice in winter and spring and are sensitive to oil (see Chapters 5.1 and 6.3.8). As oil spilled under ice tends to accumulate in the same space, there is a potential risk for overlap and impacts on the recruitment to the polar cod population in the assessment area. Presently, there is no knowledge on aggregations of spawning polar cod and subsequent accumulation of eggs and larvae in the assessment area. But if such aggregations occur, an oil spill may have the potential to impact recruitment and eventually stock size. This could have cascading effects up through the trophic web, as polar cod is a key species in the ecosystem.

Benthic fauna and flora and oil spills

In the assessment area, the shallow water (down to 50 m) communities generally have high species richness (bivalves, brittlestars, etc.), the species have long life spans and many species are only represented with a single specimen in a sample, showing that they are widely dispersed in very low densities. All these traits contribute to a slow recovery of oil spill impacted benthic communities in the assessment area. Surface spills will affect the benthic communities in shallow waters, while a subsurface spill have the potential to impact benthos in deep waters as well (cf. *Deepwater Horizon*). High mortality on the seabed have the potential to cascade higher up in the food web, if feeding areas for walrus and king eiders are affected.

The rocky tidal and subtidal zones of the assessment area are less sensitive to oiling compared to similar zones at lower latitudes. This is caused by the winter ice, which generally prevents fauna and flora from settling on the rocky surfaces. The self-cleaning potential is also high at exposed rocky coasts. There are however, also many low sedimentary coasts in the assessment area, and here oil may potentially be buried like it happened in Prince William Sound during the *Exxon Valdez* spill.

It is difficult to assess oil spill impacts (as well as the impacts from the response methods in the tidal zone) on the macroalgae communities in the assessment area. They will depend on the affected macroalgae communities, the habitats and as described in Chapter 6.3 vary from complete removal of the vegetation to almost no effects, depending on oil type, morphology and exposure of the affected sites, and on the oil spill response methods applied.

Sea ice communities and oil spills
The sea ice communities are expected to be highly exposed to oil spills as the ice may catch and accumulate oil in the interface between ice and water. Moreover, oil may penetrate the ice through brine channels, where the organism live. However, even though the organisms in the ice will be killed, the communities are probably resilient, as they are adapted to live in a temporally unstable habitat. The most vulnerable VEC in this habitat is therefore the spawning polar cods.

Fish and oil spills
Fish in the nearshore environment are particularly in risk of being exposed to oil spills hitting the coast (Wegeberg et al. 2016a). Arctic char, capelin and lumpsucker will be very sensitive to oil spills in the coastal zone and reductions in stock sizes of at least Arctic char and capelin may be expected in case of a large oil spill, as these species occur in local discrete stocks. Whether this is the case for lumpsucker is not known, but some regional genetic variation has been described (Mayoral et al. 2016), indicating local stocks.

Fish in the open sea are less sensitive, as they can avoid toxic concentrations of oil in the water. An exception could be sandeel (a key species in the bank ecology), as they are very stationary on the banks.

Fish egg and larvae are on the other hand sensitive to oil spills (see chapter on plankton and oil spills above).

Seabirds and oil spills
Many different seabird species breed in the assessment area (Chapter 3.7) and a majority are associated with habitats (sea-facing cliffs or on low islets) along the coastline where they are highly exposed to drifting oil and where oil spill response can be difficult. A particularly sensitive period occurs when the adults, by swimming, accompany their chicks away from the breeding site, a situation seen among murres and seaducks. Eiders usually stay in sheltered inshore waters, while murres move offshore and disperse over extensive areas (Box 5).

Only one breeding colony of thick-billed murre is known from the assessment area, situated in Disko Bay. Here the birds assemble on the water below the colony and also at feeding areas near the colony where many birds can be exposed to surface spills. Another risk situation is when the still flightless chicks followed by the male parents leave the colony on a swimming migration (Box 5). The breeding population is declining and therefore particularly sensitive to additional mortality. Adding to the vulnerability is the long distance to neighbouring colonies which makes immigration from other colonies less likely. The nearest thick-billed murre colonies are found in Evighedsfjorden (>500 km) and in Upernavik (>300 km).

In Prince William Sound, Alaska, the breeding population of common murres (a close relative of the thick-billed murre) was assessed as recovered after 8 years following the impacts of the *Exxon Valdez* oil spill in 1989 (NOAA 2010). This happened in an area with several colonies in neighbouring areas and no hunting. Recovery from a similar situation in the assessment area, where the murres are hunted, will take longer time – and may not happen at all, since the colony is declining (See Box 5).

Other important bird colonies for which the population could be severely impacted by an oil spill in the assessment area include colonies with kittiwakes, Arctic terns, common eiders, great cormorants, Atlantic puffins, razorbills etc. (Figure 30).

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 31. These concentrations will suffer from a high mortality if hit by an oil spill.

The number of thick-billed murres occurring in the assessment area in spring is 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, for example released from the melting ice.

The survey in September 2009 showed that particularly thick-billed murres may occur in large concentrations within the assessment area also in autumn (Box 1), while the majority of the little auks occurred to the west of the assessment area on the Canadian side of Davis Strait (Figure 40). The murre-concentrations are very vulnerable, as significant numbers may be affected and killed by a large spill.

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 vulnerable concentrations of mainly king eiders and common eiders are found, and an oil spill in the Store Hellefiskebanke area may impact a high proportion of the entire population of king eiders. A model study (Frederiksen & Mosbech 2016) indicated that the winter population of king eiders could be seriously affected by an oil spill. If the mortality for example was 30%, recovery time for the population could be up 20 years, and if the birds also were feeding on oil contaminated food the recovery time would be even longer.

In conclusion, there are many seabird concentrations that throughout the year are vulnerable to oil spills in the assessment area, and heavy losses to the populations must be expected in case such bird concentrations are hit by an oil spill.

Marine mammals and oil spills

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 entire 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. The population is generally widespread in winter in the assessment area, why it is unlikely that the population will suffer even if the mortality is increased in an oil impacted area. Concentrations of bearded seals have, however, been recorded in the ice on Store Hellefiskebanke in 2006 (Frederiksen et al. 2008).

The strong site fidelity to certain haul-out sites on land make harbour seals sensitive to oil spills and disturbing activities near these sites. As the population in the assessment area is very small, even small spills or localised activities have the potential to affect a large segment of the local population.

The walruses wintering in the assessment area are highly localised to certain parts of the Store Hellefiskebanke and sometimes also Disko Bank. A large oil spill may potentially affect a significant part of the population. How the walruses will react to direct oiling is not known, but increased mortality among affected animals must be expected.

An indirect impact on the walruses may also result from fouling of the seabed, where the walruses feed (waters less than 100 m deep on Store Hellefiskebanke and on the banks along western Disko Island). These are essential walrus foraging areas, where the majority of the population spend the winter, and food reduction may have severe impacts on the entire population. Moreover there will be a risk of ingesting oil contaminated food, with sub-lethal effects as a result.

With the effects on the killer whales in Prince William Sound in mind (two local pods never recovered from the impact, see Chapter 6.3), there will be concern for the populations of narwhals and white whales wintering in the assessment area, if their habitats are hit by an oil spill, especially in ice-covered waters where the whales can be forced to surface in oil-covered leads. This may also apply to bowhead whales, although oil spill effects on baleen whales have not been described.

The whales occurring in the summer time are less sensitive to oil spills, as they are not restricted in their surfacing behaviour as whales are in an ice covered sea.

Oil development not just in the assessment area but in the entire Arctic poses a wide range of threats to polar bears ranging from oil spills to increased human-bear interactions. It is probable that an oil spill in a sea ice habitat would result in oil being concentrated in leads and between ice floes resulting in both polar bears and their main prey (ringed and bearded seals) being directly exposed to oil. Another concern is that seals more or less covered in oil may be a target for polar bears, with risk of ingesting oil – particularly toxic to polar bears (see Chapter 6.3.8).

Among the two subpopulations of polar bears occurring within the assessment area, the Davis Strait population probably will not be impacted by oil activities including oil spills, due to the low abundance. 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. As the bears move over considerable distances, many could be at risk of being fouled by a single oil spill, and the model studies referred to in Chapter 6.3.8 showed that under certain circumstances high proportions (up to 38%) of a population could be affected by an oil spill. This may also apply to the Disko West assessment area.

Fisheries
Very important fishing grounds for Greenland halibut and northern shrimp are located in the assessment area. These fishing grounds will be closed if swept by and oil spill, and economic consequences must be expected for fishermen and local fishing industries. Even though the inshore fishery takes place far from potential new license blocks, the drift modelling carried out by DMI (Chapter 8.4) indicated that under certain conditions oil may drift this far (Annex C, Figure 7). This will result in closure of both the commercial and the subsistence fishery aimed at capelin, lumpsucker, Arctic char etc., mainly of marketing and health reasons respectively (see Chapter 6.3.4).

Long-term effects of oil spills
In certain areas of Prince William Sound recovery lasted more than 25 years (Esler et al. 2016) after the *Exxon Valdez* oil spill. Everything else equal, it may take much longer time in the assessment area due to the Arctic conditions and the limited possibilities to clean up spilled oil, at least when sea ice is present.

For example, many parts of the coastline in the assessment area have a similar morphology as the coasts of Prince William Sound where the oil was trapped as subsurface reservoirs of oil (SSOR). This contributes to the risk of long-term impacts of oil spills in the assessment area. Moreover, these coasts proved to be some of the most difficult to clean after the incident (Shigenaka 2014). A factor – not apparent in Prince William Sound – is the sea ice. This may protect the coasts at least in winter, and thereby give extra time to respond.

Most populations of fish and seabirds in Prince William Sound have recovered, although some recovered very slowly and a few did not recover (Esler et al. 2016). Similar effects must be expected in the assessment area, but it is not possible with any confidence to predict the population effects of each species. There were numerous local environmental and climatic factors specific to the Prince William Sound case after the spill, and these cannot be compared to the West Greenland conditions.

Table 21 provides an overview of potential impacts from a large oil spill.

7.3 Mitigation of impacts from oil activities

7.3.1 Mitigation of impacts from normal operations

Mitigation of impacts from seismic noise
Mitigation measures related to seismic surveys generally include a soft start or ramp up of the airgun array each time a new line is initiated (review by Compton et al. 2008). Although not verified by experiments or observations, this approach is commonly considered 'best practice'. A soft start should allow marine mammals to detect and avoid the sound source before it reaches levels dangerous to the animals. A study in Australia (Dunlop et al. 2017) could not find different response among humpback whales exposed to both soft start and constant source, but at least the whales avoided the sound source vessel at distances greater than the mitigation zones generally applied around the vessel.

Table 21. Overview of potential impacts of a large oil spill on VECs in the Disko West assessment area. See Table 19 for explanation. This assessment assumes the application of current (2020) mitigation guidelines, see text for details.

VEC	Potential overlap	Risk of impact on critical habitats	Potential impacts – worst case		
			Duration	Sublethal effects	Direct mortality
Prim. produktion.	large	yes	short term	minor	minor
Zooplankton	large	yes	short term	minor	minor
Benthic fauna	large	yes	long term	major (L)	major (L)
Benthic flora	large	yes	long term	major (L)	major (L)
Ice flora and fauna	large	yes	short term	major (L)	major (L)
Greenland halibut	small	yes	short term	minor (L)	none
Arctic char	large	yes	long term	major (L)	minor (L)
Polar cod under ice	large	yes	short term	major (L)	major (L)
Fish egg and larvae	large	yes	short term	major (L)	major (L)
Seabirds	large	large	long term	major (L)	major (L)
Walrus	large	yes	long term	major (R)	moderate (R)
Ringed seal	medium	no	long term	moderate (R)	minor (R)
Bearded seal	medium	yes	long term	moderate (R)	minor (R)
Narwhal	large	yes	long term	major (R)	minor (R)
White whale	large	yes	long term	major (R)	minor (R)
Bowhead whale	large	yes	long term	medium (R)	minor (R)
Baleen whales (summer)	large	yes	long term	minor (R)	minor (R)
Toothed whales (summer)	large	yes	long term	major (R)	medium (R)
Polar bear	large	yes	long term	moderate (R)	major (R)
Com. fisheries	large	yes	long term	–	–
Hunting	large	yes	long term	–	–
Tourism	large	yes	long term	–	–

Another measure is to include skilled marine mammal observers on board the seismic vessels to detect whales and to instruct the crew to delay seismic shooting in case whales are within a certain distance (usually 500 m) – the mitigation zone (exclusion zone, safety zone or injury zone) – from the array. These observers are usually referred to as MMO's or MMSO's (Marine Mammal and Seabird Observers). The detection of nearby whales in sensitive areas is often considered more efficient, depending on species, if supplemented by the use of hydrophones for recording whale vocalisations (Passive Acoustic Monitoring – PAM), although whales do not necessarily emit sounds when present.

These measures (soft start and MMO) are aimed at preventing physical effects, while behavioural effects and, especially, displacement of whales several kilometres from the noise source are not mitigated by this measure.

A third mitigating measure is to regulate seismic surveys in specific sensitive areas to reduce potential impacts. In such areas activities can be banned in the sensitive period or operators can be subject to specific mitigating measures.

In Arctic Canada, a number of mitigation measures were applied to minimise impacts from seismic surveys on marine mammals and the subsistence hunting of them (Miller et al. 2005). Some measures are identical to those mentioned above, while the most important measure was a delay of the start of seismic operations until the end of the white whale hunt, and during periods when the whales were utilising important habitats. Some particularly important white whale areas were completely closed for surveys.

There is an interesting and informative discussion/review of the different mitigating methods in relation to protect marine mammals from seismic surveys by Bröker (2019).

The Greenland guidelines (EAMRA 2015, Link) include similar measures, defining temporal area restrictions for seismic activities in West Greenland to protect bowhead whale, narwhal and white whale. These guidelines also follow best practice in line with the JNCC (2010) recommendations, including:

- The airgun array should not be larger than needed for the specific survey.
- Use of 'mitigation gun' – 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 mitigation zone of 500 m from the airgun array must be applied. If marine mammals are observed within this zone during full power, the output must be reduced to the mitigation gun until the mammal has left the zone.
- A pre-shooting search must be conducted prior to commencement of any use of the airguns. If waters are less than 200 m deep, this search must last 30 min. When operating in waters with a depth of more than 200 m, the search must be extended to 60 min. If marine mammals are spotted within the mitigation zone, the ramp-up procedure must be delayed 20 minutes from the time when the animal has left the mitigation zone (or the ship has moved so far that the animal is outside). The pre-shooting search can be initiated prior to the end of a survey line, while the airguns are still firing.
- The array should not be started at full power, but individual airguns should be added one by one or, if not possible, output from each airgun should be slowly increased by manipulation of pressure (ramp-up or soft start procedure).
- The ramp-up procedure must span a period of about 20 min and can be carried out while the survey ship is in route to the starting point of the transect line.
- Ramp-up should not be initiated if marine mammals are inside the array or within the mitigation zone (500 m) of the array. If marine mammals are discovered within this mitigation zone during the ramp-up procedure, the airguns must be reduced to the mitigation gun and a new ramp-up procedure initiated when the mammal has left the safety zone – i.e. at least 20 min. after the last sighting.
- If proper ramp-up cannot be performed for technical or other reasons, other measures should be taken to assure that no animals are within the mitigation zone at start up.
- Passive Acoustic Monitoring (PAM) of vocalizing whales must be deployed for monitoring purposes at start up during periods with reduced visibility (at night, when the sea state is above 3 and during fog).
- Four Marine Mammal and Seabird Observers (MMSO) must be posted on the source vessel (where the airguns are deployed from) and, at minimum, one should be continuously on the look-out, particularly for whales and seals during the pre-shooting search and when airguns are operated. Two MMSO's must be certified PAM-operators.
- Observation of marine mammals during shooting and inside the mitigation zone may not lead to shutdown, but if marine mammals are observed within the 500 m mitigation zone of the array, output should be reduced to the mitigation gun until the marine mammals are outside the 500 m zone.
- A log of marine mammal observations should be kept on the ship and reported as part of the cruise report.
- Airguns should not be used outside the transect lines, except in the cases mentioned above (ramp-up prior to arrival and on short transit lines) and for strictly necessary testing purposes. Testing the array at full power must be initiated with a ramp-up procedure as above.

- Prior to the survey, the operating company must model the noise propagation in the affected waters, and use the results for preparing the environmental impact assessment. If more seismic surveys take place in the same areas, a joint noise propagation model must be prepared.

The Greenland guidelines to seismic surveying also recommended to inform local authorities and hunters' organisations before seismic activities take place in their vicinity (EAMRA 2015). 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.

Mitigation of noise from drilling

Noise from drilling and the positioning of vessels 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 whales must be addressed because, for example, bowhead whales will avoid such areas with a distance of up to 50 km (Schick & Urban 2000).

In order to mitigate for the potential impacts of noise production from drill ships, planning is needed in order to attempt to avoid critical habitats for cetaceans, including migration routes. Additionally, activity can be timed in order to reduce overlap of drilling activity with occurrence of cetaceans within the area. Drilling activity is harder to stop and start reactively to marine mammals arriving in the area but, as stated above, they tend to avoid areas of continuous noise sources as would be the case for drilling. If there are, however, short duration noise events related to drilling activity, then Marine Mammal Observers could be employed in order to ensure that the noisy events do not occur when marine mammals are present in the vicinity.

Mitigation of impacts from the release of drilling mud and cuttings

It is important to limit discharges of environmental harmful chemicals and oil components, and special focus should be on toxicity, degradability and potential for accumulation. According to Chapter 5.1 on background levels of contaminants, a range of long-transported compounds such as mercury and chlorinated organic compounds as well as oil components do occur in the assessment area.

Environmental risk from the mud chemicals shall be mitigated by strict regulation based on data on toxicity and bio-accumulation of the chemical in aquatic organisms as well as data on biodegradability in the environment. Drilling activities should always be combined with monitoring of pollution and effects on the sites. The use of oil based drilling muds (OBM), should not be allowed for discharge at the drill site.

Impacts from drilling mud and cuttings on the marine environment can be prevented by re-injecting the material into the wellbores or to transport it to land for treatment at specialised facilities. The latter option is usually the way to treat oil OBM's. However, this creates other environmental impacts such as increased emissions of greenhouse gases in relation to transport and pumping, and problems with treatment or re-use on land (SFT 2008) which must be balanced against the exposure and impacts on the environment.

The Before-After-Control-Impact (BACI) studies on the seabed which the operating companies must perform as a part of the environmental studies and monitoring also contribute to the mitigation, at least in the long run, as lessons learned will be incorporated in future regulation.

If drilling mud and cuttings are to be discharged, the best way to reduce environmental impacts is by strict regulation of the chemicals used for the drilling process, as is the case in Greenland. There is, however, a problem with the tests of the chemicals, as they have generally not been evaluated under Arctic conditions regarding degradation and toxicity. Such evaluation is in high demand for assessing environmental impacts of oil and gas activities in Greenland.

In Norway, releases to the marine environment of environmentally hazardous substances have been reduced by 99% in the years 1997–2007 by applying international standards, BAT and BEP (SFT 2008). In Greenland the use of 'black' chemicals (cf. the Norwegian Environment Agency's colour category, Link) is not allowed and the use of 'red' chemicals requires specific permission.

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

In Greenland, the drilling mud strategy approved in 2014 (Link) prescribes:

- that all offshore chemicals planned to be used shall be classified according to the OSPAR guidelines, to Norwegian and Danish guidelines, and that they are recorded in the Danish product register PROBAS,
- application of more rigorous requirements for the documentation of chemicals critical in an environmental context, including the Norwegian requirements to offshore chemicals,
- application of more rigorous requirements for the documentation of chemicals planned to be discharged in high Arctic marine environments, including documentation for tests of biodegradability, toxicity and bioaccumulation in Arctic temperature regimes and with Arctic organisms,
- that oil based drilling mud systems can be applied, provided no drilling mud/cuttings are discharged to the marine environment and that internal safety procedures and controls are intensified.

As a consequence of previous experience, e.g. from the North Sea, the Arctic Council guidelines (PAME 2009) recommend preventing discharges as much as possible. When water-based muds are used, additives containing oil, heavy metals, or other bio-accumulating substances should be substituted, or criteria for the maximum concentrations should be established (PAME 2009). 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 drilling mud and cuttings (Cuttings Re-Injection – CRI). In the Arctic offshore Oil and Gas Guidelines, it is requested that 'discharge (of drilling waste) to the marine environment should be allowed only where zero discharge technology or reinjection are not feasible' (PAME 2009).

If zero-discharge is not possible, releases to the marine environment must, as a minimum, follow the standards described by OSPAR, applying a sound environmental management based on the Precautionary Principle, Best Available Techniques (BAT) and Best Environmental Practice (BEP).

Based on knowledge concerning site-specific biological, oceanographic and sea ice conditions, discharges of drilling mud and cuttings should occur at or near the seafloor or at a suitable depth in the water column to prevent large sediment plumes. Such plumes have the potential to affect benthic organisms, plankton and productivity and may also impact higher trophic levels such as fish and mammals. The discharges should be evaluated on a case-by-case basis.

Mitigation of impacts of produced water

The best way to mitigate effects of produced water in the marine environment is to prevent discharge. This can be achieved by re-injecting the water into wellbores or into specific injection wells, for example drilled for increasing recovery of oil. In 2017 approx. 41 million m^3 produced water was reinjected in Norway (Norsk olje og gass 2018). If produced water is to be discharged, international standards (OSPAR) must be applied, i.e. a risk based approach, BAT and BEP and the oil content may not exceed 30 mg/l. In Norway, the producers do much better than that, by applying BAT and BEP, and in 2017 the average oil content in produced water was 12.1 mg/l (Norsk olje og gass 2018).

Mitigation of impacts from other discharges

Best Available Technology (BAT), Best Environmental Practice (BEP), application of international standards (OSPAR and MARPOL) and use of chemicals that cause low or no harm to the environment, and reduction of their releases are the best ways 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 25 years by applying these measures (SFT 2008).

There are methods to minimise the risks from releasing ballast water; the IMO ballast water management convention was adopted in 2017, and guidelines has been issued (IMO Link). All vessels and drilling units involved in oil and gas activities in Greenland should follow the IMO guidelines or the relevant Canadian regulations (Link).

However, invasive species can also be introduced by transport of organisms attached to the hull of the ships, which is more difficult to prevent.

Mitigation of impacts from emissions to the air

Best Environmental Practice (BEP) and Best Available Technology (BAT) should be used to reduce emissions into the atmosphere. This will include using renewable technologies for power generation and avoiding fuels that are particularly polluting.

Emission of black carbon (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 treaty (Annex 1) from August 2011 that IMO recommend to avoid using and transporting heavy fuel oil (HFO) in Arctic Waters and also work on a total ban here from 2023. Moreover, MARPOL from January 1 2020 has introduced a general limit of 0.5% sulphur in ship fuel. For the existing fleet of ships, ship owners must in 2020 largely choose between a fuel inherently low in sulphur (e.g. Marine Diesel Oil or Liquefied Natural Gas), the recently marketed low sulphur hybrid residual oil products, or combine heavy fuel oil with an exhaust gas cleaning system (scrubber). In the scrubber, SO_2 is converted to sulphuric acid and a number of other pollutants (e.g. metals, PAH's) occurring in the exhaust gas are trapped in the scrubber wash water. Discharges from the scrubber to the sea should however be avoided, as this only will move the pollution of the atmosphere to the sea water.

The international Convention on Long-Range Transboundary Air Pollution (LRTAP) includes all the mentioned emissions, and it was ratified by the kingdom of Denmark (incl. Greenland) in 1982.

Mitigation of impacts from infrastructure
There are few mitigation measures for the presence of infrastructures themselves as they are vital for the operations, but many impacts can be prevented by a combination of accurate background knowledge, careful planning in the design phase and strict regulation. This may secure that noisy activities are avoided in sensitive areas and in sensitive periods and that infrastructure is not placed in vulnerable habitats and landscapes. Because many of such constructions will exist in the marine environment for decades there will also be a need to consider how they develop as habitats, and how they influence the surrounding environment, to guide decisions about eventual decommissioning.

Possible impacts from decommissioning activities are mainly related to disturbance from the removal of material and waste from the site and transport out of the assessment area. There is also a risk of pollution from accidental releases. These activities are usually short-term, and careful planning (including the construction phase) and adoption of BAT, BEP and international standards will contribute to minimise impacts.

Mitigation of impacts related to transportation
Ship transport (incl. ice-breaking) has the potential to displace marine mammals and seabird concentrations. The impacts can be mitigated by careful planning of sailing routes.

Flying in Greenland, both with fixed-wing aircrafts and helicopters, is regulated in areas with seabird breeding colonies (order no. 17 of 28 Oct. 2019, on protection and hunting of birds): In the period 15 April to 15 September a distance to breeding colonies of seabirds is required to be >3000 m both horizontally and vertically. Disturbance impacts from intensive helicopter transport can be mitigated by specific requirements to flight altitudes and corridors.

Flying in relation to exploration is also regulated by special field rules issued by EAMRA (Link). These rules encompass areas with staging and moulting geese, areas with moulting seaducks, seabird colonies etc. (Figure 60).

7.3.2 Mitigating impacts from oil spills

The primary mitigation task is preventing oil spills from happening. This is done by application of high health, safety and environment (HSE) standards, BAT, BEP and by strict regulation by the authorities. When a spill happens, impacts must be minimised by an effective oil spill response, based on an Environment & Oil Spill Response tool (EOS), *spill* impact mitigation assessment (*SIMA*), contingency planning including on-site response capacity, response strategies and oil spill sensitivity maps (Chapter 8). However, an effective oil spill response in the assessment area will be almost impossible when ice covers the sea, as no effective large scale response methods exist for collecting spilled oil in waters with dynamic drift ice. This situation applies to most of the assessment area in the winter. Winter darkness, limited infrastructure and harsh weather conditions contribute additional challenges to an oil spill response.

Another limitation is that DCE recommended not to disperse large oil spills in the summer time in the Store Hellefiskebanke/Disko Bay area, because there is a risk of impacting ecosystem key species such as copepods (*Calanus* spp.) (Wegeberg et al. 2016a). During the winter month, the copepods are less vulnerable to oil exposure and dispersion may be an option.

When exploration drillings were approved in the assessment area in 2010 and 2011, the company needed to develop a relief well plan, which should include allocation of sufficient time (two months) to drill a relief well before the winter ice conditions prohibited drilling.

Another important mitigating measure is the dual-rig policy adopted in Greenland (two rigs operating in the same general area, and in case of a blowout there will be one readily available for drilling a relief well).

A tool for oil spill response planning (See Chapter 8.2) and implementation of contingency plans is oil spill sensitivity maps, which focuses on the coastal zone and its resources, but also includes offshore areas. The assessment area is covered by such maps (Clausen et al. 2012). See also Chapter 8.2. A Spill Impact Mitigation Analysis (SIMA) is also an important tool to apply, for example to assess the use of dispersants as a response technique along coasts with extensive macroalgae vegetation.

A supplementary way to mitigate the potential impact on animal populations that are vulnerable to oil spills, for example seabirds and marine mammals, is by applying ecosystem based management, where all the other human stressors (such as hunting) are included. The ability to compensate for extra mortality due to an oil spill could, for example, be increased by a reduction in the hunting pressure (Figure 91).

7.3.3 Monitoring

Monitoring of the surrounding environment is an essential part of mitigation of impacts, both during and after the life cycle of an oil field. In this respect, a proper baseline is needed. The environmental studies plan, which is part of the EIA process (see EAMRA guidelines to explorations drillings 2011 Link) shall secure such a baseline.

The purpose of the monitoring is to identify and record unexpected impacts in the environment and to document failures to comply with the environmental requirements specified when the activities gets approval.

The results of the monitoring also provide an important tool for assessing whether the regulations are appropriate, or should be adjusted for subsequent activities.

Monitoring must be carried out at several levels:

- at the point of discharge, emission or disturbance; in order to record levels of potentially hazardous substances discharged or to record physical and biological impacts at the site of activity,
- in the surrounding environment, in order to document how far away impacts have occurred. This monitoring should proceed after the activities have stopped, to follow any long-term developments,
- at regional level, to document the health and status of the ecosystem. This monitoring should focus on selected indicators and document potential cumulative impacts. This is most relevant if production is initiated.

The best way to prepare and mitigate impacts from oil and gas activities is to combine detailed background studies of the environment (in order to locate sensitive VEC's) with careful planning of structure placement, transport corridors and operations, i.e. planning based on the knowledge from the background studies. Application of BEP, BAT and international standards, for example OSPAR (HOCNF), and guidelines (for example issued by Arctic Council) can contribute to reducing emissions to air and the sea. Furthermore, adhering to a policy like the 'zero harmful discharge policy' for the Barents Sea (Knol 2011, Klima- og Miljødepartementet 2020) could contribute substantially to minimise impacts.

7.4 Recommendations to offshore normal operations in Greenland

The regulation of offshore exploration and exploitation activities in Greenland include the mitigation of environmental impacts described above and is outlined in the different EAMRA-guidelines to the development of Environmental Impact Assessment (EIA) of the specific activities (offshore seismic survey Link, Environmental Impact Assessment (EIA) report for activities related to oil and gas exploration and exploitation off shore Greenland Link, Environmental Impact Assessment (EIA) report related to stratigraphic drilling offshore Greenland Link). The EIA is the most important tool for environmental regulation, it is prepared by the operator, shall address all environmental issues and how to mitigate impacts and finally it shall be approved by the Government of Greenland.

8 Oil spill countermeasures

Janne Fritt-Rasmussen (AU), Susse Wegeberg (AU), Anders Mosbech (AU) & Josephine Nymand (GINR)

8.1 Response and preparedness

The most serious threat to the environment from oil exploration/exploitation activities in the Disko West area will be a large oil spill (see Chapter 7). This could derive from a blowout of a well, from pipeline rupture, when loading tankers and from accidents with the tankers transporting oil during the production phase. Minor accidents might also occur from ships, fuel tanks etc. (see Chapter 7.2 and 7.3).

Oil spilt in the marine environment will change its original properties when entering the environment because of evaporation, natural dispersion, water-in-oil emulsification and other weathering processes.

Although oil in ice is not expected to weather, oil spill response during freeze-up and breakup is considered to be especially challenging. See also Figure 89.

In this chapter, measures to respond to marine oil spills are described. The focus is on the Arctic and, in particular, conditions relevant for the Disko West region.

Sea ice (both first year sea ice and some multiyear sea ice) is present in the entire assessment area during winter and spring, and the highest densities (up to 100% ice cover) are found in the northern and western parts of the assessment area. In addition to sea ice, icebergs originating from calving glaciers are very frequent. More details about the ice conditions are given in Chapter 2.3.

8.1.1 Oil spill response planning

Oil spills shall be prevented by applying the highest health, safety and environmental standards (HSE) combined with the highest technical standards (BEP and BAT). However, the risk of oil spills is always present and a fast, robust and efficient oil spill response must be in place to counteract spilled oil. This includes that proper equipment is in place, and that the oil spill responders are sufficiently trained to use it (Fritt-Rasmussen et al. 2020). Besides the response equipment, supporting logistics such as waste handling and containment facilities and vessels of opportunity shall be available. It is also important to avoid risks for human health during the response activities, why besides the oil spill response equipment, HSE equipment for personnel shall be in place or can be mobilised quickly.

If an oil spill occurs, the first priority is to stop and contain the out flowing oil for example with containment booms, followed by a fast and effective oil spill response to minimise the impacts to the environment. A fast and effective oil spill response is dependent on realistic and detailed contingency planning. In the planning phase when selecting suitable response strategies, valuable information and input can be obtained from, e.g., oil spill sensitivity maps (Link) as well as by completing an EOS (Environment and Oil Spill Response) analysis (Link) for the target area of the oil spill response plan. The oil spill sensitivity atlases for Greenland focus on the coastal zone (Figure 93) and the resources at risk and also include oil spill sensitivity of offshore areas segregated by season (Figure 94). An EOS is a desktop analysis that, from an environmental point of view, supports decisions regarding inclusion of me-

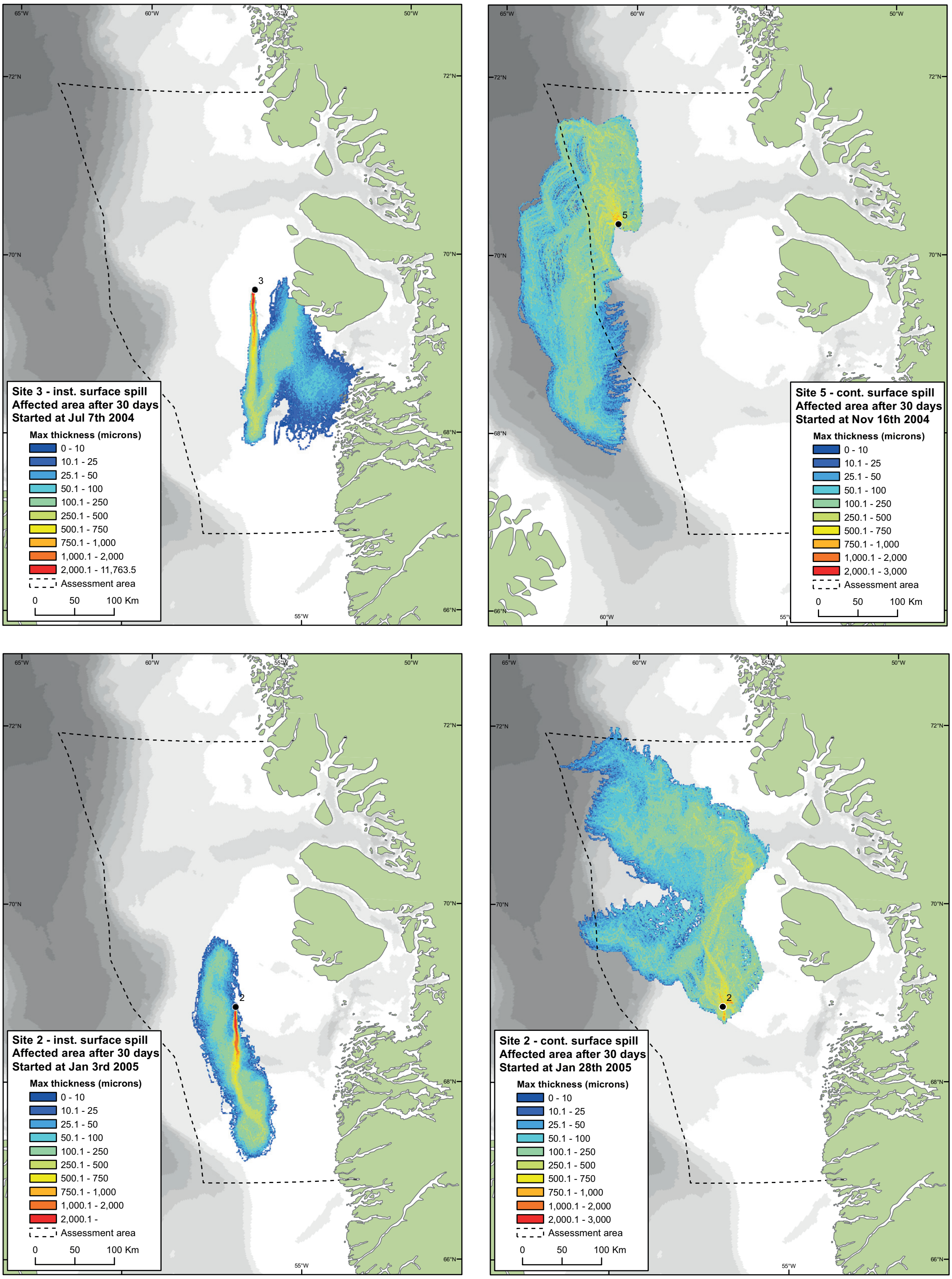
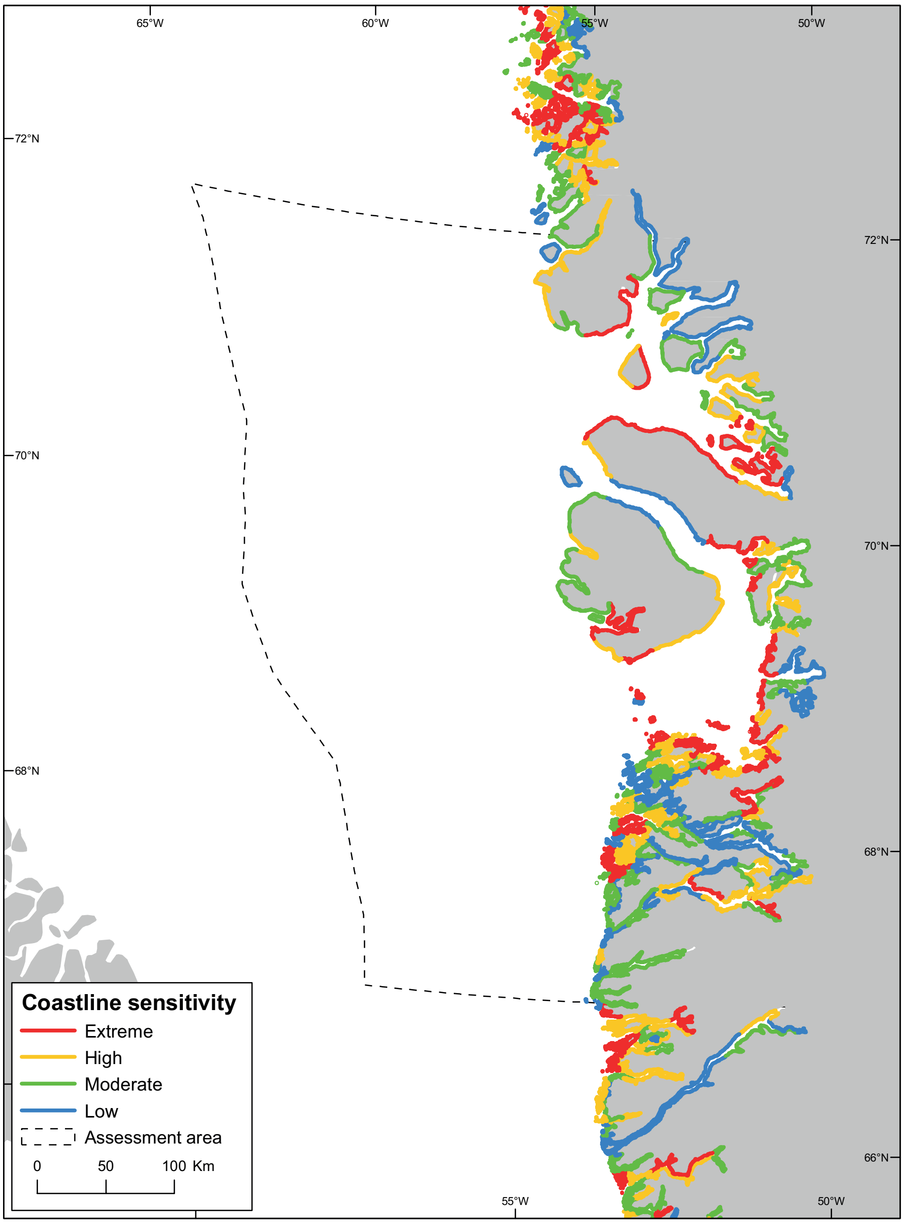


Figure 92. Four examples of the DMI oil spill trajectory simulations.

chanical recovery and in situ burning and chemical dispersants in the oil spill contingency plan by assessing the overall environmental mitigation obtained from each technology, segregated by season. The EOS also forms the base for a SIMA (Spill Impact Mitigation Assessment, formerly known as NEBA, Net Environmental Benefit Analysis) in the acute oil spill situation.

Figure 93. Oil spill sensitivity of coast lines in the assessment area according to the oil spill sensitivity atlas covering the assessment area (Clausen et al. 2012).



Among the mitigating efforts in 2010 and 2011, when the exploration wells were drilled in the assessment area, drilling activities were stopped two months before the winter ice would put an end to the activities. This time window would leave a period to drill a relief well in case of a blowout. Ice management was also a part of the mitigation, and this focused on removing icebergs on a collision course away from the drill platform.

8.2 Offshore oil spill response

Since the previous SEIA for the Disko West area was completed in 2013, the large Arctic Response Technology Joint Industry Project was undertaken to improve the Arctic oil spill response capabilities (Link). The results of this effort are incorporated in the following, which will describe the three overall oil spill response technologies in an Arctic context including environmental pros and cons of the methods.

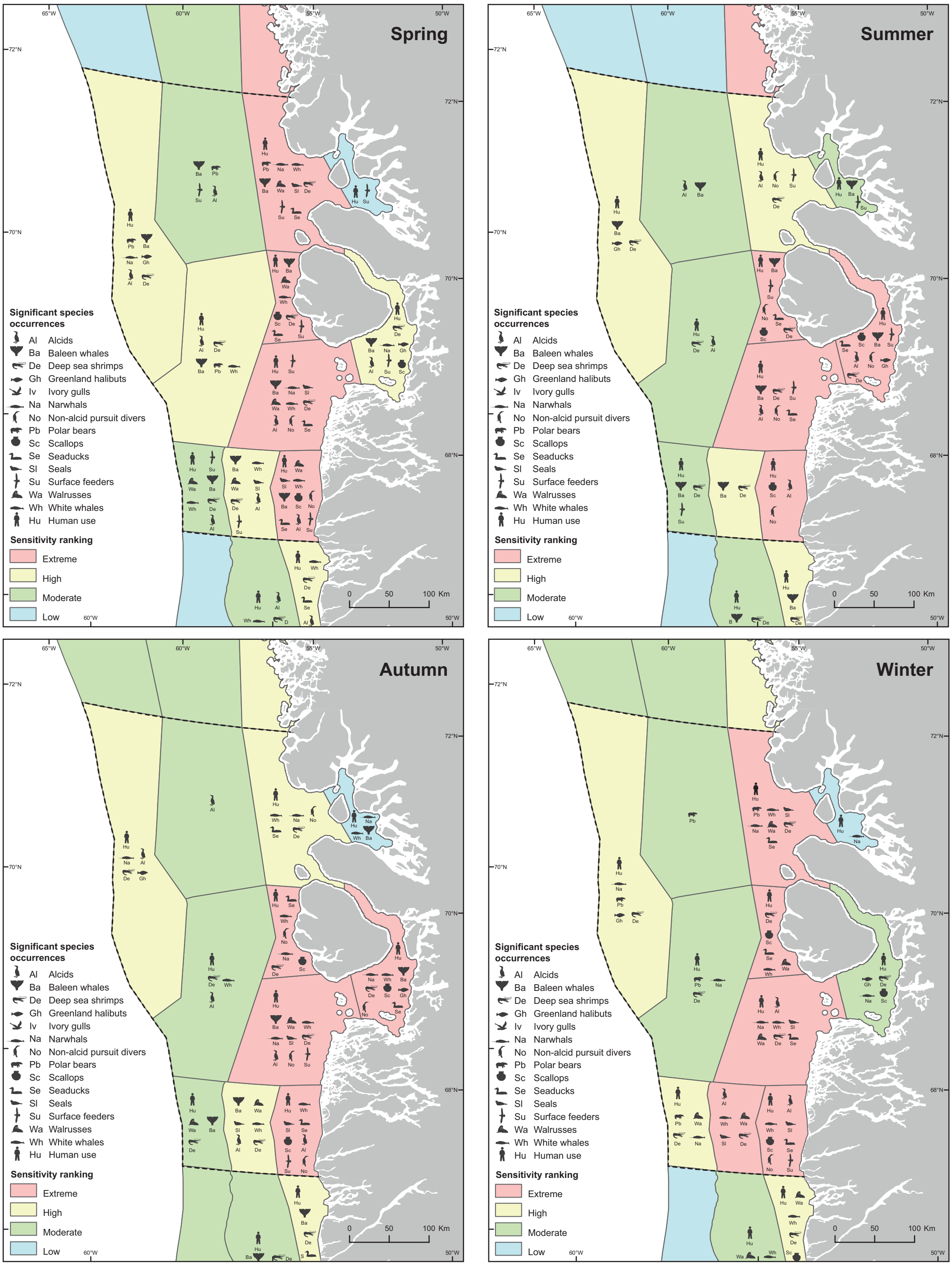


Figure 94. Oil spill sensitivity of offshore areas in the assessment area based on the oil spill sensitivity atlas covering the assessment area (Clausen et al. 2012).

8.2.1 Mechanical recovery

Mechanical recovery removes the oil from the environment and is the method of first choice in many countries. In general, the principle of the method is to contain the oil, followed by recovery from the sea surface to storage facilities where the oil is kept for further handling. Such storage facilities may have limited capacity and become a bottleneck for the operation since very large volumes of oil and water are often recovered.

Oil spills on open water will spread out to form a thin oil film; hence, containment booms are necessary to confine the oil in a thicker layer for more efficient recovery. Containment booms requires working space on the sea surface, which can be limited by ice. Thus, problems when using mechanical oil recovery in ice-infested waters are accessibility to the oil, manoeuvrability of a working platform and deployment of booms (Brandvik et al. 2006). In addition, the effectiveness of the containment booms may be reduced due to the ice (EPPR 2015). On the other hand, sea ice may also act as a natural containment barrier to the oil.

A wide range of different containment booms and skimmers are available on the market. Most of the equipment is developed for open water (0-30% ice cover) and non-arctic conditions. Such open water conditions are expected to occur during the summer and autumn in the assessment area, while icebergs will always be a hazard in the assessment area (See Chapter 2.3).

Skimmers are available for oil spilled amongst ice; these recovery systems should be able to effectively remove oil from such waters. In addition, recovery systems exist that work from underneath the ice. Even though the oil type is unknown for the assessment area, the ambient conditions, with the all-year low temperatures, is expected to influence the oil towards high viscosity, less spreading (due to the ice/ice-free water) and hence less evaporation and dissolving/dispersion.

Mechanical recovery is very labour demanding and field experiments in Arctic conditions show that high recovery rates are difficult to achieve (Potter et al. 2012). Challenges are associated with the limited flow of oil due to low temperatures (change in oil properties), separation of oil from ice, icing of equipment, detection of oil in ice etc. (Brandvik et al. 2006). In open waters, mechanical recovery is often reported with an efficiency of less than 15% of the oil volume and most often less than 5% of the oil (EPPR 1998). For example, was 12% of the oil spilled from *Exxon Valdez* recovered mechanically and only 3% after the *Deepwater Horizon* spill (Shigenaka 2014, Beyer et al. 2016).

Finally, oil in ice/snow is difficult to detect, so it is important to consider methods for detection of the oil.

8.2.2 Chemical dispersants

The principle of chemical dispersant is that by adding a chemical (the dispersant) to the oil slick the natural dispersion of the oil increases. With sufficient mixing energy the oil then breaks up into droplets less than 70 µm across, which are mixed into the water column for possible further dilution and degradation (Blondina et al. 1999). A range of different products exists, adapted to different oil types, salinities, temperatures etc.

Another approach using dispersants in case of a blowout is sub-sea dispersant injection (SSDI) directly to the wellhead where the oil is pouring out. This method was developed and used during the *Deepwater Horizon* incident.

For application of chemical dispersants in the Arctic, some critical parameters must be considered prior to the possible use. The parameters are mostly related to the presence of ice and the low temperatures. Generally, the method is considered viable with less than 30% ice (EPPR 2017). For situations with ice, the contact between the oil and dispersant will be challenged, and the unit for spraying the dispersant should be selected carefully to fit the given conditions. The possible fate and environmental effects from dispersants not hitting the oil are still not known. Furthermore, sufficient mixing energy might be hampered by the presence of a dense ice cover. During field test in the Barents Sea, with around 60-70% ice coverage, it was found that applying chemical dispersant with a manoeuvrable arm from a vessel, and subsequently applying mechanical mixing from the vessels' thrusters and by the water jet from a rescue boat, was a successful combination (Brandvik et al. 2010). Research results indicate that with presence of ice even small waves (in amplitude and frequency) might facilitate the chemical dispersion (Lewis & Daling 2007a). Dense ice cover (> 60%) would likely increase the window of opportunity for the method, due to a slower weathering of the oil (Lewis & Daling 2007b). On the other hand, the low temperatures will increase the viscosity of the oil and thereby (if the limiting viscosity is exceeded) reduce the effectiveness of the dispersant (Lewis & Daling 2007b). For oil that had been frozen into ice for three months, research results have shown that the dispersibility of oil did not change during this period (Cedre 2016).

Chemical dispersion removes oil from the water surface, preventing sea surface-associated organisms (seabirds and marine mammals) to be smothered in oil as well as prevents the oil from beaching. However, the concentration of oil will increase in the water column, potentially reaching toxic concentrations for organisms until the dispersed oil is diluted. Moreover, are the dispersant toxic in themselves or increase the toxicity of the oil (e.g. Vad et al. 2020). The dilution rate depends on the dilution capacity of the oil spill site, e.g., water volume and water exchange. Thus, the environmental side effects from the use of dispersants are related to the (initial) increased toxicity in the upper water column from the oil and dispersant and oil/dispersant mixtures.

Another rationale behind using chemical dispersants (or mechanical dispersion, see below) is to facilitate natural degradation and thereby removing the oil from the environment. The potential for oil degradation of dispersed oil in the Greenland Sea was studied in laboratory tests (Johnsen et al. 2019), see Chapter 8.3 below. Some of the experiments with seawater from Disko Bay did not reveal specific oil-degrading bacteria, which might limit oil degradation of particular PAH's (see Chapter 8.3 below).

Mechanical dispersion is a new technique that has been developed in recent years. The idea is to disperse the oil into the water column by the use of an unmanned response boat equipped with high-pressure water jets. Further research is needed to document the effectiveness of the method, also in an Arctic perspective, and to learn more about the environmental effects.

8.2.3 In situ burning

In situ burning is a technique where the oil is ignited and burned on site under controlled conditions. Thereby a large part of the oil is converted into primarily CO_2, soot and other combustion products. The oil can be ignited by a handheld torch from a boat or ice floe, but ignition from an aircraft is also a possibility (heli-torch from helicopter or, as the latest development, a drone ignition devise). The burning efficiency is considered to be high. During the *Deepwater Horizon* incident it was for example about 85% when more than 400 burns were carried out (Stout & Payne 2016). However, in total only an estimated 5% of the total spill was handled by burning (McNutt et al. 2012). Field trials, also in the Arctic, have found even higher burning efficiencies (Buist et al. 2013). A successful burn requires a relatively thick oil layer. The thickness depends on oil type (see (Buist et al. 2013)) but, for example, a sheen cannot be ignited. The required thickness could be achieved by the use of fire resistant booms (< 30% ice), or in areas with dens ice cover (> 60-70%) where the ice acts as containment.

Studies have also been undertaken to investigate the effectiveness of herding agents. Herding agents are chemicals that, when sprayed around the oil slick, changes the interfacial tension of the oil/water resulting in a contraction of the oil to ignitable thicknesses (SL Ross Environmental Research Ltd 2015). The use of herding agents might have some potential for improving in situ burning operations, e.g., thickening the oil to ignitable thickness in 30-60% ice cover (Buist et al. 2017, Rojas-Alva et al. 2020). However, little is known about fate and environmental effects of the herding agents (Buist et al. 2017).

After flame out, burn residues may be found on the sea surface or, in some situations, the residues sink, challenging the residue recovery with risk of affecting seabed organisms. The environmental impact from the burn residue is still little investigated; however, there seems to be a tendency towards the residue being less toxic than the initial oil (Fritt-Rasmussen et al. 2015).

Based on field trials in Arctic ice-filled waters, in situ burning has shown a great potential, in particular since the cold and ice-filled conditions slow down the oil weathering and thereby expands the window of opportunity for burning. Other field studies under Arctic conditions showed that oil trapped in the ice might be released in spring through the brine channels of the sea ice and end up in melt pools on the ice surface. This oil had not weathered while being contained in the ice, and thus the oil was still ignitable (NORCOR 1975).

Nevertheless, it is still an open question how in situ burning can be applied and how effective it will be in a real offshore situation such as in the Disko West region. The potential success of an in situ burning operation depends to a large extend on the specific ice conditions, the oil type and weathering of the oil and on the actual weather conditions. The weather can be quite harsh in the assessment area and the operational conditions for the methods necessitate wind less than 10-12 m/s and relatively calm sea (DNV GL 2015).

The environmental side effects of the method relates mostly to the generation of soot during burning, but also the residue (floating or sinking) may cause environmental impacts unless the residues are recovered. In the Arctic, the possible soot deposition on ice, resulting in reduced albedo and, hence, potentially increased melting of the ice cover, is an issue to consider.

8.2.4 Experience from previous spills

The response methods applied at the oil spill in Prince William Sound in 1989 was primarily mechanical. Both chemical dispersion and in situ burning was tried, but too late for the methods to be effective, and it was the first time in situ burning was used as spill response.

At the *Deepwater Horizon* spill in the Mexican Gulf in 2010, both mechanical recovery, chemical dispersants and in situ burning were included among the massive oil spill response operations (see Chapter 6.3.4).

8.2.5 Coastline oil spill clean-up

Oil stranding on the shore can cause significant environmental and economic impacts, and may result in considerable efforts in cleaning-up the affected areas. In remote Arctic areas, this might be even more demanding in terms of labour requirements than combating the oil spill offshore.

Shoreline clean-up is often a three step operation: First step includes removing the bulk to avoid remobilisation of the oil, followed by the second step where stranded oil and oiled shoreline material are removed and, finally, the third step, where the less contaminated sites are cleaned-up (ITOPF 2018).

In situ burning in the Artic is considered as an offshore response method, but a field study in Greenland has shown that it might be possible to burn a light crude oil at the coastline, and with relatively minor environmental impact. However, more work is required to fully understand the potential for coastline in situ burning and the environmental impacts with respect to, e.g. oil type (Fritt-Rasmussen et al. in prep.).

Ice and snow containing the oil may be scraped or pumped away. Another way to handle oil contained in snow is by burning. In a case where oil content in snow reached 70%, the oil was burned successfully (Buist 2000).

8.3 Biodegradation of oil

Microbial degradation is a significant factor in the removal of spilled oil from the water column. For example, a large part of the spilled oil from the *Deepwater Horizon* spill was probably removed in that way, facilitated by an intrinsic potential for biodegradation in the Gulf of Mexico (see Chapter 6.3.4). Such degradation potential may develop naturally due to exposure of oil components from natural oil seeps. Natural oil seeps exist in Greenland, but it is questionable whether a similar priming effect on the microbial degrader community can be expected as the amount of oil leaked into the marine environment is quite low compared to the Gulf of Mexico (Wegeberg et al. 2018).

The potential for biodegradation in the Arctic areas is more or less unknown, but several factors such as low levels of nutrients, low temperatures and sea ice may limit the ability of the microbes to clean up (Vergeynst et al. 2018).

Knowledge on biodegradation of oil in Greenland waters is sparse and limited to a few studies in the Disko Bay area (Kristensen et al. 2015, Scheibye et al. 2017, Brakstad et al. 2018b) and one in the Greenland Sea area (Johnsen et al. 2019).

For two studies from Disko Bay, seawater was sampled at 150 m depth and incubated in laboratories with crude oil. Microbial degradation of n-alkanes was observed in both studies, whereas almost no degradation of PAH's, dibenzothiophenes and their alkyl-substituted homologues was observed (Kristensen et al. 2015, Scheibye et al. 2017). Probably adaptation to PAH degradation did not occur during the test period in the pristine Disko Bay water, where bacteria adapted to degrade these structurally more complex molecules may be extremely rare (Vergeynst et al. 2018).

The third study from Disko Bay (Brakstad et al. 2018b), however, found microbial communities capable of degrading oil compounds, but compared to waters from Norway, the degradation was significantly slower.

Incubation studies with water and sediments from the Greenland Sea (Johnsen et al. 2019) showed that there is a potential for biodegradation in the water column at the shelf break if the intrinsic microbial degraders can be activated, but the degradation will be hampered by the nutrient limitation. The study also showed that the intrinsic potential for oil biodegradation in the water column and sediment on the shelf was very low, even when mineral nutrients were not a limiting factor (Johnsen et al. 2019). Dispersion with the agent *Slickgone NS* was effective, but the biodegradation was still low. Hence, the authors suggested that if chemical dispersant are to be used as an oil spill response method, the strategy should also include application of mineral nutrients ("fertilizers") to enhance the degradation. Similar studies are not available for the assessment area, but comparable findings can be expected.

8.4 Oil spill drift simulations

As part of the first SEIA assessment for Disko West (Mosbech et al. 2007a), DMI prepared a range of different oil spill fate simulations (Nielsen et al. 2006). The purpose was to look into the possible spreading and areas of potential impact from an oil spill in the assessment area. See also Annex 3.

The oil drift model includes oil weathering for the first days after the spill followed by oil drift simulations (passive advection) for a longer period. The model build upon knowledge of wind (HIRLAM model) and 3-D motion of the sea (HYCOM model) (Nielsen et al. 2006). The oil drift 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. 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.

The model result may be tracked as the average position of all particles, or by mapping all particles geographically at any given time after the initial release (Nielsen et al. 2006). The oil will either settle or stay in the water phase, and the only way oil can disappear from the simulations is by evaporation or emigration out of the model domain (Nielsen et al. 2006).

The oil drift model does not explicitly consider oil and sea-ice interactions. Where ice hampers the oil drift, the model will therefore over-predict the drift and spreading of the oil.

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. Locations 6 and 7 were selected for simulating spills from tankers near a potential oil terminal.

For each of the offshore spill locations (1-5) a continuous spill taking place at the surface and at the seabed were simulated. For the two oil tanker locations, only surface spills were simulated. For all the spill locations, also instantaneous spills were simulated. The total length of each simulation was 30 days and 114 simulations were completed in total. For continuous spills, a constant release rate of 3,000 t/d for the first ten days of the simulation period was assumed, totalling 30,000 t. For instantaneous spills, the amount of oil released was 15,000 t.

The crude oil Statfjord was selected by GEUS among eight types in the DMI database as the most representative oil to potentially be discovered in the assessment area. Statfjord crude oil is a paraffinic and relatively light oil type, API density 886.3 kg/m³, and with a low content of asphalthenes (Faksness 2008). This oil is lighter than seawater and from weathering studies, it has been found that around one third would evaporate during the first 24 hours of a surface spill (Faksness 2008). Statfjord crude oil is expected to produce relatively stable water-in-oil emulsions.

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.

8.4.1 Results

Generally, no major differences in surface conditions between a continuous surface and a continuous bottom release was seen due to a fast buoyant rise of the oil in the DMI simulations. Thus, only surface spill results are included in the Nielsen et al. (2006) report.

The spreading of the oil is during the first 10 days on average twice as large for the instantaneous spill as for the continuous spill, with a slick area equivalent to a disc with a radius of 5-6 km for a continuous spill, and 10-12.5 km for instantaneous spill. After 30 days, the slick radius has increased to 20-25 km, and the slick typically covers an area of 1500-2000 km² of very irregular shape. A typical slick layer thickness after 10 days is 0.4-0.6 mm for continuous release, but only 0.05-0.15 mm for instantaneous release. After 30 days the mean thickness has decreased to 0.01-0.05 mm regardless of release type.

In practice, the oil will form isolated patches within this area, with regions of high concentration interspersed with regions with no oil at a given time. This means that the area actually covered with oil is smaller than figured, but the oil thickness can be higher. The model gives no indication of how much smaller the actual oil-covered area was.

In calm weather, the oil stays at the surface, and is only mixed into the water column during strong winds. A maximum of about 20% of the oil is temporarily mixed down. The average mixing depth is usually just a few meters, with a maximum of 12 m. The maximum mixing depth of an oil particle is 10-34 m, depending on the wind period. The highest concentration of oil is found in the top meter of the water column, with a gradual decrease towards the seabed.

The maximum displacement of the oil is about 375 km away from the release site in ten days, and the preferred drift directions are along shore. In 30 days, oil may be found as much as 580 km from the release site. After 30 days, the spills located farthest off-shore (site 1, 4, and 5) still have not reached any coast and no further bottom settling has taken place. For the spill locations closer to the shore (site 2, 3, 6 and 7), the overall trend is that oil ends up at the coast, when the winds are westerly. The exact amount depends on the specific location and type of release (continuous/instantaneous). More details can be found in DMI report (Nielsen et al. 2006).

Some examples of the results are presented in Figure 92 and Annex 3 gives a descriptions of potential impacts from the spills.

As part of evaluating the potential for combating oil spill at Store Hellefiske-banke in the southern part of the assessment area, a range of oil spill dispersions simulations were completed (Wegeberg et al. 2016a, based on data from ClimateLab 2014a). Five different scenarios were selected. The model assumed total dispersion of the oil, and is thus simulating a natural or chemical dispersion situation. From the scenarios located on Store Hellefiskebanke and close to the coast at the northern part of the bank, the simulations showed that the dispersed oil might stay on the bank, beach on nearby coasts or spread into Disko Bay. In addition to the dispersion simulations, very simple surface drift estimation was completed based on the same wind and surface current data as the dispersion modelling. The overall trend for these drift estimations is alongshore drift. For the locations at the continental shelf the oil-drift towards south without reaching the coast. For the locations closer to the coast, there is a risk that the oil might end up on shore. Thus, this is in overall agreement with the DMI model results. More details are found in Wegeberg et al. (2016).

The oil spill drift simulations presented by DMI were based on a predefined oil type, predefined spill sites, and to some extent predefined weather and no ice influence. So the results should be considered as examples of what might happen during a large oil spill. However, it can be concluded that following a large oil spill, large sea surface areas will be swept by the oil due to spreading and drifting of the oil. This process however, is much influenced by the oil viscosity, and a different oil type could for example change the outcome significantly. The spreading of the oil is rarely uniform, but show usually large variations in oil film thickness and distribution. Moreover will the oil film will break up and form windrows parallel to the wind direction (ITOPF 2019). Most likely, large amounts of oil (emulsions) and oil sheen could be found on the surface 20 days after a spill event and long stretches of shorelines can be polluted depending on the oil spill location, ice conditions and wind direction.

8.5 Concluding remarks on countermeasures

Three overall countermeasures are available for combating oil spills in the marine environment: mechanical recovery, chemical dispersion and in situ burning.

Mechanical recovery is very labour demanding, and field experiments in Arctic conditions have shown that high recovery rates are difficult to achieve. In addition, handling of recovered oil and water is quite difficult in offshore Arctic areas. Therefore this method will most likely be ineffective if applied alone during a large oil spill. Mechanical recovery will be more relevant for minor spills in the assessment area.

To secure a successful in situ burning, oil slick thickness is one of the most important parameters. Fire resistant booms to contain the oil are not expected to be working in ice conditions from 30-60% coverage. In such conditions, herding agents can act as barriers containing oil into thicker films suited for burning. In more dense ice conditions the ice can contain the oil. These methods have proved very successful in experiments (laboratory and field), but are not yet developed and implemented at full operational scale, and especially not for dynamic drift ice conditions. Moreover strong winds and high waves may also impact the results negatively. But under the right conditions, in situ burning could be an effective response option.

Chemical dispersion of oil moves the surface oil to the water column, and splits the oil into droplets, which increases the ‘surface area to volume ratio’ of the oil, which, in turn, facilitates biodegradation. However, biodegradation may only have limited effect as a result of the low amounts of available nutrients and low abundance of oil-degrading microorganisms. Furthermore, there is a lack of knowledge about possible environmental effects of dispersed oil in the assessment area. Finally, methods for applying dispersants to the oil between ice floes and secure sufficient mixing are still to be tested in full operational scale. While chemical dispersion in theory can be effective in removing oil from the surface and facilitate a dilution process, it is expected to cause only a limited increase in the biodegradation processes.

The fate of an oil spill at sea depends on e.g. the physical/chemical properties of the oil, the ambient conditions and the release conditions. At sea, a number of weathering processes will change the properties and thereby the fate of the oil that will also change the window of opportunity for the different oil spill response techniques. Of these weathering processes, particular evaporation and emulsification are in focus.

In 2017, the Arctic Council's Emergency Prevention, Preparedness, and Response (EPPR) Working Group commissioned a viability analysis to better understand how often weather and sea conditions may hinder or impede marine oil spill response systems in the Arctic. The analysis (Circumpolar Oil Spill Response Viability Analysis – COSRVA) was published in a report and recently, the results of the report was made available in an online portal (Link). COSRVA build on different metocean conditions: wind, waves (sea state), sea ice, air and sea temperature, and visibility. The sea ice dataset was prepared by the U.S. National Snow and Ice Data Center (NSIDC).

From this portal an extract of the viability of 10 different predefined oil spill response systems for the assessment area were prepared and compiled in Table 22. The numbers in the table reflect system operability that includes fraction of time with favourable[8] or marginal[9] conditions. The figures does not include information about the systems effectiveness, but solely on operational viability.

Much more details and variations in the results can be found by accessing the portal Circumpolar Oil Spill Response Viability Analysis (Link). Nevertheless, it is clear that oil spill response systems aided by ice is not a viable option and that airborne applications have limited operational potential compared to vessel applications in the assessment area. The viability for vessel application of chemical dispersant seems to be relatively high most of the year, except during the winter months. However, the low intrinsic potential for natural degradation of spilled oil, in particular the more complex compounds, adds to increase the environmental impacts in a spill situation. Mechanical recovery and vessel-based in situ burning also have some potential, particularly during the ice free months, and therefore it is important to be well prepared in case of an oil spill, particular for seasons with least response viability of the assessment area (Fritt-Rasmussen et al. 2020).

8 Favourable conditions are when the tactic could be expected to be deployed safely and operate as intended.

9 Marginal conditions are when the tactic can be deployed but operations may be challenged or compromised.

Table 22. Comparison of viability of all response systems potentially avaiable in the assessment area for each month. Figures indicate system operability in percent of days, including favourable and marginal conditions combined. From the COSRVA online portal (https://maps.dnvgl.com/cosrva/map.html).

System		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Dispersant	Fixed-wing aircraft application	4	3	1	4	20	25	26	34	50	39	23	7
	Helicopter application	5	4	3	9	33	43	45	52	58	43	25	9
	Vessel application	26	14	8	19	48	65	68	76	98	98	86	50
In-situ burning	Helicopter-based application of herders as well as ignition	3	2	2	7	24	30	32	31	29	19	10	4
	Helicopter-based ignition, using ice for containment (no boom)	2	4	8	19	32	7						1
	Vessel-based ignition with fire boom for containment	15	7	3	6	27	50	61	66	72	67	55	31
Mechanical recovery	Single vessel in ice	7	10	16	28	39	11					1	4
	Single vessel with outrigger	15	8	3	6	28	52	63	68	76	70	58	34
	Three vessels-of-opportunity with boom	7	3	1	3	18	35	45	40	27	23	19	13
	Two vessels with boom	18	8	3	7	29	54	65	75	92	88	75	42

A factor which tends to intensify effects in the assessment area compared to those from the *Exxon Valdez* incident is the more difficult conditions for an oil spill response. Only 14% of the oil was actively recovered/burned during *Exxon Valdez* and 25% during and after the *Deepwater Horizon* spill. In the assessment area the winter ice is one obstacle, limited infrastructure is another and the winter darkness is a third factor contributing to reduce the efficiency of an oil spill response in the assessment area – at least in the winter time. In fact, no effective proven response methods are available for a sea covered with dynamic drift ice like the ice occurring in the assessment area in winter and spring.

9 Recommended area restrictions

Anders Mosbech (AU), David Boertmann (AU), Kasper L. Johansen (AU), Josephine Nymand (GINR) & Flemming Merkel (GINR)

9.1 Area restrictions

DCE and GINR recommended in their contribution to the oil and gas strategy 2020-2024 (Mosbech et al. 2019): *"A major oil spill in the sea may have major and long-term effects. Oil exploration drilling should therefore focus on safety. So far, practice has been that exploration drilling could only be carried out during the ice-free season and with a safety margin to the expected arrival of sea ice to ensure a sufficiently long operative window in case of blowout and oil spill. It is recommended to continue this practice and continue to set high standards for safety and oil spill response and preparedness in exploration drilling.*

No well-documented methods are yet available for handling major oil spill in drift ice and in the dark. As a result, considerable technological advancement is necessary before it can be considered environmentally safe to explore and exploit oil in Greenland offshore areas all year round.

The development and establishment of oil spill contingency plans and preparedness for the activities of the mineral resource industry is a substantial task, which is, however, also relevant for other ship traffic in Greenland. The development of an efficient strategy for combating oil spill requires technological advancement, research into any harmful effects of the oil and the control methods, analysis of vulnerable biological resources and mapping of the potential for degradation and spreading of oil in the various waters."

Based on the knowledge acquired about particularly sensitive areas in Greenland waters and the limited possibilities for establishing an efficient oil spill response in ice covered waters, DCE/GINR recommend to consider to keep certain areas free from oil exploration (hydrocarbon licenses) to safeguard the environment. For this assessment, DCE/GINR have applied three selection criteria to identify the areas we recommend to keep free from oil exploration in this strategy period (2020-2024):

Critierion 1: Especially valuable areas. As a contribution to the oil and gas strategy 2020-2024, DCE/GINR recommended that three areas in Greenland should be kept free from oil and gas activities (Mosbech et al. 2019). These areas are especially valuable on a national (and international) scale, in terms of ecological and biological importance and sensitivity to oil spills. Other especially valuable and sensitive areas could also have been identified by this assessment and would have been included under criterion 1, unless already covered by criteria 2 or 3. However, no such areas were identified, cf. the strategic environmental impact assessment of oil activities in the Davis Strait licencing area (Merkel et al. 2021)

Critierion 2: Distance to coast. Areas close to the coast are generally more likely to suffer long-time impact from an oil spill than offshore areas. Moreover will longer distances from the coast allow more time for oil spill combat, natural degradation and dispersion of the oil. When DCE/GINR assessed applications for licence blocks in Baffin Bay and Disko West in 2010 (NERI 2010), special focus was on on the distance to the coast, and it was stated that the protection of the coast from oil spill effects is especially challenging and that the requirements to oil spill response and preparedness should be especially stringent for licence blocks with distances less than 30 km to the coast (NERI 2010).

In the DCE/GINR contribution to the oil and gas strategy 2020-2024 (Mosbech et al. 2019), it was recommended that the demarcation of offshore license areas planned to be opened, should be given a specific environmental assessment, which in particular shall include the distance to the nearest coast, the vulnerability of the coast and the possibility of combating oil spills there.

Critierion 3: Areas covered with ice for a part of the year. While oil exploration can take place only in ice-free seasons, an offshore production entails the risk of oil spills year-round (see Chapter 6). Therefore, accepting exploration activities outside the ice season in seasonally ice-covered areas is pushing ahead the problem that no well-documented methods are yet available for handling major oil spill in drift ice and in the dark. Further, the marginal ice zone in late winter and spring is generally a very important biological zone with high primary productivity and important food webs for zooplankton, fish larvae and seabirds and mammals.

9.1.1 International environmental standards for area restrictions in relation to oil activities in seasonally ice-covered waters in the Arctic

In recent years there has been increased international concern for the environmental implications of oil industry activities in Arctic ice-covered waters. Only Russia seems to proceed with offshore licencing in such waters waters, and has currently offshore production in the seasonally ice-covered Pechora Sea.

In the US, there are no lease sales currently planned for the Arctic offshore areas in Alaska (PAME 2020). President Obama stopped considering leasing in Alaska's Arctic waters in 2016, and the Alaska's District Court decision in March 2019 overturned the portion of President Trump's executive order on offshore energy that would have opened the area again. Oil and gas production and exploration from existing licenses is taking place in shallow waters from gravel islands on the Alaska North Slope.

In Canada, the Nunavut Impact Review Board (NIRB) has in 2019 recommended to prolong the 5 year moratorium from 2016 on oil and gas development in Baffin Bay and Davis Strait for a decade (NIRB 2019a): *"Given the importance of the marine environment to the well-being of Nunavummiut, significant gaps in knowledge of the environment necessary to support impact assessment, and an overall lack of regulatory, industry, and infrastructure readiness in Nunavut, the 2016 moratorium on oil and gas development in the Canadian Arctic should remain in place for Baffin Bay and Davis Strait until such time as the key issues set out in this Report can be addressed. The Board expects that it will take at least a decade to complete the research, planning, and consultation identified as necessary prior to undertaking a reassessment by the Minister to determine if the moratorium should be lifted".*

Among 79 NIRB recommendations, several concern the environmental and societal risks related to large oil spills, and it is recommended to address many of these before lifting the current moratorium, e.g. recommendation 32 (NIRB 2019b): *"Recommendation 32: Conduct baseline research to assess the capacity and infrastructure required to manage and respond to a well blowout or major spill in the Arctic and to determine whether an effective response can be mounted in remote locations under harsh weather conditions with periods of prolonged darkness and in the presence of ice".*

The European Parliament wrote in their resolution of 16 March 2017 on an integrated European Union policy for the Arctic (Link):*"Calls on the EU to pro-*

mote strict precautionary regulatory standards in the field of environmental protection and safety for oil exploration, prospection and production internationally; calls for a ban on oil drilling in the icy Arctic waters of the EU and the EEA and for promotion by the EU of comparable precautionary standards in the Arctic Council and for Arctic coastal states."

The Norwegian regulation is generally considered setting "the high international environmental standard" for oil producing countries. In the recent update of the management plans for Norwegian waters (Klima- og Miljødepartementet 2020), the parliament decided to keep the Barents Sea closed for oil and gas exploration north of a limit defined by sea ice occurrence in spring. The ice limit was defined by the presence of sea ice in 15% of the days in April, the month with the largest ice extend, based on ice data for the 30 years 1988–2017. This will apply until management plans are updated, in 2024 at the earliest (Klima- og Miljødepartementet 2020):" *Ikke igangsette ny petroleumsvirksomhet i områder der det forekommer havis mer enn 15 prosent av dagene i april, beregnet på grunnlag av isdata for 30-årsperioden 1988–2017"* (p. 132).

However, the scientific recommendations for the update of the integrated management plans from The Norwegian Institute of Marine Research and the Norwegian Polar Institute were to push the limit even further south (Havforskningsinstituttet 2020, Norsk Polarinstitutt 2020). Both scientific institutions recommended to use a limit defined by a frequency of only 0.5% of the days in April to have occurrence of ice, based on ice data for the 30 years 1988–2017, resulting in a limit situated further to the south: *"Menneskelige aktiviteter nær iskantsonen som kan gi negativ påvirkning på miljø eller dyreliv er heftet med usikkerhet. Som det presiseres i Faglig Forum's grunnlag for revisjon av forvaltningsplan for Barentshavet er det for eksempel få faktiske analyser om drift av oljesøl inn mot is og i tillegg lite erfaringer med oljesøl i is, så usikkerheten rundt dette er stor og vanskeliggjør risikovurderinger. Siden konsekvensene er heftet med betydelig usikkerhet, men muligens store for økosystemet i Barentshavet knyttet til is, bør sannsynligheten for overskridelse være lav. For å sikre en helhetlig og bærekraftig forvaltning av iskantsonen og dyrelivet som er helt avhengig av dette sårbare og høyproduktive området, har HI derfor anbefalt å avgrense iskantsonen til maksimal sørlig utbredelse observert i perioden 1988-2017, det vil si der man finner 0,5% isfrekvens slik som definert i Faglig forum for norske havområder (2019)"* (Havforskningsinstituttet 2020).

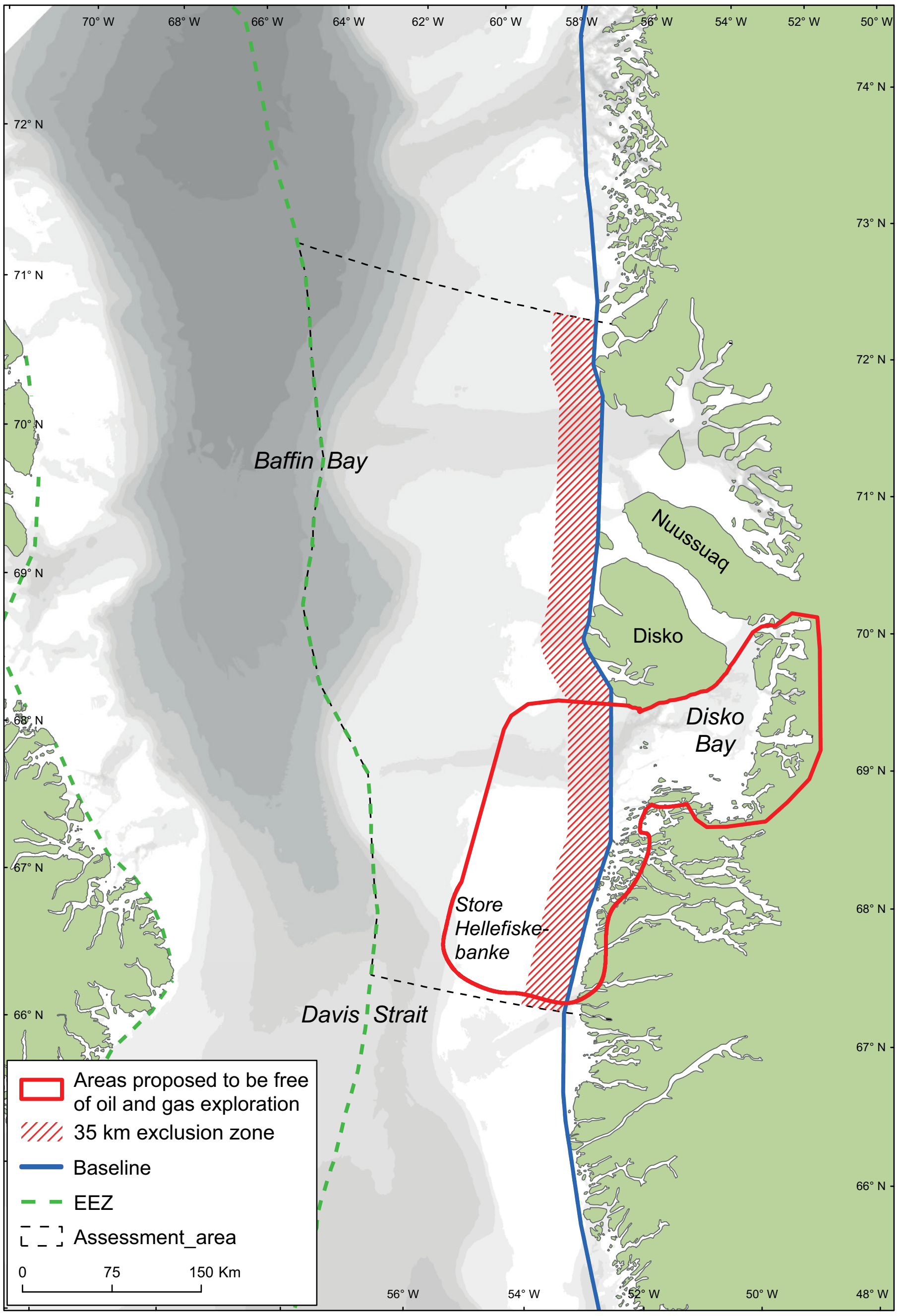
Regarding coastal sensitivity to oil spills, the coast of mainland North Norway is considered vulnerable to oil spills and a 35 km zone from the coast is closed for oil and gas exploration. At coasts considered particularly vulnerable (such as the coasts of the island Bjørnøya) this zone is 65 km (Klima- og Miljødepartementet 2020).

9.1.2 DCE/GINR identification of areas according to the three criteria

On the basis of the three criteria described above and the current international standards, DCE/GINR recommend the following:

Criterion 1: Especially valuable areas
In the Disko West area, an area termed as Store Hellefiskebanke has been recommended to be kept free of exploration (Mosbech et al. 2019). This area includes besides Store Hellefiskebanke also Disko Bay (Figure 95). The new information provided in this updated assessment supports this recommendation. (See also a description of the area in Annex D).

Figure 95. The area proposed to be closed for oil exploration in the DCE/GINR contribution to the oil and gas strategy 2020-2024 (Mosbech et al. 2019) and the Norwegian 35 km exclusion zone outside the base line applied to the assessment area.



Criterion 2: Distance to coast

Outside the area identified according to criterion 1, DCE and GINR recommend to apply the Norwegian criteria for distance to coasts in the Barents Sea. Based on these criteria, DCE and GINR recommend an exploration free 35 km coastal zone (Figure 95), corresponding to the zone for the Norway mainland. The baseline define the coast.

Criterion 3: Ice cover

In Figure 96 we have applied the Norwegian criteria for defining an exclusion zone based on ice frequency in March and April. When applied to Greenland waters, both the 15% frequency limit decided by the Norwegian parliament, and the 0.5% frequency limit recommended by the research institutions (see above) are situated south of the Disko West assessment area. Figure 96 shows both the March situation, when the ice has its largest distribution off West Greenland and the situation in April, which is the month with maximum ice cover in the Barents Sea.

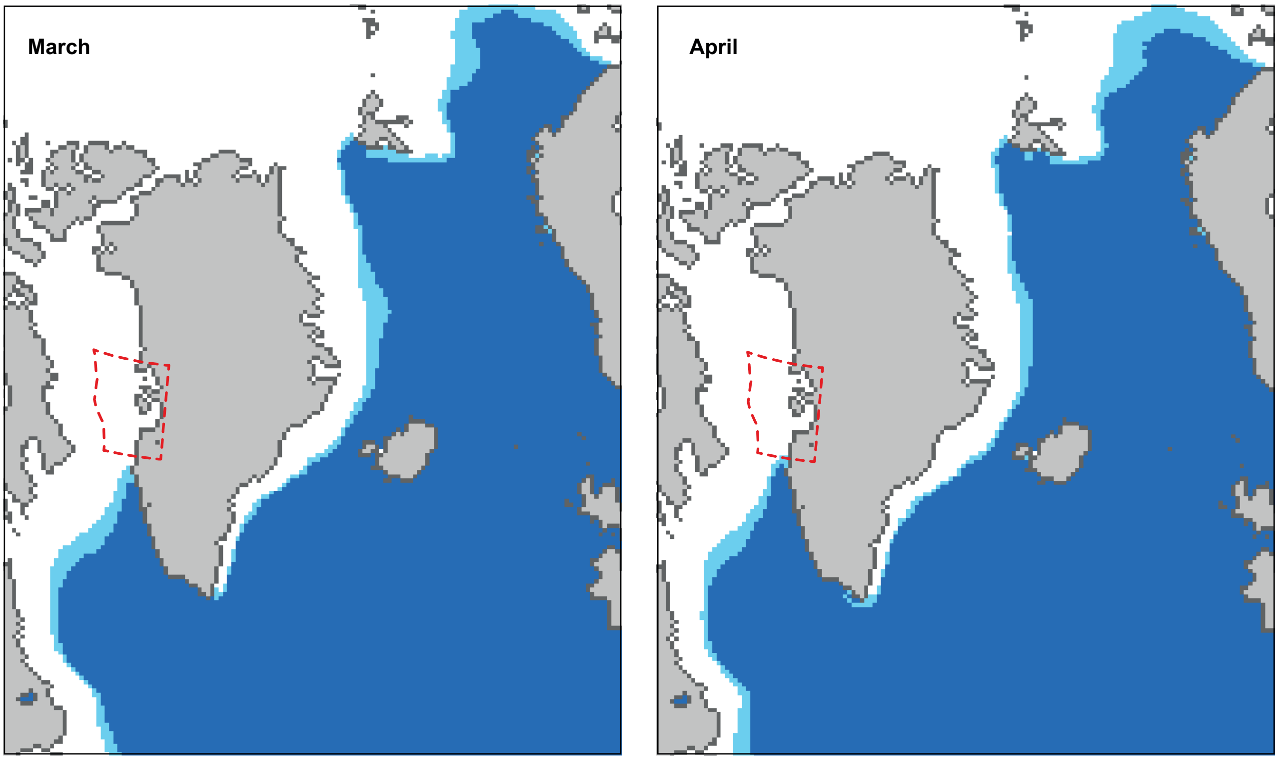


Figure 96. Mean sea ice concentrations in Greenland waters in March and April. Based on data from 1970 to 2019. The assessment area is shown with a hatched line.

A relevant question is then if the ecological conditions of the Barents Sea and the waters off West Greenland can be compared? The most significant ecological features in the Barents Sea are 1/ the Polar Front, where cold and Arctic waters meet warmer Atlantic waters and 2/ the Marginal Ice Zone (MIZ). The spatial position of the MIZ is highly variable. The primary production is very high at the MIZ in the Barents Sea, attracting fish, seabirds and marine mammals (Quillfeldt 2017). The situation off West Greenland are in some respects similar to the Barents Sea, because the waters in the northern part are covered with winter ice and warm and cold waters meet and create fronts. There is also a Marginal Ice Zone, but it is less well studied than in the Barents Sea and it may be less important because the primary production in West Greenland is known to be highly driven by tidal upwelling events along the banks. The primary production off West Greenland fuels the food web in much the same way as in the Barents Sea, and is important for fish, seabirds and marine mammals. In spring particularly, high concentrations of seabirds are found in the Marginal Ice Zone of Baffin Bay (Chapter 3.7, Frederiksen et al. 2008, LeBlanc et al. 2019, Merkel et al. 2021) and the Marginal Ice Zone is an important winter habitat for white whales and walruses on Store Hellefiskebanke (see Chapter 3.8). There is also an important fishery taking place off West Greenland (Chapter 5.3), but in size and species diversity much smaller than the fisheries in the Barents Sea.

As there are yet no proven methods available for handling major oil spill in drift ice and in winter darkness, and as research and development of such method are halted after the major oil companies have withdrawn from the Arctic, DCE/GN recommend to apply the Norwegian 15% criteria for ice frequency in the assessment area as a limit for further oil exploration in the present strategy period (2020-20124).

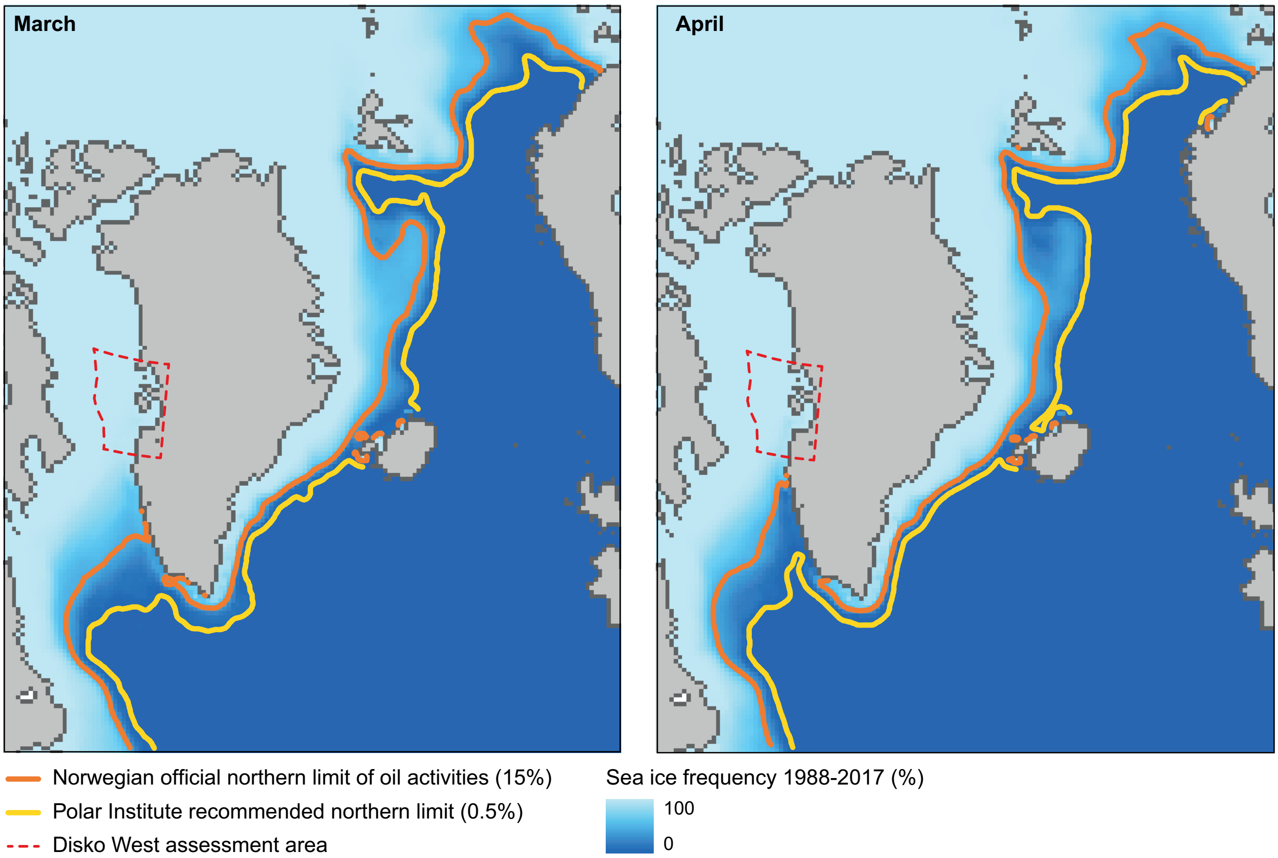


Figure 97. In Norway, the politically agreed northern limit of oil activities is currently set at 15% frequency of ice cover in the month of peak ice cover in the Barents Sea (April), based on a 30 year time series of sea ice data (1988-2017). However, the Norwegian Polar Institute has recently argued that the threshold should be lowered to 0.5% probability of ice cover in April, based on new data on the ecological importance of the marginal ice zone. In the map to the right, we have calculated both of these threshold values for Greenland waters in April, using the exact same methods and data as in Norway (Itkin et al. 2014). Since ice cover in West Greenland peaks in March, we have also performed the calculation for March (map to the left).

9.1.3 Conclusion on area restrictions

Based on the three criteria (primarily criterion 3, as this cover the entire area) and the above analysis DCE/GINR recommend to consider not to open the Disko West assessment area for oil exploration in the present strategy period (2020-2024). This is in line with high international environmental standards (cf. above).

9.2 Data gaps for future regulation of oil activities in the Disko West area

According to the recommendation above the most urgent need to address in the Disko West assessment area is the lack of effective methods to combat oil spills in waters covered with sea ice, and relevant for the assessment area especially in dynamic drift ice, which occurs in winter and spring. DCE/GINR recommend that these challenges are solved before the assessment area is opened for new applications for exploration and exploitation licenses.

Further it is recommended to get a better understanding of the ecological importance and seasonal sensitivity of the marginal ice zone.

When these issues have been addressed, knowledge relevant to the regulation of activities will be important to improve. For example on:

- background data on the local environment including ecosystem dynamics,
- effects of oil on local populations such as seabirds, marine mammals, macroalgae, seabed communities etc.,
- toxicological effects of oil compounds in the local marine environment,
- effects of response methods,
- natural degradation of oil compounds in the local marine environment.

Finally, will it be relevant to update the oil spill sensitivity map covering the Disko West assessment area, which was issued in 2012. Much new information is available and many ecological elements may have changed in abundance, distribution etc.

10 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.

Aastrup P; Rigét F; Dietz R, Asmund GI (2000). Lead, Zinc, Cadmium, Mercury, Selenium and Copper in Greenland Caribou and Reindeer (*Rangifer tarandus*). Science of the Total Environment 245: 149-159.

Acona (2012). Blowout risk evaluation in the Labroador Sea. Report No AFT-2011-0444-023. Acona Flow Technology AS. Skien.

Acquarone M, Born EW, Speakman JR (2006). Field metabolic rates of walrus (*Odobenus rosmarus*) measured by the doubly labeled water method. Aquatic Mammals 32: 363-369.

Aderhold DGR, Lindeberg MR, Holderied K, Pegau WS (2018). Spatial and temporal ecological variability in the northern Gulf of Alaska: What have we learned since the Exxon Valdez oil spill? Deep-sea Research Part II, Topical Studies in Oceanography 147: 3-8. doi:10.1016/j.dsr2.2017.11.015

Agersted MD, Møller EF, Gustavson K (2018). Bioaccumulation of oil compounds in the high-Arctic copepod *Calanus hyperboreus*. Aquatic Toxicology 195: 8-14. doi:10.1016/j.aquatox.2017.12.001

Ajiad AM, Gjøsætter H (1990). Diet of polar cod, *Boreogadus saida*, in the Barents Sea related to fish size and geographical distribution. International Council for the Exploration of the Sea, Council Meeting G:48

Akvaplan-niva, Acona (2003). Muligheder for og konsekvenser ved deponering av borekaks på land og konsekvenser ved reinjektion. Unpublished Report. Akvaplan-niva. Tromsø.

Albert TF (1981) Some thoughts regarding the possible effects of oil contamination on the bowhead whale, *Balaena mysticetus*, pp.945-953. 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.

Allen RC, Keay I (2006). Bowhead whales in the eastern Arctic, 1611-1911: Population reconstruction with historical whaling records. Environment and History 12: 89-113. doi:10.3197/096734006776026791

Almeda R, Baca S, Hyatt C, Buskey EJ (2014). Ingestion and sublethal effects of physically and chemically dispersed crude oil on marine planktonic copepods. Ecotoxicology 23: 988-1003. doi:10.1007/s10646-014-1242-6

Alonso-Alvarez C, Munilla I, López-Alonso M, Velando A (2007). Sublethal toxicity of the Prestige oil spill on yellow-legged gulls. Environment International 33: 773-781. doi:10.1016/j.envint.2007.02.012

AMAP (2004). Persistent organic pollutants in the Arctic. AMAP assessment report 2002. Arctic Monitoring and Assessment Programme (AMAP). Oslo, Norway.

AMAP (2005). Heavy metals in the Arctic. AMAP assessment report. Oslo, Norway.

AMAP (2010a). 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, Norway.

AMAP (2010b). Persistent organic pollutants (POPs) in the Arctic. AMAP assessment report. Oslo, Norway.

AMAP (2011). Mercury in the Arctic. Assessment report 2011. Arctic Monitoring and Assessment programme (AMAP). Oslo, Norway.

AMAP (2018a). Adaptation Actions for a Changing Arctic: Perspectives from the Baffin Bay/Davis Strait Region. Arctic Monitoring and Assessment Programme (AMAP). Oslo, Norway.

AMAP (2018b). Assessment 2018: Biological Effects of Contaminants on Arctic Wildlife and Fish. AMAP assessment report. Oslo, Norway.

AMAP (2019). AMAP Climate Change Update 2019. An Update to Key Findings of Snow, Water, Ice and Permafrost in the Arctic (SWIPA) 2017. Arctic Monitoring and Assessment Programme (AMAP). Oslo, Norway.

Ambrose WG, Renaud PE (1995). Benthic response to water column productivity patterns: evidence for benthic-pelagic coupling tn the Northeast Water polynya. Journal of Geophysical Research Oceans 100: 4411-4421.

Amélineau F, Bonnet D, Heitz O, Mortreux V, Harding AMA, Karnovsky N, Walkusz W, Fort J, Grémillet D (2016). Microplastic pollution in the Greenland Sea: Background levels and selective contamination of planktivorous diving seabirds. Environmental Pollution 219: 1131-1139. doi:10.1016/j.envpol.2016.09.017

Amstrup SC, Durner GM, McDonald TL, Johnson WR (2006). Estimating potential effects of hypothetical oil spills on polar bears. US Geological Survey. US Department of Interior.

Andersen OGN (1985). Forsøgsfiskeri efter tobis i Vestgrønland 1978. Biologiske resultater. Grønlands Fiskeri- og Miljøundersøgelser. Copenhagen.

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, Øien 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. doi:10.3354/meps247263

Andersen JM, Wiersma YF, Stenson G, Hammill MO, Rosing-Asvid A (2009a). Movement patterns of hooded seals (*Cystophora cristata*) in the Northwest Atlantic Ocean during the post-moult and pre-breeding seasons. Journal of Northwest Atlantic Fishery Science 42: 1-11. doi:10.2960/J.v42.m649

Andersen LW, Born EW, Doidge DW, Gjertz I, Wiig, Waples RS (2009b). Genetic signals of historic and recent migration between sub-populations of Atlantic walrus *Odobenus rosmarus rosmarus* west and east of Greenland. Endangered Species Research 9: 197-211. doi:10.3354/esr00242

Andersen LW, Born EW, Stewart REA, Dietz R, Doidge DW, Lanthier C (2009c). A genetic comparison of West Greenland and Baffin Island (Canada) walruses. NAMMCO Working Paper SC/17/WWG/06. NAMMCO Scientific Committee Working Group on Walrus Stock Status of Atlantic walrus in Greenland and adjacent seas. Copenhagen, Denmark. 23-26 November 2009.

Andersen JM, Skern-Mauritzen M, Boehme L, F Wiersma Y, Rosing-Asvid A, O Hammill M, B Stenson G (2013). Investigating annual diving behaviour by hooded seals (*Cystophora cristata*) within the Northwest Atlantic Ocean. Plos One 11: doi:10.1371/journal.pone.0080438

Andersen LW, Born EW, Stewart REA, Dietz R, Doidge DW, Lanthier C (2014). A genetic comparison of West Greenland and Baffin Island (Canada) walruses: Management implications. NAMMCO Scientific Publications Volume 9.

Andersen JH, Berzaghi F, Christensen T, Geertz-Hansen O, Mosbech A, Stock A, Zinglersen KB, Wisz MS (2017a). Potential for cumulative effects of human stressors on fish, sea birds and marine mammals in Arctic waters. Estuarine, Coastal and Shelf Science 184: 202-206. doi:10.1016/j.ecss.2016.10.047

Andersen LW, Jacobsen MW, Lydersen C, Semenova V, Boltunov A, Born EW, Wiig Ø, Kovacs KM (2017b). Walruses (*Odobenus rosmarus rosmarus*) in the Pechora Sea in the context of contemporary population structure of Northeast Atlantic walruses. Biological Journal of the Linnean Society 122: 897-915. doi:10.1093/biolinnean/blx093

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. doi:10.1016/j.csr.2005.05.003

Anker-Nilssen T (1987). Metoder til konsekvensanalyser olje/sjøfugl. Vildtrapport. No 44. Norsk Institutt for Naturforskning. Trondheim.

Anonymous (1978). Bundinvertebrater på Store og Lille Hellefiskebanke og i Holsteinsborgdybet. Rapport til Ministeriet for Grønland. Marine Identification Agency Aps. Skodsborg, Denmark.

Anonymous (2003). Utredning av konsekvens av helårlig petroleumsvirksomhet i området Lofoten-Barentshavet. Sammendragsrapport. Olje- og Energiministeriet. Oslo.

Anonymous (2006). Quotas for the catch of walruses and polar bears for the years 2007-2009. Press release 13 December 2006 (Jno 6622/04) Greenland Home Rule Government. Department of Fishery, Hunting and Agriculture, Nuuk.

Anononymous (2019). 2020 kvoter for hvalros. Accessed 13 December 2019 https://naalakkersuisut.gl/da/Naalakkersuisut/Nyheder/2019/12/1312_Aaffattassat_2020

APA (2003). Greenland offshore (West Disko) oil development feasibility assessment. Project no 10166 Unpublished Report. APA Petroleum Engeneering Inc.

Arendt K, Gulliksen B, Lønne OJ, Berge J (2009) Sea-ice fauna, in: Sakshaug E, Johnsen G, Kovacs KM (eds) Ecosystem Barents Sea. Tapir Academic Press, Trondheim.

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, pp.485-547. 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.

Armsworthy SL, Cranford PJ, Lee K (2005). Offshore oil and gas environmental effects monitoring. Approaches and technologies. Batelle Press, Columbus, Ohio.

Arrigo KR (2017) Sea ice as a habitat for primary producers, pp.352-369. in: Thomas DN (ed) Sea Ice. Wiley Blackwell. doi:10.1002/9781118778371.ch14

Arrigo KR, Perovich DK et al. 2014. Phytoplankton blooms beneath the sea ice in the Chukchi Sea. Deep Sea Research Part II: Topical Studies in Oceanography. 105: 1-16. https://doi.org/10.1016/j.dsr2.2014.03.018

Asmund G; Nielsen SP (2000). Mercury in Dated Greenland Marine Sediments. Science of the Total Environment 245: 61-72.

Au WWL, Carder DA, Penner RH, Scronce BL (1985). Demonstraton 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. doi:10.1016/j.marpolbul.2009.07.001

Baguley JG, Montagna PA, Cooksey C, Hyland JL, Bang HW, Morrison C, Kamikawa A, Bennetts P, Saiyo G, Parsons E, Herdener M, Ricci M (2015). Community response of deep-sea soft-sediment metazoan meiofauna to the Deepwater Horizon blowout and oil spill. Marine Ecology Progress Series 528: 127-140. doi:10.3354/meps11290

Baird RW (2000) The killer whale, foraging specializations and group hunting, pp.127-154. in: Mann J, Connor RC, Tyack PL, Whitehead H (eds) Cetacean societies, field studies of dolphins and whales. University of Chicago Press, Chicago.

Bakke T, Klungsøyr J, Sanni S (2013). Environmental impacts of produced water and drilling waste discharges from the Norwegian offshore petroleum industry. Marine Environmental Research 92: 154-169. doi:10.1016/j.marenvres.2013.09.012

Balk L, Hylland K, Hansson T, Berntssen MHG, Beyer J, Jonsson G, Melbye A, Grung M, Torstensen BE, Børseth JF, Skarphedinsdottir H, Klungsøyr J (2011). Biomarkers in natural fish populations indicate adverse biological effects of offshore oil production. Plos One 6: doi:10.1371/journal.pone.0019735

Ballachey BE, Monson DH, Esslinger GG, Kloecker K, Bodkin J, Bowe L, Miles AK (2014). 2013 update on sea otter studies to assess recovery from the 1989 Exxon Valdez oil spill. U.S. Geological Survey Open-File Report. Prince William Sound, Alaska.

Barber DG, Hop H, Mundy CJ, Else B, Dmitrenko IA, Tremblay JE, Ehn JK, Assmy P, Daase M, Candlish LM, Rysgaard S (2015). Selected physical, biological and biogeochemical implications of a rapidly changing Arctic Marginal Ice Zone. Progress in Oceanography 139: 122-150. https://doi.org/10.1016/j.pocean.2015.09.003.

Barber DG, Meier WN, Gerland S et al. (2017) Arctic Sea Ice. Pp. 103-136 in AMAP 2017. Snow, Water, Ice and Permafrost in the Arctic (SWIPA) 2017. Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway.

Barnes DKA (2002). Biodiversity: Invasions by marine life on plastic debris. Nature 416: 808-809. doi:10.1038/416808a

Barnes DKA, Galgani F, Thompson RC, Barlaz M (2009). Accumulation and fragmentation of plastic debris in global environments. Philosophical Transactions of the Royal Society of London Series B, Biological Sciences 364: doi:10.1098/rstb.2008.0205

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

Barrett RT, Chapdelaine G, nker-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. Report 2006/038. IRIS.

Becker S, Walter B, Bischof K (2009). Freezing tolerance and photosynthetic performance of polar seaweeds at low temperatures. Botanica Marina 52: 609-616. doi:10.1515/bot.2009.079

Beirão J, Baillon L, Litt MA, Langlois VS, Purchase CF (2019). Impact of crude oil and the dispersant Corexit™ EC9500A on capelin (*Mallotus villosus*) embryo development. Marine Environmental Research 147: 90-100. doi:10.1016/j.marenvres.2019.04.004

Beirão J, Litt MA, Purchase CF (2018). Chemically-dispersed crude oil and dispersant affects sperm fertilizing ability, but not sperm swimming behaviour in capelin (*Mallotus villosus*). Environmental Pollution 241: 521-528. doi:10.1016/j.envpol.2018.05.080

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. doi:DOI: 10.1134/S1063771006020023

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. doi:DOI: 10.1134/S1063771007040148

Benjaminsen T, Christensen I (1979) The Natural History of the Bottlenose Whale, *Hyperoodon ampullatus* (Forster), pp.143-164. in: Winn HE, Olla BL (eds) Behavior of Marine Animals. Springer US. doi:10.1007/978-1-4684-2985-5_5

Berge JA, Brevik EM, Bjørge A, Følsvik N, Gabrielsen GW, Wolkers H (2004). Organotins in marine mammals and seabirds from Norwegian territory. J Environ Monit 6: 108-112. doi:10.1039/b311662j

Bergmann M, Klages M (2012). Increase of litter at the Arctic deep-sea observatory HAUSGARTEN. Marine Pollution Bulletin 64: 2734-2741. doi:10.1016/j.marpolbul.2012.09.018

Bergmann M, Sandhop N, Schewe I, D'Hert D (2016). Observations of floating anthropogenic litter in the Barents Sea and Fram Strait, Arctic. Polar Biology 39: 553-560. doi:10.1007/s00300-015-1795-8

Bergmann M, Mützel S, Primpke S, Tekman MB, Trachsel J, Gerdts G (2019). White and wonderful? Microplastics prevail in snow from the Alps to the Arctic. Science Advances 5: eaax1157. doi:10.1126/sciadv.aax1157

Bergstrom BI (2000). The biology of Pandalus. Advances in Marine Biology 38: 55-245.

Bergstrøm B, Vilhjalmarsson H (2007). Preliminary results of the acoustic/pelagic trawl survey off West Greenland for capelin and polar cod 2005. Cruise report. No 66. Pinngortitaleriffik, Greenland Institute of Natural Resources. Nuuk.

Bertness MD, Leonard GH, Levine JM, Schmidt PR, Ingraham AO (1999). Testing the Relative Contribution of Positive and Negative Interactions in Rocky Intertidal Communities. Ecology 80: 2711. doi:10.2307/177252

Best PB (1979) Social organization in sperm whales, Physeter macrocephalus, pp.227-289. in: Winn HE, Olla BL (eds) Behaviour of marine animals, Vol 3. Plenum Press, New York.

Beyer J, Jonsson G, Porte C, Krahn MM, Ariese F (2010). Analytical methods for determining metabolites of polycyclic aromatic hydrocarbon (PAH) pollutants in fish bile: A review. Environmental Toxicology and Pharmacology 30: 224-244. doi:10.1016/j.etap.2010.08.004

Beyer J, Trannum HC, Bakke T, Hodson PV, Collier TK (2016). Environmental effects of the Deepwater Horizon oil spill: A review. Marine Pollution Bulletin 110: 28-51. doi:10.1016/j.marpolbul.2016.06.027

Beyer J, Bakke T, Lichtenthaler R, Klungsøyr J (2019). Environmental effects of offshore produced water discharges evaluated for the Barents Sea. NIVA report no. 7391-2019. Norwegian Environment Agency report M-1370/2019. https://www.miljodirektoratet.no/globalassets/publikasjoner/m1370/m1370.pdf

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. doi:10.1121/1.1701899

Blackwell SB, Nations CS, McDonald TL, Thode AM, Mathias D, Kim KH, Greene CR, Macrander AM (2015). Effects of airgun sounds on bowhead whale calling rates: Evidence for two behavioral thresholds. Plos One 10: doi:10.1371/journal.pone.0125720

Blicher M, Hammeken Arboe N (2017). Evaluation of proposed common standards for benthos monitoring in the Arctic-Atlantic – pilot study in Greenland (INAMon). Technical Report. No 105. Greenland Institute of Natural Resources. Greenland. doi:87-91214-82-3, ISSN 1397-3657

Blicher ME, Sejr MK, Rysgaard S (2009). High carbon demand of dominant macrozoobenthic species indicates their central role in ecosystem carbon flow in a sub-Arctic fjord. Marine Ecology Progress Series 383: 127-140. doi:10.3354/meps07978

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.

Blicher ME, Rasmussen LM, Sejr MK, Merkel F, Rysgaard S (2011). Abundance and energy requirements of eiders (*Somateria* spp.) suggest high predation pressure on macrobenthic fauna in a key wintering habitat in SW Greenland. Polar Biology 34: 1105-1116. doi:doi 10.1007/s00300-011-0968-3

Blondina GJ, Singer MM, Lee I, Ouano MT, Hodgins M, Tjeerdema RS, Sowby ML (1999). Influence of salinity on petroleum accommodation by dispersants. Spill Science and Technology Bulletin 5: 127-134. doi:10.1016/s1353-2561(98)00048-6

Bluhm BA, Hop H, Vihtakari M, Gradinger R, Iken K, Melnikov IA, Søreide JE (2018). Sea ice meiofauna distribution on local to pan-Arctic scales. Ecology and Evolution 8: 2350-2364. doi:10.1002/ece3.3797

Boehm PD, Cook LL, Murray KJ (2011). Aromatic Hydrocarbon Concentrations in Seawater: Deepwater Horizon Oil Spill. International Oil Spill Conference Proceedings 2011: doi:10.7901/2169-3358-2011-1-371

Boertmann D (1994). An annotated checklist to the birds of Greenland. Meddelelser om Grønland, Bioscience 38:

Boertmann D (2006). Optælling af ridekolonier i Disko Bugt, Arfersiorfik Fjord og Nordre Strømfjord. DMU Arbejdsrapport nr 225. Danmarks Miljøundersøgelser.

Boertmann D (2007). Grønlands Rødliste 2007. Grønlands Hjemmestyre & Danmarks Miljøundersøgelser, Nuuk.

Boertmann D (2008). The lesser black-backed gull, Larus fuscus, in Greenland. Arctic 61: 129-133.

Boertmann D, Bay C (2018). Grønlands Rødliste 2018: Fortegnelse over grønlandske dyr og planters trusselstatus.

Boertmann D, Mosbech A (2001). Important summer concentrations of seaducks in West Greenland. An input to oil spill sensitivity mapping. No 345. National Environmental Research Institute (NERI). Copenhagen.

Boertmann D, Mosbech A (2002). Molting Harlequin ducks in Greenland. Waterbirds 25: 326-332.

Boertmann D, Mosbech A (2017). Baffin Bay. An updated strategic Environmental Impact Assessment of petroleum activities in the Greenland part of Baffin Bay. Scientific Report. No 218. DCE – Danish Centre for Environment and Energy. Aarhus University.

Boertmann D, Mosbech A, Falk K, Kampp K (1996). Seabird Colonies in Western Greenland. NERI Technical Report No 170. National Environmental Research Institute.

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, Lyngs P, Merkel FR, Mosbech A (2004). The significance of Southwest Greenland as winter quarters for seabirds. Bird Conservation International 14: 87-112. doi:10.1017/s0959270904000127

Boertmann D, Mosbech A, Merkel FR (2006). The importance of Southwest Greenland for wintering seabirds. British Birds 99: 282-298.

Boertmann D, Mosbech A, Schiedek D, Dünweber M (2013). Disko West. A strategic environmental impact assessment of hydrocarbon activities. Scientific Report. No 71. DCE – Danish Centre for Environment and Energy. Aarhus University.

Boertmann D, Merkel F, Gilg O (2020). Seabird breeding colonies in East and North Greenland: A baseline. Arctic 73: 20-39. doi:10.14430/arctic69885

Boitsov S, Klungsøyr J, Dolva H (2012). Erfaringer etter oljeutslipp langs kysten av Norge. Skipsulykker med større oljeutslipp, effekter på miljøet og erfaringer med gjennomførte miljøundersøkelser. Havforskningsinstituttet. Tromsø, Norge.

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 Ice Edge Zone and Its Significance to the Davis Strait Ecosystem. Arctic 37: 234-243. doi:10.14430/arctic2196

Born EW (2001). Reproduction in female Atlantic walruses (*Odobenus rosmarus rosmarus*) from north-west Greenland. Journal of Zoology 255: 165-174. doi:10.1017/S0952836901001236

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. ISBN 82-7970-006-4

Born EW, Knutsen LØ (1990). Satellite tracking and behavioural observations of Atlantic walrus (*Odobenus rosmarus rosmarus*) in NE Greenland in 1989. Technical Report No 20. Greenland Home Rule, Dept. of Environment and Nature. Nuuk.

Born E, Dietz R, Heide-Jørgensen MP (1982). Catch and distribution of walrus (*Odobenus rosmarus*) in West Greenland. ICES Report CM 1982/N: 10. International Council for Exploration of the Sea (ICES). Copenhagen.

Born EW, Heide-Jørgensen M, Larsen F, Martin AR (1994a). Abundance and stock composition of narwhals (*Monodon monoceros*) in Inglefield Bredning (NW Greenland). Meddelelser om Grønland, Bioscience 39: 51-68.

Born EW, Heide-Jørgensen MP, Davis RA (1994b). The Atlantic walrus (*Odobenus rosmarus rosmarus*) in West Greenland. Meddelelser om Grønland, Bioscience 40: 1-33.

Born EW, Gjertz I, Reeves RR (1995). Population assessment of Atlantic walrus (*Odobenus rosmarus rosmarus* L.). Norsk Polarinstitutt Meddelelser 138: 1-100.

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, Aquarone M, Knutsen LØ, Pedersen LT (2005). Homing Behaviour in an Atlantic Walrus (*Odobenus rosmarus rosmarus*). Aquatic Mammals 31: 23-33.

Born EW, Kingsley MCS, Rigét 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. doi:10.2981/0909-6396(2007)13[84:AMATIO]2.0.CO;2

Born EW, Heilmann A, Kielsen Holm L, Laidre KL, Iversen M (2017). Walruses in West and Northwest Greenland – An interview survey about the catch and the climate. Meddelelser om Grønland / Monographs on Greenland. Man and Society 44: 265.

Botello AV, Soto LA, Ponce-Vélez G, Susana Villanueva F (2015). Baseline for PAHs and metals in NW Gulf of Mexico related to the Deepwater Horizon oil spill. Estuarine, Coastal and Shelf Science 156: 124-133. doi:10.1016/j.ecss.2014.11.010

Bouchard C, Fortier L (2008). Effects of polynyas on the hatching season, early growth and survival of polar cod Boreogadus saida in the Laptev Sea. Marine Ecology Progress Series 355: 247-256. doi:10.3354/meps07335

Bouchard C, Fortier L (2011). Circum-arctic comparison of the hatching season of polar cod Boreogadus saida: A test of the freshwater winter refuge hypothesis. Progress in Oceanography 90: 105-116. doi:10.1016/j.pocean.2011.02.008

Bouchard C, Mollard S, Suzuki K, Robert D, Fortier L (2016). Contrasting the early life histories of sympatric Arctic gadids Boreogadus saida and Arctogadus glacialis in the Canadian Beaufort Sea. Polar Biology 39: 1005-1022. doi:10.1007/s00300-014-1617-4

Bourne WRP (1979). Birds and gas flares. Marine Pollution Bulletin 10: 124-125. doi:10.1016/0025-326X(79)90069-9

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.

Bowman JS, Larose C, Vogel TM, Deming JW (2013). Selective occurrence of Rhizobiales in frost flowers on the surface of young sea ice near Barrow, Alaska and distribution in the polar marine rare biosphere. Environ Microbiol Rep 5: 575-82. doi:10.1111/1758-2229.12047

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. doi:10.1017/S0025315410000755

Boye TK, Garde E, Nielsen J, Hedeholm R, Olsen J, Simon (2020a). Estimating the Age of West Greenland Humpback Whales Throug Aspartic Acid Racemization and Eye Lens Bomb Radiocarbon Methods. Front. Mar. Sci. 6: 811 .doi: 10.3389/fmars.2019.00811

Boye T., Simon MJ, Laidre KL, Rigét F, Stafford KM (2020b). Seasonal detections of bearded seal (*Erignathus barbatus*) vocalizations in Baffin Bay and Davis Strait in relation to sea ice concentration. Polar Biology (2020) 43:1493–1502 https://doi.org/10.1007/s00300-020-02723-1

Bradstreet M (1982). Occurrence, Habitat Use, and Behavior of Seabirds, Marine Mammals, and Arctic Cod at the Pond Inlet Ice Edge. Arctic 35: doi:10.14430/arctic2305

Braithwaite LF, Aley MG, Slater DL (1983). The Effects of Oil on the Feeding Mechanism of the Bowhead Whale. Report AA851-CTO-55. Department of the Interior. Brigham Young University.

Brakstad OG, Lewis A, Beegle-Krause CJ (2018a). A critical review of marine snow in the context of oil spills and oil spill dispersant treatment with focus on the Deepwater Horizon oil spill. Marine Pollution Bulletin 135: 346-356. doi:10.1016/j.marpolbul.2018.07.028

Brakstad OG, Davies EJ, Ribicic D, Winkler A, Brönner U, Netzer R (2018b). Biodegradation of dispersed oil in natural seawaters from Western Greenland and a Norwegian Fjord. Polar Biology 41: 2435-2450. https://doi.org/10.1007/s00300-018-2380-8

Brandvik PJ, Sørheim KR, Singsaas I, Reed M (2006). Short state-of-the-art report on oil spills in ice-infested waters. SINTEF report No A06148. Materials and Chemistry, Marine Environmental Technology. Trondheim, Norway.

Brandvik PJ, Daling PS, Faksness LG, Fritt-Rasmussen J, Daae RL, Leirvik F (2010). Experimental oil release in broken ice – A large-scale field verification of results from laboratory studies of oil weathering and ignitability of weathered oil spills. SINTEF report No A15549. SINTEF Materials and Chemistry, Marine Environmental Technology. Trondheim, Norway.

Braulik G, Minton G, Amano M, Bjørge A. (2020). *Phocoena phocoena*. The IUCN Red List of Threatened Species 2020: e.T17027A50369903.https://dx.doi.org/10.2305/IUCN.UK.2020-2.RLTS.T17027A50369903.en. Downloaded on 15 July 2020.

Breuer E, Shimmield G, Peppe O (2008). Assessment of metal concentrations found within a North Sea drill cuttings pile. Marine Pollution Bulletin 56: 1310-1322. doi:10.1016/j.marpolbul.2008.04.010

Breuer E, Stevenson AG, Howe JA, Carroll J, 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. doi:10.1016/j.marpolbul.2003.08.009

Brewer K, Gallagher M, Regos P, Isert P, Hall J (1993). Kuvlum #1 Exploration Prospect: Site Specific Monitoring Program. Final Report. Prepared by Coastal and Offshore Pacific Corporation, Walnut Creek, CA. ARCO Alaska, Inc., Anchorage, AK.

Brown TA, Assmy P, Hop H, Wold A, Belt ST (2017). Transfer of ice algae carbon to ice-associated amphipods in the high-Arctic pack ice environment. Journal of Plankton Research 39: 664-674. doi:10.1093/plankt/fbx030

Brown TA, Galicia MP, Thiemann GW, Belt ST, Yurkowski DJ, Dyck MG (2018). High contributions of sea ice derived carbon in polar bear (Ursus maritimus) tissue. PLoS One 13: e0191631. doi:10.1371/journal.pone.0191631

Bruce B, Bradford R, Foster S, Lee K, Lansdell M, Cooper S, Przeslawski R (2018). Quantifying fish behaviour and commercial catch rates in relation to a marine seismic survey. Marine Environmental Research 140: 18-30. doi:10.1016/j.marenvres.2018.05.005

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.

Bröker KC (2019). An overview of potential impacts of hydrocarbon exploration and production on marine mammals and associated monitoring and mitigation measures. Aquatic Mammals 45: 576-611. doi:10.1578/am.45.6.2019.576

Bråte ILN, Hurley R, Lusher A, Buenaventura N, Halsband C, Green N (2020). Microplastics in marine bivalves from the Nordic environment. Norwegian Environment Agency publication series M-1629|2020. Nordic Council of Ministers.

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.

Buhl-Mortensen L, Burgos J, Steingrund P, Buhl-Mortensen P, Ólafsdóttir S, Ragnarsson S (2019). Vulnerable marine ecosystems (VMEs). Coral and sponge VMEs in Arctic and sub-Arctic waters - Distribution and threats. TemaNord: 519. doi:http://dx.doi.org/10.6027/TN2019-519

Buist I (2000). In situ burning of oil spills in ice and snow. International Oil and Ice Workshop 2000. Alaska Clean Seas. Anchorage and Prudehoe Bay.

Buist I, Potter SG, Trudel BK, Shelnutt SR, Walker AH, Scholz DK, Brandvik PJ, Fritt-Rasmussen J, Allen AA, Smith P (2013). In□Situ Burning in Ice□Affected Waters. State of Knowledge Report. International Association of Oil & Gas Producers. London, UK.

Buist I, Trudel K, Fritt-Rasmussen J, Wegeberg S, Gustavson K, Lassen P, Alva WUR, Jomaaas G, Zabilansky L (2017). Research investigations into herder fate, effects and windows-of-opportunity. Oill Spill Preparedness. Arctic Oil Spill Response Technology Joint Industry Programme (JIP).

Burmeister A (2002) Preliminary notes on the reproductive condition of mature female snow crabs (Chionoecetes opilio) from Disko Bay and Sisimiut, West Greenland, pp.255-267. 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.

Burmeister A, Rigét FF (2019a). A Provisional Assessment of the Shrimp Stock off West Greenland in 2019. NAFO SCR Doc 019/046 Ser, No N7010.

Burmeister A, Rigét FF (2019b). The West Greenland trawl survey for *Pandalus borealis*, 2019, with reference to earlier results. NAFO SCR Doc 019/043, Ser No N7007.

Burns JJ (1981) Bearded seal Erignatus barbatus, pp.97-101. 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 2: 787.

Böning CW, Behrens E, Biastoch A, Getzlaff K, Bamber JL (2016). Emerging impact of Greenland meltwater on deepwater formation in the North Atlantic Ocean. Nature Geoscience 9: 523-527. doi:10.1038/ngeo2740

Baak JE, Provencher JF, Mallory ML (2020). Plastic ingestion by four seabird species in the Canadian Arctic: Comparisons across species and time. Marine Pollution Bulletin 158: 111386. doi:https://doi.org/10.1016/j.marpolbul.2020.111386

CAFF (ed) (2013). Arctic Biodiversity Assessment. Status and trends in Arctic biodiversity. Conservation of Arctic Flora and Fauna, Akureyri, Iceland

CAFF (2017). State of the Arctic Marine Biodiversity Report. CAFF International Secretariat, Akureyri, Iceland Isbn:9789935431639

Campbell JS, Simms JM (2009). Status Report on Coral and Sponge Conservation in Canada. Fisheries and Oceans Canada. 87.

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. doi:10.1016/j.marenvres.2008.02.074

Camus L, Jones MB, Børseth JF, Grøsvik BE, Regoli 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. doi:10.1016/S0141-1136(02)00140-X

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, Grøsvik BE, Gulliksen B, Lønne 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. doi:10.1016/S0048-9697(02)00616-2

Carassou L, Hernandez FJ, Graham WM (2014). Change and recovery of coastal mesozooplankton community structure during the Deepwater Horizon oil spill. Environmental Research Letters 9: 124003. doi:10.1088/1748-9326/9/12/124003

Carls MG, Rice SD, Hose JE (1999). Sensitivity of fish embryos to weathered crude oil: Part I. Low-level exposure during incubation causes malformations, genetic damage, and mortality in larval Pacific herring (Clupea pallasi). Environmental Toxicology and Chemistry 18: 481-493. doi:10.1002/etc.5620180317

Carroll AG, Przeslawski R, Duncan A, Gunning M, Bruce B (2017). A critical review of the potential impacts of marine seismic surveys on fish & invertebrates. Marine Pollution Bulletin 114: 9-24. doi:10.1016/j.marpolbul.2016.11.038

Castège I, Milon E, Pautrizel F (2014). Response of benthic macrofauna to an oil pollution: Lessons from the "Prestige" oil spill on the rocky shore of Guéthary (south of the Bay of Biscay, France). Deep-sea Research Part Ii: Topical Studies in Oceanography 106: 192-197. doi:10.1016/j.dsr2.2013.09.035

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: 1726-1726. doi:10.1121/1.3383433

Cedre (2016). Analysis of dispersibility of oil frozen into ice with and without dispersant. Oill Spill Preparedness. Arctic Oil Spill Response Technology Joint Industry Programme (JIP).

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. doi:10.1006/anbe.2001.1747

Chadwick M (2005). Proceedings of the peer review on potential impacts of seismic energy on snow crab. Proceedings series (Canadian Science Advisory Secretariat) No 45.

Challenger G, Mauseth G (2011) Seafood Safety and Oil Spills, pp.1083-1100. in: Fingas M (ed) Oil spill science and technology. Elsevier Inc. doi:10.1016/B978-1-85617-943-0.10032-2

Chambault P, Albertsen CM, Patterson TA, Hansen RG, Tervo O, Laidre KL, Heide-Jørgensen MP (2018). Sea surface temperature predicts the movements of an Arctic cetacean: the bowhead whale. Scientific Reports 8: doi:10.1038/s41598-018-27966-1

Chanton J, Zhao T, Rosenheim BE, Joye S, Bosman S, Brunner C, Yeager KM, Diercks AR, Hollander D (2015). Using natural abundance radiocarbon to trace the flux of petrocarbon to the seafloor following the deepwater horizon oil spill. Environmental Science and Technology 49: 847-854. doi:10.1021/es5046524

Chapman PM, Riddle MJ (2003). Missing and needed: polar marine ecotoxicology. Marine Pollution Bulletin 46: 927-928. doi:10.1016/s0025-326x(03)00252-2

Chapman PM, Riddle MJ (2005). Polar marine toxicology - Future research needs. Marine Pollution Bulletin 50: 905-908. doi:10.1016/j.marpolbul.2005.06.001

Charrier I, Aubin T, Mathevon N (2009). Mother-Calf vocal communication in Atlantic walrus: a first field experimental study. Animal Cognition 13: 471-482. doi:10.1007/s10071-009-0298-9

Charrier I, Burlet A, Aubin T (2011). Social vocal communication in captive Pacific walruses *Odobenus rosmarus* divergens. Mammalian Biology 76: 622-627. doi:10.1016/j.mambio.2010.10.006

Christensen T, Mosbech A, Geertz-Hansen O, Johansen KL, Wegeberg S, Boertmann D, Clausen DS, Zinglersen KB, Linnebjerg JF (2015). Analyse af mulig økosystembaseret tilgang til forvaltning af skibstrafik i Disko Bugt og Store Hellefiskebanke. DCE Teknisk rapport nr 61. Nationalt Center for Miljø og Energi. Aarhus Universitet.

Christensen T, Aastrup P, Boye T, Boertmann D, Hedeholm R, Johansen KL, Merkel F, Rosing-Asvid A, Bay C, Blicher M, Clausen DS, Ugarte F, Arendt K, Burmeister A, Topp-Jørgensen E, Retzel A, Hammeksen N, Falk K, Frederiksen M, Bjerrum M, Mosbech A (2016). Biologiske interesseområder i Vest- og Sydøstgrønland. Kortlægning af vigtige biologiske områder. Teknisk rapport fra DCE nr 89. Nationalt Center for Miljø og Energi. Aarhus Universitet.

Christensen T, Lasserre JD, Guy, E, Pelletier J-F (2018). Shipping. Pp. 243-259 in AMAP 2017. Adaptation Actions for a Changing Arctic. Perspectives from the Baffin Bay/Davis Strait Region. Arctic Monitoring and Assessment Programme (AMAP). Oslo, Norway.

Christian JR, Mathieu A, Thomson DH, White D, Buchanan RA (2003). Effects of seismic enegry on Snow crab (Chionoecetes opilio). Environmental Studies Research Funds Report No 144. Oceans Ltd. & National Energy Board. Calgary, Canada.

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. doi:10.1007/s00300-010-0783-2

Clark RC, Finley JS (1977) Effects of oil spills in arctic and subarctic environments, pp.411-476. in: Malins DC (ed) Effects of petroleum on arctic and subarctic marine environments and organisms Vol II Biological effects. Academic Press, New York.

Clark CW, Ellison WT, Southall BL, Hatch L, Van Parijs SM, Frankel A, Ponirakis D (2009). Acoustic masking in marine ecosystems: Intuitions, analysis, and implication. Marine Ecology Progress Series 395: 201-222. doi:10.3354/meps08402

Clarke A (2003). Costs and consequences of evolutionary temperature adaptation. Trends in Ecology and Evolution 18: 573-581. doi:10.1016/j.tree.2003.08.007

Clausager I (1979). Olieudslippet fra Thun Tank III i januar 1976. Vildtbiologisk Station, Kalø.

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 Scientific Report No 44. Danish Centre for Environment and Energy.

Cleemann M, Rigét F, Paulsen GB, Dietz R (2000a). Organochlorines in Greenland glaucous gulls (*Larus hyperboreus*) and Icelandic gulls (*Larus glaucoides*). Science of the Total Environment 245: 117-130. https://doi.org/10.1016/S0048-9697(99)00437-4

Cleemann M, Rigét F, Paulsen GB, Klungsøyr J, Dietz R (2000b). Organochlorines in Greenland marine fish, mussels and sediments. Science of the Total Environment 245: 87-102. https://doi.org/10.1016/S0048-9697(99)00435-0

ClimateLab (2014a). Scenarios at St. Hellefiske Bank.

ClimateLab (2014b). Dispersion analysis St. Hellefiskebanke.

ClimateLab (2014c). Dispersion analysis II St. Hellefiske bank.

ClimateLab (2014d). Dispersion analysis III St. Open sea oil spill scenario at St. Hellefiske bank.

Cohen DM, Inada T, Iwamoto T, Scialabba N (1991). FAO species catalogue vol. 10. gadiform fishes of the world order gadiformes an annotated and illustrated catalogue of cods hakes grenadiers and other gadiform fishes known to date. Fao (food and Agriculture Organization of the United Nations) Fisheries Synopsis 125: 1-442.

Comiso JC, Parkinson CL, Gersten R, Stock L (2008). Accelerated decline in the Arctic Sea ice cover. Geophysical Research Letters 35:6: doi:10.1029/2007gl031972

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. doi:10.1016/j.marpol.2007.05.005

Convention on Biological Diversity (CBD) (2012). Impacts of Marine Debris on Biodiversity: Current Status and Potential Solutions. Technical Series No 67. Secretariat of the Convention on Biological Diversity and the Scientific and Technical Advisory Panel GEF. Montreal.

Cooke J, Reeves R (2018). Balaena mysticetus East Greenland-Svalbard-Barents Sea subpopulation. The IUCN Red List of Threatened Species, Accessed 06 September 2019 http://dx.doi.org/10.2305/IUCN.UK.2018-1.RLTS.T2472A50348144.en

Cooke JG (2018a). Balaenoptera acutorostrata. The IUCN Red List of Threatened Species, Accessed 06 September 2019 http://dx.doi.org/10.2305/IUCN.UK.2018-2.RLTS.T2474A50348265.en

Cooke JG (2018b). *Balaenoptera borealis*. The IUCN Red List of Threatened Species, Accessed 08 May 2019 http://dx.doi.org/10.2305/IUCN.UK.2018-2.RLTS.T2475A130482064.en

Cooke JG (2018c). Balaenoptera musculus. The IUCN Red List of Threatened Species, Accessed 08 May 2019 http://dx.doi.org/10.2305/IUCN.UK.2018-2.RLTS.T2477A50226195.en

Cooke JG (2018d). Balaenoptera physalus. The IUCN Red List of Threatened Species, Accessed 08 May 2019 http://dx.doi.org/10.2305/IUCN.UK.2018-2.RLTS.T2478A50349982.en

Cooke JG (2018e). Megaptera novaeangliae. The IUCN Red List of Threatened Species, Accessed 08 May 2019 http://dx.doi.org/10.2305/IUCN.UK.2018-2.RLTS.T13006A50362794.en

Cornwall W (2015). Deepwater Horizon after the oil. Science 348: 6230.

COSEWIC (2006). Assessment and update status report on the Atlantic walrus (*Odobenus rosmarus rosmarus*). Committee on the status of endangered wildlife in Canada. No ix. Canada, Ottawa.

COSEWIC (2017). COSEWIC assessment and status report on the Atlantic Walrus *Odobenus rosmarus rosmarus*, High Arctic population, Central-Low Arctic population and Nova Scotia-Newfoundland-Gulf of St. Lawrence population in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa.

COSEWIC. 2019. Canadian Wildlife Species at Risk. Committee on the Status of Endangered Wildlife in Canada. Web site: https://www.canada.ca/en/environmentclimate-change/services/species-risk-public-registry/cosewic-list-species-assessed.html [accessed 10 September 2019]

Cózar A, Martí E, Duarte CM, García-de-Lomas J, van Sebille E, Ballatore TJ, Eguíluz VM, González-Gordillo JI, Pedrotti ML, Echevarría F, Troublè R, Irigoien X (2017). The Arctic Ocean as a dead end for floating plastics in the North Atlantic branch of the Thermohaline Circulation. Science Advances 3: doi:10.1126/sciadv.1600582

Craig PC, McCart PJ (1976). Fish use of near-shore coastal waters in the western Arctic: Emphasis on anadromous species. Assessment of the Arctic marine environment: Selected Topics. University of Alaska, Fairbanks.

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.

Culbertson JB, Valiela I, Pickart M, Peacock EE, Reddy CM (2008). Long-term consequences of residual petroleum on salt marsh grass. Journal of Applied Ecology 45: 1284-1292. doi:10.1111/j.1365-2664.2008.01477.x, 10.1111/j.1365-2664.2008.01477.x

Cummings WC, Thompson PO (1971). Underwater Sounds from the Blue Whales, *Balaenoptera musculus*. Journal of the Acoustical Society of America 4: 1193-1198.

Curry B, Lee CM, Petrie B, Moritz RE, Kwok R (2014). Multiyear volume, liquid freshwater, and sea ice transports through Davis Strait, 2004-10. Journal of Physical Oceanography 44: 1244-1266. doi:10.1175/jpo-d-13-0177.1

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. doi:10.1007/s003000050461

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 of Statens Forureningstilsyn. Bergen.

Daly KL, Passow U, Chanton J, Hollander D (2016). Assessing the impacts of oil-associated marine snow formation and sedimentation during and after the Deepwater Horizon oil spill. Anthropocene 13: 18-33. doi:10.1016/j.ancene.2016.01.006

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, D.R. B, Blackman RAA, Addy JM, Appelbee JF, Grogran WC, J.G. P, Whitehead A (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, November 9, 1990. Finnish Initiative on Protection of the Artic Environment.

Dawson J, Kaae B, Johnston, Bjorst LR, Pizzolato L (2018). Tourism. Pp 223-242 in AMAP 2017. Adaptation Actions for a Changing Arctic. Perspectives from the Baffin Bay/Davis Strait Region. Arctic Monitoring and Assessment Programme (AMAP). Oslo, Norway.

Day RD, McCauley RD, Fitzgibbon QP, Hartmann K, Semmens JM (2019). Seismic air guns damage rock lobster mechanosensory organs and impair righting reflex. Proceedings of the Royal Society B: Biological Sciences 286: doi:10.1098/rspb.2019.1424

Dean TA, Jewett SC (2001). Habitat-specific recovery of shallow subtidal communities following the Exxon Valdez oil spill. Ecological Applications 11: 1456-1471. doi:10.1890/1051-0761(2001)011[1456:HSROSS]2.0.CO;2

Deming JW (2010) Sea ice bacteria and viruses, pp.247-282. in: Thomas DN, Dieckmann GS (eds) Sea Ice. Wiley Blackwell, UK.

Deming JW, Collins RE (2017) Sea ice as a habitat for bacteria, archaea and viruses, pp.326-351. in: Thomas DN (ed) Sea Ice. Wiley Blackwell, UK.

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.

Descamps S, Anker-Nilssen T, Barrett RT, Irons DB, Merkel F, Robertson GJ., Yoccoz NG, Mallory ML, Montevecchi WA, Boertmann D, Artukhin Y, Christensen-Dalsgaard S, Erikstad KE, Gilchrist HG, Labansen AL, Lorentsen SH, Mosbech A, Olsen B, Petersen A, Rail JF, Renner HM, Strøm H, Systad GH, Wilhelm SI, Zelenskaya L (2017). Circumpolar dynamics of a marine top-predator track ocean warming rates. Global Change Biology 23, 3770–3780. doi: 10.1111/gcb.13715.

Desforges JP, Hall A, McConnell B, Rosing-Asvid A, Barber JL, Brownlow A, De Guise S, Eulaers I, Jepson PD, Letcher RJ, Levin M, Ross PS, Samarra F, Víkingson G, Sonne C, Dietz R (2018). Predicting global killer whale population collapse from PCB pollution. Science 361: 1373-1376. doi:10.1126/science.aat1953

DFO (2004). Review of scientific information on impacts of seismic sound on fish, invertebrates, marine turtles and marine mammals. Habitat Status Report 2004/002. DFO Can. Sci. Advis. Sec.

Di Iorio L, Clark CW (2010). Exposure to seismic survey alters blue whale acoustic communication. Biology Letters 6: 51-54. doi:10.1098/rsbl.2009.0651

Diercks AR, Asper VL, Highsmith RC, Woolsey M, Lohrenz SE, McLetchie K, Gossett A, Lowe M, Joung D, McKay L (2010a). The discovery of deep oil plumes at the Deepwater Horizon oil spill site. American Geophysical Union, Fall Meeting 2010.

Diercks AR, Highsmith RC, Asper VL, Joung D, Zhou Z, Guo L, Shiller AM, Joye SB, Teske AP, Guinasso N, Wade TL, Lohrenz SE (2010b). Characterization of subsurface polycyclic aromatic hydrocarbons at the Deepwater Horizon site. Geophysical Research Letters 37: L20602. doi:10.1029/2010GL045046

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-revue Canadienne De Zoologie 73: 2106-2119. doi:10.1139/z95-248

Dietz R, Rigét F, Johansen P (1996). Lead, cadmium, mercury and selenium in Greenland marine animals. Science of the Total Environment 186: 67-93. doi:10.1016/0048-9697(96)05086-3

Dietz R, Heide-Jørgensen 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. doi:10.14430/arctic785

Dietz R, Heide-Jørgensen MP, Richard P, Orr J, Laidre K, Schmidt HC (2008). Movements of narwhals (Monodon monoceros) from Admiralty Inlet monitored by satellite telemetry. Polar Biology 31: 1295-1306. doi:10.1007/s00300-008-0466-4

Dietz R, Born EW, Stewart REA, Heide-Jørgensen MP, Stern H, Rigét F, Toudal L, Lanthier C, Jensen MV, Teilmann J (2014). Movements of walruses (*Odobenus rosmarus*) between Central West Greenland and Southeast Baffin Island, 2005-2008. Nammco Scientific Publications 9: doi:10.7557/3.2605

Dietz R, Gustavson K, Sonne C, Desforges JP, Rigét FF, Pavlova V, McKinney MA, Letcher RJ (2015). Physiologically-based pharmacokinetic modelling of immune, reproductive and carcinogenic effects from contaminant exposure in polar bears (*Ursus maritimus*) across the Arctic. Environmental Research 140: 45-55. doi:10.1016/j.envres.2015.03.011

Dietz R, Desforges JP, Gustavson K, Rigét FF, Born EW, Letcher RJ, Sonne C (2018). Immunologic, reproductive, and carcinogenic risk assessment from POP exposure in East Greenland polar bears (*Ursus maritimus*) during 1983–2013. Environment International 118: 169-178. doi:10.1016/j.envint.2018.05.020

Dietz R, Letcher RJ, Desforges J-P, Eulaers I, Sonne C, Wilson S, Andersen-Ranberg E, Basu N, Barst BD, Bustnes JO, Bytingsvik J, Ciesielski TM, Drevnick PE, Gabrielsen GW, Haarr A, Hylland K, Jenssen BM, Levin M, McKinney MA, Nørregaard RD, Pedersen KE, Provencher J, Styrishave B, Tartu S, Aars J, Ackerman JT, Rosing-Asvid A, Barrett R, Bignert A, Born EW, Branigan M, Braune B, Bryan CE, Dam M, Eagles-Smith CA, Evans M, Evans TJ, Fisk AT, Gamberg M, Gustavson K, Hartman CA, Helander B, Herzog MP, Hoekstra PF, Houde M, Hoydal K, Jackson AK, Kucklick J, Lie E, Loseto L, Mallory ML, Miljeteig C, Mosbech A, Muir DCG, Nielsen ST, Peacock E, Pedro S, Peterson SH, Polder A, Rigét FF, Roach P, Saunes H, Sinding M-HS, Skaare JU, Søndergaard J, Stenson G, Stern G, Treu G, Schuur SS, Víkingsson G (2019). Current state of knowledge on biological effects from contaminants on arctic wildlife and fish. Science of The Total Environment 696: 133792. doi:https://doi.org/10.1016/j.scitotenv.2019.133792

Dietz R, Sonne C, Albert C, Bustes J, Christensen T, Ciesielski T, Danielsen J, Dastnai S, Eens M, Erikstad K, Fort J, Galatius A, Garbus S-E, Gilg O, Hanssen S, Helander B, Helberg M, Jaspers V, Jenssen B, Kauhala K, Kyhn LA, Labansen AL, Larsen M, Lindstøm U, Reiertsen T, Rigét F, Roos A, Strand J, Strøm H, Sveegaard S, Søndergaard J, Sun J, Teilmann J, Therkildsen O, Tjørnløv R, Wilson S, Eulaers I (submitted). A risk assessment of the effects of mercury on Baltic Sea, Greater North Sea and North Atlantic wildlife, fish and bivalves. Environment International Special Issue submitted.

DNV-GL (2015). Risk reduction and oil spill response, Oil spill contingency study. Greenland Report. No 2015-0587, rev 2.

Donovan GP (1991). A review of IWC stock boundaries. Report of the International Whaling Commission Special Issue No 13. Cambridge.

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. doi:10.1890/1051-0761(2001)011[0815:LTSODF]2.0.CO;2

Dunlop RA, Noad MJ, McCauley RD, Kniest E, Slade R, Paton D, Cato DH (2017). The behavioural response of migrating humpback whales to a full seismic airgun array. Proceedings of the Royal Society B: Biological Sciences 284: doi:10.1098/rspb.2017.1901

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. doi:10.1121/1.3158929

Dunton KH, Schell DM (1987). Dependence of consumers on macroalgal (Laminaria solidungula) carbon in an arctic kelp community: δ13C evidence. Marine Biology 93: 615-625. doi:10.1007/BF00392799

Durner GM, Amstrup SC (2000). Estimating the impacts of oil spills on Polar Bears. Arctic Research of the United States 14: 33-37.

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. doi:10.3354/meps08813

Düwel D, Wegeberg S (1992) Kalkinkrusterede rødalger på Disko: Artsbestemmelse, systematik og biologi, pp.61-94. in: Andersen PF, Düwel L, Hansen OS (eds) Feltkursus i Arktisk Biologi, Godhavn 1990. Copenhagen University.

EAMRA (2015). Offshore Seismic Surveys in Greenland. Guidelines to Best Environmental Practices. Danish Centre for Environment and Energy, Greenland Institute of Natural Resources, Environmental Agency for the Mineral Resource Activities. Greenland.

Edinger E, Baker K, DeVillers R, Wareham V (2007). Coldwater corals off Newfoundland and Labrador. Distribution and fisheries impacts. World Wildlife Foundation. Toronto, Canada.

Edmonds NJ, Firmin CJ, Goldsmith D, Faulkner RC, Wood DT (2016). A review of crustacean sensitivity to high amplitude underwater noise: Data needs for effective risk assessment in relation to UK commercial species. Marine Pollution Bulletin 108: 5-11. doi:10.1016/j.marpolbul.2016.05.006

Egevang C, Boertmann D (2001a). The Greenland Ramsar Sites. NERI Technical Report No 346. National Environmental Research Institute.

Egevang C, Boertmann D (2001b). The Ramsar sites of Disko, West Greenland. A Survey in July 2001. NERI Technical Report No 368. National Environmental Research Institute. Denmark.

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 (2012). De grønlandske fuglebeskyttelsesområder – en statusrapport. Teknisk rapport nr 87. Pinngortitaleriffik, Grønlands Naturinstitut.

Egevang C, Boertmann D, Mosbech A, Tamstorf MP (2003). Estimating colony area and population size of little auks *Alle alle* at Northumberland island using aerial images. Polar Biology 26: 8-13. doi:10.1007/s00300-002-0448-x

Elarbaoui S, Richard M, Boufahja F, Mahmoudi E, Thomas-Guyon H (2015). Effect of crude oil exposure and dispersant application on meiofauna: An intertidal mesocosm experiment. Environmental Sciences: Processes and Impacts 17: 997-1004. doi:10.1039/c5em00051c

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 (*Melanogrammus aeglefinus*). Canadian Journal of Fisheries and Aquatic Sciences 53: 2238-2249. doi:10.1139/f96-177

Enstipp MR, Descamps S, Fort J, Grémillet D (2018). Almost like a whale – first evidence of suction feeding in a seabird. Journal of Experimental Biology 221: doi:10.1242/jeb.182170

EPPR (1998). Field Guide for Oil Spill Response in Arctic Waters. Emergency Prevention, Preparedness and Response (EPPR). Arctic Council.

EPPR (2015). Guide to Oil Spill Response in Snow and Ice Conditions. Emergency, Prevention, Preparedness and Response. Arctic Council.

EPPR (2017). Circumpolar Oil Spill Response Viability Analysis; Technical Report. Emergency Prevention, Preparedness and Response (EPPR). Arctic Council http://hdl.handle.net/11374/1928

Escajeda E, Laidre KL, Born EW, Wiig Ø, Atkinson S, Dyck M, Ferguson SH, Lunn NJ (2018). Identifying shifts in maternity den phenology and habitat characteristics of polar bears (*Ursus maritimus*) in Baffin Bay and Kane Basin. Polar Biology 41: 87-100. doi:10.1007/s00300-017-2172-6

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.

Esler D, Ballachey BE, Matkin C, Cushing D, Kaler R, Bodkin J, Monson D, Esslinger G, Kloecker K (2016). Timelines and mechanisms of wildlife population recovery following the Exxon Valdez oil spill. Deep-sea Research Part Ii: Topical Studies in Oceanography 147: 36-42. doi:10.1016/j.dsr2.2017.04.007

European Commission (2001). Decision no 2455/2001/ec of the European parliament and of the council. 20 November 2001 establishing the list of priority substances in the field of water policy and amending Directive 2000/60/EC. No 331.

EVOS (2014a). Harlequin Duck recovering. Accessed 14 Sept http://www.evostc.state.ak.us/index.cfm?FA=status.harlequinduck

EVOS (2014b). Pacific herring not recovered. Accessed 14 Sept http://www.evostc.state.ak.us/index.cfm?FA=status.herring

EVOS (2014c). Pigeon Guillemot, not recovered. Accessed 14 Sept http://www.evostc.state.ak.us/index.cfm?FA=status.pigeonguillemot

Faglig forum for norske havområder (2019) Særlig verdifulle og sårbare områder - Faggrunnlag for revisjon og oppdatering av forvaltningsplanene for norske havområder. M-1303/2019. https://www.miljodirektoratet.no/globalassets/publikasjoner/m1303/m1303.pdf

Faksness LG (2008). Weathering of oil under Arctic conditions - Distribution and toxicity of water soluble oil components dissolving in seawater and migrating through sea ice. A combined laboratory and field study. Dissertation for the degree philosophiae doctor (PhD).

Faksness LG, Altin D, Nordtug T, Daling PS, Hansen BH (2015). Chemical comparison and acute toxicity of water accommodated fraction (WAF) of source and field collected Macondo oils from the Deepwater Horizon spill. Marine Pollution Bulletin 91: 222-229. doi:10.1016/j.marpolbul.2014.12.002

Faksness LG, Brandvik PJ (2005). Dissolution of water soluble components from oil spills encapsulated in ice. 28th Arctic and Marine Oilspill Program Technical Seminar

Falk K, Durinck J (1993). The winter diet of thick-billed murres, *Uria lomvia*, in western Greenland, 1988–1989. Canadian Journal of Zoology 71: 264-272. doi:10.1139/z93-038

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, pp.147-166. in: Ørbæk JB, Tombre T, kallenborn R, hegseth E, Falk-Petersen S (eds) Arctic Alpine Ecosystems and Pople. Springer Berlin Heidelberg. doi:10.1007/978-3-540-48514-8_9

Falk-Petersen S, Mayzaud P, Kattner G, Sargent JR (2009). Lipids and life strategy of Arctic Calanus. Marine Biology Research 5: 18-39. doi:10.1080/17451000802512267

FAO (2008). Report of the Technical Consultation on International Guidelines for the Management of Deep-sea Fisheries in the High Seas. Rome, 4–8 February and 25–29 August 2008. No 881. FAO Fisheries and Aquaculture.

Fay FH (1982). Ecology and Biology of the Pacific walrus, *Odobenus rosmarus divergens* Illiger. North American Fauna No 74. U.S. Department of the Interior Fish and Wildlife Service.

Fay FH, Ray GC, Kibal´chich AA (1984) Time and location of mating and associated behaviour of the Pacific walrus *Odobenus rosmarus divergens* Illiger, pp.89-99. in: Fay FH, Fedoseev GA (eds) Soviet-American Cooperative Research on Marine Mammals Vol 1- Pinnipeds NOAA Technical Reports NMFS 12. Washington D.C.

Fetterer F, Knowles K, Meier WN, Savoie M, Windnagel AK (2017) updated daily. Sea Ice Index, Version 3. Boulder, Colorado USA. NSIDC: National Snow and Ice Data Center. doi: https://doi.org/10.7265/N5K072F8.

Fields DM, Handegard NO, Dalen J, Eichner C, Malde K, Karlsen Ø, Skiftesvik AB, Durif CMF, Browman HI (2019). Airgun blasts used in marine seismic surveys have limited effects on mortality, and no sublethal effects on behaviour or gene expression, in the copepod Calanus finmarchicus. Ices Journal of Marine Science 76: 2033-2044. doi:10.1093/icesjms/fsz126

Filbee-Dexter K, Scheibling RE (2014). Sea urchin barrens as alternative stable states of collapsed kelp ecosystems. Marine Ecology Progress Series 495: 1-25.

Finley KJ, Miller GW, Davis RA, Koski WR (1983). A Distinctive Large Breeding Population of Ringed Seals (Phoca hispida) Inhabiting the Baffin Bay Pack Ice. Arctic 36: 162-173. doi:10.14430/arctic2259

Fisher CR, Hsing PY, Kaiser CL, Yoerger DR, Roberts HH, Shedd WW, Cordes EE, Shank TM, Berlet SP, Saunders MG, Larcom EA, Brooks JM (2014). Footprint of deepwater horizon blowout impact to deep-water coral communities. Proceedings of the National Academy of Sciences of the United States of America 111: 11744-11749. doi:10.1073/pnas.1403492111

Fleeger JW, Riggio MR, Mendelssohn IA, Lin Q, Deis DR, Johnson DS, Carman KR, Graham SA, Zengel S, Hou A (2019). What Promotes the Recovery of Salt Marsh Infauna After Oil Spills? Estuaries and Coasts 42: 204-217. doi:10.1007/s12237-018-0443-2

Fodrie FJ, Able KW, Galvez F, Heck KL, Jensen OP, LÓPez-Duarte PC, Martin CW, Turner RE, Whitehead A (2014). Integrating Organismal and Population Responses of Estuarine Fishes in Macondo Spill Research. Bioscience 64: 778-788.

Foote AD, Osborne RW, Hoelzel AR (2004). Environment: whale-call response to masking boat noise. Nature 428: doi:10.1038/428910a

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, Fisher HD (1978). Underwater acoustic signals of the narwhal (Monodon monoceros). Canadian Journal of Zoology 56: 552-560.

Frasier TR, Petersen SD, Postma L, Johnson L, Heide-Jørgensen MP, Ferguson SH (2015). Abundance estimates of the Eastern Canada-West Greenland bowhead whale (*Balaena mysticetus*) population based on genetic capture-mark-recapture analyses. DFO Can. Sci. Advis. Sec. Res. Doc. 2015/008. iv + 21 p.

Frasier TR, Petersen SD, Postma L, Johnson L, Heide-Jørgensen MP, Ferguson SH (2020). Abundance estimation from genetic mark-recapture data when not all sites are sampled: An example with the bowhead whale. Global ecology and conservation. Vol 22. https://doi.org/10.1016/j.gecco.2020.e00903

Frandsen MS, Fort J, Rigét FF, Galatius A, Mosbech A (2014). Composition of chick meals from one of the main little auk (*Alle alle*) breeding colonies in Northwest Greenland. Polar Biology 37: 1055-1060. doi:10.1007/s00300-014-1491-0

Frantzen M, Falk-Petersen IB, Nahrgang J, Smith TJ, Olsen GH, Hangstad TA, Camus L (2012). Toxicity of crude oil and pyrene to the embryos of beach spawning capelin (*Mallotus villosus*). Aquatic Toxicology 108: 42-52. doi:10.1016/j.aquatox.2011.09.022

Fraser GS, Russell J, von Zharen WM (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 (δ13C and δ15N) analysis. Marine Ecology Progress Series 260: 71-81.

Frederiksen M, Mosbech M (2016). Risikovurdering for kongeederfugle på Store Hellefiskebanke. Pp. 64-67 in Store Hellefiskebanke, Grønland. Miljøvurdering af oliespild samt potentialet for oliespildsbekæmpelse. Videnskabelig rapport fra DCE. No 216. DCE - Nationalt Center for Miljø og Energi. https://dce2.au.dk/pub/SR216.pdf

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. NERI Technical Report No 694. National Environmental Research Institute (NERI), University of Aarhus. Roskilde, Denmark.

Frederiksen M, Descamps S, Erikstad KE, Gaston AJ, Gilchrist HG, Grémillet D, Johansen KL, Kolbeinsson Y, Linnebjerg JF, Mallory ML, McFarlane Tranquilla LA, Merkel FR, Montevecchi WA, Mosbech A, Reiertsen TK, Robertson GJ, Steen H, Strøm H, Thórarinsson TL (2016). Migration and wintering of a declining seabird, the thick-billed murre *Uria lomvia*, on an ocean basin scale: Conservation implications. Biological Conservation 200: 26-35. doi:10.1016/j.biocon.2016.05.011

Frederiksen M, Moe B, Daunt F, Phillips RA, Barrett RT, Bogdanova MI, Boulinier T, Chardine JW, Chastel O, Chivers LS, Christensen-Dalsgaard S, Clément-Chastel C, Colhoun K, Freeman R, Gaston AJ, González-Solís J, Goutte A, Grémillet D, Guilford T, Jensen GH, Krasnov Y, Lorentsen SH, Mallory ML, Newell M, Olsen B, Shaw D, Steen H, Strøm H, Systad GH, Thórarinsson TL, Anker-Nilssen T (2012). Multicolony tracking reveals the winter distribution of a pelagic seabird on an ocean basin scale. Diversity and Distributions 18: 530-542. doi:10.1111/j.1472-4642.2011.00864.x

Frederiksen M, Boertmann D, Labansen A, Laursen K, Loya W, Merkel FR, Mosbech A, Aastrup P (2017a). Review af det videnskabelige grundlag for færdselsregler i følsomme områder for dyrelivet i Grønland. DCE Scientific Report No 242. Danish Centre for Environment and Energy.

Frederiksen M, Mosbech A, Merkel F, Johansen KL (2017b) Identification of migration routes of thick-billed murres and black-legged kittiwakes using satellite telemetry and geolocation, pp.102-103. in: Boertmann D, Mosbech A (eds) An updated strategic Environmental Impact Assessment of petroleum activities in the Greenland part of Baffin Bay – Scientific Report from DCE No 218. Danish Centre for Environment and Energy, Aarhus University.

Freiwald A, Fosså JH, Grehan A, Koslow T, Roberts JM (2004). Cold-water Coral Reefs. UNEP-WCMC. Cambridge, UK.

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.

Fritt-Rasmussen J, Wegeberg S, Gustavson K (2015). Review on Burn Residues from In Situ Burning of Oil Spills in Relation to Arctic Waters. Water Air and Soil Pollution 226: 1-12. doi:10.1007/s11270-015-2593-1

Fritt-Rasmussen J, Linnebjerg JF, Sørensen MX, Brogaard NL, Rigét FF, Kristensen P, Jomaas G, Boertmann DM, Wegeberg S, Gustavson K (2016). Effects of oil and oil burn residues on seabird feathers. Marine Pollution Bulletin 109: 446-452. doi:10.1016/j.marpolbul.2016.05.029

Fritt-Rasmussen J, Boertmann D, Christensen T, Clausen DS, Gustavson K, Wegeberg S, Mosbech A (2020). Oliespild i grønlandske farvande, miljømæssige udfordringer og beredskab. 1 mar. Technical reports. No 163. DCE.

Fritt-Rasmussen J, Wegeberg S, Wilms LB, Renvald L, Larsen MB, Geertz-Hansen O, Lassen P, Gustavson K (in prep.). Coastline in situ burning of oil spills in the Arctic. A Greenland field study.

Fuller SD, Perez FJM, Wareham V, Kenchington E (2008). Vulnerable Marine Ecosystems Dominated by Deep-Water Corals and Sponges in the NAFO Convention Area. NAFO SCR Doc. 08/22, serial No. N5524.

Furness RA (1975). Inventory and cataloquing of Arctic area waters. Annu Rep Prog, Project F-9-7, 16(G1-1). Alaska Dep. Fish Game. Fed. Aid Fish. Rest.

Gall SC, Thompson RC (2015). The impact of debris on marine life. Marine Pollution Bulletin 92: 170-179. doi:10.1016/j.marpolbul.2014.12.041

Garde E, Hansen RG, Heide-Jørgensen MP (2018a). Catch Statistics and age structures for Atlantic walrus in Greenland 1993 to 2018- A preliminary compilation. Working paper NAMMCO SC/25/14-WWG/04. NAMMCO Scientific Committee Working Group on walrus. Copenhagen.

Garde E, Jung-Madsen S, Ditlevsen S, Hansen RG, Zinglersen KB, Heide-Jørgensen MP (2018b). Diving behavior of the Atlantic walrus in high Arctic Greenland and Canada. Journal of Experimental Marine Biology and Ecology 500: 89-99. doi:10.1016/j.jembe.2017.12.009

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. doi:10.1139/cjz-77-4-571

Geraci JR, St. Aubin DJ (eds) (1990). Sea Mammals and Oil. Confronting the risk. Academic Press, San Diego.

GESAMP (1993). Impact of oil and related chemicals on the marine environment. GESAMP Reports and Studies No 50. Joint group of experts on the scientific aspects of marine pollution (GESAMP). International Maritime Organization (IMO), London.

Gilbert F, Stora G, Cuny P (2015). Functional response of an adapted subtidal macrobenthic community to an oil spill: macrobenthic structure and bioturbation activity over time throughout an 18-month field experiment. Environmental Science and Pollution Research 22: 15285-15293. doi:10.1007/s11356-014-3906-4

GINR (2019). Cites non detriment findings for havpattedyr i Grønland 2019. CITES Scientific Authority in Greenland. Greenland Institute of Natural Resources.

GINR (2020). Non Detriment Findings for havpattedyr I Grønland. https://naturgl/raadgivning/raadgivning-havpattedyr/,

Girard F, Shea K, Fisher CR (2018). Projecting the recovery of a long-lived deep-sea coral species after the Deepwater Horizon oil spill using state-structured models. Journal of Applied Ecology 55: 1812-1822. doi:10.1111/1365-2664.13141

Gjertz I, Kovacs KM, Lydersen C, Wiig (2000). Movements and diving of bearded seal (*Erignathus barbatus*) mothers and pups during lactation and post-weaning. Polar Biology 23: 559-566. doi:10.1007/s003000000121

Goodale DR (1981). The temporal and geographic distribution of Humpback, Finback and Right Whale Calves. M.S. Thesis, University of Rhode Island

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. doi:10.4031/002533203787536998

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 Ii-topical Studies in Oceanography 44: 1623-1644.

Gougeon S, Kemp KM, Blicher ME, Yesson C (2017). Mapping and classifying the seabed of the West Greenland continental shelf. Estuarine, Coastal and Shelf Science 187: 231-240. doi:http://dx.doi.org/10.1016/j.ecss.2017.01.009

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 Ii-topical Studies in Oceanography 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.

Graham L, Hale C, Maung-Douglass E, Sempier S, Skelton T, Swann L, Wilson M (2017). The Deepwater Horizon oil spill's impact on bottlenose dolphins. Oil spill science MASGP-17-002:

Gray JS (2002). Species richness of marine soft sediments. Marine Ecology Progress Series 244: 285-297. doi:10.3354/meps244285

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 J, McRoy C (1989). Pelagic-benthic coupling on the northern Bering and Chukchi seas. III. Benthic food supply and carbon cycling. Marine Ecology Progress Series 53: 79-91.

Greene CR, 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. Acoust Soc Am 116: 799-813. doi:10.1121/1.1765191

Greenland statistics 2020. http://www.stat.gl/default.asp?lang=en

Grenvald JC, Nielsen TG, Hjorth M (2012). Effects of pyrene exposure and temperature on early development of two co-existing Arctic copepods. Ecotoxicology 22: 184-198. doi:10.1007/s10646-012-1016-y

Griffiths DJ, Øritsland NA, Øritsland T (1987). Marine mammals and petroleum activities in Norwegian waters. Fisken og Havet Serie B No 1.

Grønlands Selvstyre (2020). Oliestrategi (2020-2024). Departementet for Erhverv, Energi, Forskning og Arbejdsmarked. Grønland.

Grønlands Selvstyre (without year). Turismeudvikling i Grønland – hvad skal der til.? National sektorplan for turisme 2016-2020. Link

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. doi:10.1111/j.1095-8649.2010.02671.x

Gustavson K, Agersted MD, Møller EF, Badawi N, Aamand, J. (2019). Forbedring af vidensgrundlaget for miljørisikovurdering for anvendelse og udledning af offshorekemikalier i arktiske havområder. Aarhus Universitet, DCE – Nationalt Center for Miljø og Energi teknisk rapport nr. 134.

Gustavson K, Kyhn L, Møller EF (in prep.). Bioaccumulation, elimination and depuration of oil compounds in the high-Arctic copepod *Calanus hyperboreus* as function of lipid content.

Gustavson K, Hansson SV, van Beest FM, Fritt-Rasmussen J, Lassen P, Geertz-Hansen O, Wegeberg S (submitted). Natural removal of crude and heavy fuel oil on rocky shorelines in Arctic climate regimes. Submitted to Water, Air & Soil Pollution.

Gutt J (1995). The occurrence of sub-ice algal aggregations off northeast greenland. Polar Biology 15: 247-252. doi:10.1007/BF00239844

Hall JD, Gallagher M, Brewer K, Regos P, Isert P (1994). 1993 Kuvlum exploration area site specific monitoring program. Prepared for ARCO Alaska, Inc. Coastal and Offshore Pacific Corporation. Anchorage, AK,.

Halsband C, Herzke D (2019). Plastic litter in the European Arctic: What do we know? Emerging Contaminants 5: 308-318. doi:10.1016/j.emcon.2019.11.001

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. doi:10.1139/f91-288

Hammond PS, Bearzi G, Bjørge A, Forney K, Karczmarski L, Kasuya T, Perrin WF, Scott MD, Wang JY, Wells RS, Wilson B (2008). *Phocoena phocoena*. The IUCN Red List of Threatened Species 2008: e.T17027A6734992. IUCN.

Hancke K, Lund-Hansen LC, Lamare ML, Højlund Pedersen S, King MD, Andersen P, Sorrell BK (2018). Extreme Low Light Requirement for Algae Growth Underneath Sea Ice: A Case Study From Station Nord, NE Greenland. Journal of Geophysical Research: Oceans 123: 985-1000. doi:10.1002/2017jc013263

Haney JC, Geiger HJ, Short JW (2014a). Bird mortality from the Deepwater Horizon oil spill. I. Exposure probability in the offshore Gulf of Mexico. Marine Ecology Progress Series 513: 225-237. doi:10.3354/meps10991

Haney JC, Geiger HJ, Short JW (2014b). Bird mortality from the Deepwater Horizon oil spill. II. Carcass sampling and exposure probability in the coastal Gulf of Mexico. Marine Ecology Progress Series 513: 239-252. doi:10.3354/meps10839

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. doi:10.1016/j.aquatox.2009.01.010

Hannam ML, Bamber SD, John Moody A, 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. doi:10.1016/j.ecoenv.2010.06.012

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 RG, Heide-Jørgensen MP (2013). Spatial trends in abundance of long-finned pilot whales, white-beaked dolphins and harbour porpoises in West Greenland. Marine Biology 160: 2929-2941. doi:10.1007/s00227-013-2283-8

Hansen OS, Schlütter H (1992) Makroalgezonering i tidevandszonen på Disko, pp.95-136. in: Andersen PF, Düwel L, OS H (eds) (eds) Feltkursus i Arktisk Biologi, Godhavn 1990. Københavns Universitet.

Hansen BW, Levinsen H, Nielsen TG (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). Meteorological trends (1991–2004) at Arctic Station, Central West Greenland (69°15′N) in a 130 years perspective. Geografisk Tidsskrift-danish Journal of Geography 106: 45-55. doi:10.1080/00167223.2006.10649544

Hansen BH, Altin D, Olsen AJ, Nordtug T (2012a). Acute toxicity of naturally and chemically dispersed oil on the filter-feeding copepod *Calanus finmarchicus*. Ecotoxicology and Environmental Safety 86: 38-46. doi:10.1016/j.ecoenv.2012.09.009

Hansen MO, Nielsen TG, Stedmon CA, Munk P (2012b). Oceanographic regime shift during 1997 in Disko Bay, Western Greenland. Limnology and Oceanography 57: 634-644. doi:10.4319/lo.2012.57.2.0634

Hansen BH, Altin D, Øverjordet IB, Jager T, Nordtug T (2013a). Acute exposure of water soluble fractions of marine diesel on Arctic *Calanus glacialis* and boreal *Calanus finmarchicus*: Effects on survival and biomarker response. Science of The Total Environment 449: 276-284. doi:10.1016/j.scitotenv.2013.01.020

Hansen JLS, Hjorth M, Rasmussen MB, Bruhn A, Christensen PB (2013b) Mapping of macroalgae in the Disko West coastal zone - Box 2, in: Schiedek D, Dünweber M, Boertmann D (eds) Disko West A strategic environmental impact assessment of hydrocarbon activities in the Disko West area. DCE - Danish Centre for Environment and Energy, Aarhus University, Roskilde.

Hansen KA, Maxwell A, Siebert U, Larsen ON, Wahlberg M (2017). Great cormorants (Phalacrocorax carbo) can detect auditory cues while diving. Science of Nature 104: 45. doi:10.1007/s00114-017-1467-3

Hansen RG, Boye TK, Larsen RS, Nielsen NH, Tervo OM, Nielsen RD, Rasmussen MH, Sinding MHS, Heide-Jørgensen MP (2018). Abundance of whales in West and East Greenland in summer 2015. NAMMCO Scientific Publications 11: doi:https://doi.org/10.7557/3.4689

Hansen JLS, Sejr MK, Holm-Hansen TH, Andersen OGN (2019a). Benthic macrofauna communities on the Northeast Greenland shelf 2017. Results and data from the NEG Dana cruise 2017. DCE Scientific Report No 361. Danish Centre for Environment and Energy. Aarhus University.

Hansen RG, Boye TK, Larsen RS, Nielsen NH, Tervo O, Nielsen RD, Rasmussen MH, Sinding MHS, Heide-Jørgensen MP (2019b). Abundance of whales in West and East Greenland in summer 2015. Nammco Scientific Publications 11: doi:10.7557/3.4689

Hansen KA, Hernandez A, Mooney AA, Rasmussen MH, Sørensen K, Wahlberg M (2020). The common murre (*Uria aalge*), an auk seabird, reacts to underwater sound. The Journal of the Acoustical Society of America 147, 4069https://doi.org/10.1121/10.0001400

Harding AMA, Egevang C, Walkusz W, Merkel F, Blanc S, Grémillet D (2009). Estimating prey capture rates of a planktivorous seabird, the little auk (*Alle alle*), using diet, diving behaviour, and energy consumption. Polar Biology 32: 785-796. doi:10.1007/s00300-009-0581-x

Harvey JT, Dalheim ME (1994) Cetaceans in oil, pp.257-264. in: Loughin TR (ed) Marine Mammals and the Exxon Valdez. Academic Press, San Diego.

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. doi:10.1016/j.icesjms.2004.07.008

Hauser DDW, Laidre KL, Stern HL (2017). Vulnerability of arctic marine mammals to vessel traffic in the increasingly ice-free northwest passage and Northern Sea Route. Proceedings of the National Academy of Sciences of the United States of America 115: 7617-7622. doi:10.1073/pnas.1803543115

Havforskningsinstituttet 2020. Presisering av Havforskningsinstituttets anbefaling av avgrensning av iskantsonen. Råd og Kunnskabsbidrag fra Havforskningsinstituttet, Bergen, 24.03.2020 https://www.regjeringen.no/contentassets/0a9b07dccc024e6cbe6910994350 0f9d/presisering-av-havforskningsinstituttets-anbefaling-av-avgrensning-av-iskantsonen-l806673.pdf

Hawkins SJ, Gibbs PE, Pope ND, Burt GR, Chesman BS, Bray S, Proud SV, Spence SK, Southward AJ, Southward GA, Langston WJ (2002). Recovery of polluted ecosystems: the case for long-term studies. Marine Environmental Research 54: 215-222.

Hazen TC, Dubinsky EA, DeSantis TZ, Andersen GL, Piceno YM, Singh N, Jansson JK, Probst A, Borglin SE, Fortney JL, Stringfellow WT, Bill M, Conrad ME, Tom LM, Chavarria KL, Alusi TR, Lamendella R, Joyner DC, Spier C, Baelum J, Auer M, Zemla ML, Chakraborty R, Sonnenthal EL, D'Haeseleer P, Holman HYN, Osman S, Lu Z, Van Nostrand JD, Deng Y, Zhou J, Mason OU (2010). Deep-sea oil plume enriches indigenous oil-degrading bacteria. Science 330: 204-208. doi:10.1126/science.1195979

Heath MF, Evans MI (2000). Important bird areas in Europe. Priority sites for conservation. BirdLife International, Cambridge, UK.

Hedeholm R, Grønkjær 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. doi:10.1093/icesjms/fsq024

Hedeholm RB (2010). The importance of small pelagic fishes to the energy flow in marine ecosystems: the Greenlandic capelin. Ph.D. Thesis, Aarhus University

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. doi:10.1111/j.1748-7692.2004.tb01154.x

Heide-Jørgensen MP, Acquarone M (2002). Size and trends of the bowhead whale, beluga and narwhal stocks wintering off West Greenland. Nammco Scientific Publications 4: doi:10.7557/3.2844

Heide-Jørgensen MP, Laidre K (2007). Autumn-space use patterns of humpback whales 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. 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. GINR report to NERI for the Disko West Environmental Forum. Greenland Institute of Natural Resources. Nuuk.

HeideJorgensen 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, Teilmann J (1994). Growth, reproduction, age structure and feeding habits of belugas (Delphinapterus leucas) in West Greenland waters. Meddelelser om Grønland, Bioscience 39: 195-212.

Heide-Jørgensen MP, Lassen H, Teilmann J, Davis RA (1993). An Index of the Relative Abundance of Wintering Belugas, *Delphinapterus leucas*, and Narwhals, *Monodon monoceros*, off West Greenland. Canadian Journal of Fisheries and Aquatic Sciences 50: 2323-2335. doi:10.1139/f93-257

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. doi:10.1007/s00300-001-0347-6

Heide-Jorgensen MP, Richard P, Dietz R, Laidre KL, Orr J, Schmidt HC (2003). An estimate of the fraction of belugas (*Delphinapterus leucas*) in the Canadian high Arctic that winter in West Greenland. Polar Biology 26: 318-326. doi:10.1007/s00300-003-0488-x

Heide-Jørgensen MP, Laidre KL, Jensen MV, Dueck L, Postma LD (2006). Dissolving stock discreteness with satellite tracking: Bowhead whales in Baffin Bay. Marine Mammal Science 22: 34-45.

Heide-Jørgensen MP, Garde E, Nielsen NH, Andersen ON (2010a). Biological data from the hunt of bowhead whales in West Greenland 2009 and 2010. Report of the International Whaling Commission No SC/62/BRG27. Cambridge.

Heide-Jørgensen MP, Laidre KL, Borchers D, Marques TA, Stern H, Simon M (2010b). The effect of sea-ice loss on beluga whales (*Delphinapterus leucas*) in West Greenland. Polar Research 29: 198-208. doi:10.1111/j.1751-8369.2009.00142.x

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. doi:10.1644/09-mamm-a-198.1

Heide-Jørgensen MP, Laidre KL, Simon M, Burt ML, Borchers DL, Rasmussen M (2010d). Abundance of fin whales in West Greenland in 2007. Journal of Cetacean Research and Management 11: 83-88.

Heide-Jørgensen MP, Witting L, Laidre KL, Hansen RG, Rasmussen M (2010e). Fully corrected estimates of common minke whale abundance in West Greenland in 2007. Journal of Cetacean Research and Management 11: 75-82.

Heide-Jorgensen MP, Laidre KL, Wiig O, Postma L, Dueck L, Bachmann L (2010f). Large-scale sexual segregation of bowhead whales. Endangered Species Research 13: 73-78. doi:10.3354/esr00315

Heide-Jørgensen MP, Iversen M, Nielsen NH, Lockyer C, Stern H, Ribergaard MH (2011). Harbour porpoises respond to climate change. Ecol Evol 1: 579-85. doi:10.1002/ece3.51

Heide-Jørgensen MP, Laidre KL, Hansen RG, Burt ML, Simon M, Borchers DL, Hansen J, Harding K, Rasmussen M, Dietz R, Teilmann J (2012). Rate of increase and current abundance of humpback whales in West Greenland. Journal of Cetacean Research and Management 12: 1-14.

Heide-Jørgensen MP, Laidre K, Fossette S, Rasmussen MH, Nielsen NH, Hansen RG (2014). Abundance of walruses in Eastern Baffin Bay and Davis Strait. Nammco Scientific Publications 9: 171. doi:10.7557/3.2606

Heide-Jørgensen MP, Sinding MHS, Nielsen NH, Rosing-Asvid A, Hansen RG (2016). Large numbers of marine mammals winter in the North Water polynya. Polar Biology 39: 1605-1614. doi:10.1007/s00300-015-1885-7

Heide-Jørgensen MP, Hansen RG, Fossette S, Nielsen NH, Borchers DL, Stern H, Witting L (2017). Rebuilding beluga stocks in West Greenland. Animal Conservation 20: 282-293. doi:10.1111/acv.12315

HELCOM (2010). Hazardous substances in the Baltic Sea- An integrated thematic assessment of hazardous substances in the Baltic Sea. Baltic Sea Environment Proceedings No 120B. Helsinki Commission. https://helcom.fi/media/publications/BSEP120B.pdf

Hermabessiere L, Dehaut A, Paul-Pont I, Lacroix C, Jezequel R, Soudant P, Duflos G (2017). Occurrence and effects of plastic additives on marine environments and organisms: A review. Chemosphere 182: 781-793. doi:10.1016/j.chemosphere.2017.05.096

Hirst AG, Rodhouse PG (2000). Impacts of geophysical seismic surveying on fishing success. Reviews in Fish Biology and Fisheries 10: 113-118. doi:10.1023/A:1008987014736

Hjermann D, Melsom A, Dingsør GE, Durant JM, Eikeset AM, Røed LP, Ottersen G, Storvik G, Stenseth NC (2007). Fish and oil in the Lofoten-Barents Sea system: Synoptic review of the effect of oil spills on fish populations. Marine Ecology Progress Series 339: 283-299. doi:10.3354/meps339283

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. doi:10.1007/s00300-008-0483-3

Hjorth M, Nielsen TG (2011). Oil exposure in a warmer Arctic: potential impacts on key zooplankton species. Marine Biology 158: 1339-1347. doi:10.1007/s00227-011-1653-3

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. doi:10.1007/s00244-001-0046-x

Hoffman MD, Garfield N, Bland RW (2010). Frequency synchronization of blue whale calls near Pioneer Seamount. Journal of the Acoustical Society of America 128: 490-494. doi:10.1121/1.3446099

Holth TF, Beylich BA, Skarphédinsdóttir H, 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. doi:10.1021/es803479p

Hooker SK, Baird RW (1999). Deep-diving behaviour of the northern bottlenose whale, *Hyperoodon ampullatus* (Cetacea: Ziphiidae). Proceedings of the Royal Society B: Biological Sciences 266: 671-676. doi:10.1098/rspb.1999.0688

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. doi:10.3354/meps225287

Hop H, Gjøsæter H (2013). Polar cod (*Boreogadus saida*) and capelin (*Mallotus villosus*) as key species in marine food webs of the Arctic and the Barents Sea. Marine Biology Research 9: 878-894. doi:10.1080/17451000.2013.775458

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. doi:10.1007/s003000050456

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 35: 485-503.

Horsted SA (1978). The life cycle of shrimp, *Pandalus borealis* Krøyer, in Greenland waters in relation to potential yield. ICNAF Selected Papers 4: 51-60.

Horsted SA, Smidth E (1956). The deep sea prawn (*Pandalus borealis*) in Greenland waters. Meddelelser fra Danmarks Fiskeri- og Havundersøgelser 1: 1-118.

Hopwood MJ, Carroll D, Dunse T, Hodson A, Holding JM, Iriarte JL, Ribeiro S, Achterberg EP, Cantoni C, Carlson DF, Chierici M, Clarke JS, Cozzi S, Fransson A, Juul-Pedersen T, Winding MS, Meire L (2019). Review Article: How does glacier discharge affect marine biogeochemistry and primary production in the Arctic?, Cryosph. Discuss. 1–51, doi:10.5194/tc-2019-136

Hovgaard H, Wieland K (2008). Fishery and Environmental Aspects Relevant for the Emergence and Decline of Atlantic Cod (*Gadus morhua*) in West Greenland Waters. Pp 98-100 in Kruse GH et al. (eds): Resiliency of Gadid Stocks to Fishing and Climate Change, Vol 24.

Huse G (1998). Sex-specific life history strategies in capelin (*Mallotus villosus*)? Canadian Journal of Fisheries and Aquatic Sciences 55: 631-638. doi:10.1139/f97-275

Hylland K (2006). Polycyclic aromatic hydrocarbon (PAH) ecotoxicology in marine ecosystems. Journal of Toxicology and Environmental Health - Part a 69: 109-123. doi:10.1080/15287390500259327

Hylland K, Tollefsen KE, Ruus A, Jonsson G, Sundt RC, Sanni S, Røe Utvik TI, Johnsen S, Nilssen I, Pinturier L, Balk L, Baršiene 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. doi:10.1016/j.marpolbul.2007.11.004

Iannilli V, Pasquali V, Setini A, Corami F (2019). First evidence of microplastics ingestion in benthic amphipods from Svalbard. Environmental Research 179: doi:10.1016/j.envres.2019.108811

Ibarbalz FM, Henry N, Brandão MC, Martini S, Busseni G, Byrne H, Coelho LP, Endo H, Gasol JM, Gregory AC, Mahé F, Rigonato J, Royo-Llonch M, Salazar G, Sanz-Sáez I, Scalco E, Soviadan D, Zayed AA, Zingone A, Labadie K, Ferland J, Marec C, Kandels S, Kandels S, Picheral M, Dimier C, Poulain J, Pisarev S, Carmichael M, Pesant S, Pesant S, Acinas SG, Acinas SG, Babin M, Babin M, Bork P, Boss E, Boss E, Bowler C, Bowler C, Cochrane G, de Vargas C, de Vargas C, Follows M, Gorsky G, Grimsley N, Guidi L, Hingamp P, Iudicone D, Iudicone D, Jaillon O, Jaillon O, Karp-Boss L, Karp-Boss L, Karsenti E, Not F, Ogata H, Ogata H, Poulton N, Raes J, Sardet C, Speich S, Stemmann L, Stemmann L, Sullivan MB, Sullivan MB, Sunagawa S, Sunagawa S, Wincker P, Wincker P, Pelletier E, Bopp L, Lombard F, Zinger L (2019). Global Trends in Marine Plankton Diversity across Kingdoms of Life. Cell 179: doi:10.1016/j.cell.2019.10.008

ICES (2006). Report of the Working Group on ICES/NAFO Working Group on Harp and Hooded Seals (WGHARP). ICES Working Group Report CM 2006/ACFM. No 32. ICES Headquarters. Copenhagen.

ICES (2014). Report of the ICES/NAFO Working Group on Harp and Hooded Seals (WGHARP). ICES CM 2014/ACOM. No 20. Quebec, Canada.

ICEC (2019a). Cod (G*adus morhua*) in NAFO Subarea 1, inshore (West Greenland cod). ICES Advice on fishing opportunities, catch, and effort Greenland Sea and Icelandic Waters ecoregions Published 13 June 2019. http://www.ices.dk/sites/pub/Publication%20 Reports/Advice/2019/2019/cod.21.1.pdf

ICES (2019b). ICES/NAFO/NAMMCO Working Group on Harp and Hooded Seals (WGHARP). ICES Scientific Reports. No 1. doi:http://doi.org/10.17895/ices.pub.5617

Ikävalko J, Gradinger R (1997). Flagellates and heliozoans in the Greenland Sea ice studied alive using light microscopy. Polar Biology 17: 473-481. doi:10.1007/s003000050145

Incardona JP, Gardner LD, Linbo TL, Brown TL, Esbaugh AJ, Mager EM, Stieglitz JD, French BL, Labenia JS, Laetz CA, Tagal M, Sloan CA, Elizur A, Benetti DD, Grosell M, Block BA, Scholz NL (2014). Deepwater horizon crude oil impacts the developing hearts of large predatory pelagic fish. Proceedings of the National Academy of Sciences of the United States of America 111: 5455-5455. doi:10.1073/pnas.1320950111

Incardona JP, Carls MG, Holland L, Linbo TL, Baldwin DH, Myers MS, Peck KA, Tagal M, Rice SD, Scholz NL (2015). Very low embryonic crude oil exposures cause lasting cardiac defects in salmon and herring. Scientific Reports 5: doi:10.1038/srep13499

Irwin BD (1990). Primary production of ice algae on a seasonally-ice-covered, continental-shelf. Polar Biology 10: 247-254. doi:10.1007/BF00238421

Isaksen I, Bakken V, Wiig Ø (1998). Potential effects on seabirds and marine mammals of petroleum activity in the northern Barents Sea. Norsk Polarinstitutt, Meddelelser. No 154.

Itkin M, König M, Spreen G., Vongraven D. (2014). Arctic sea ice frequency with maximum and minimum extents [Data set]. Norwegian Polar Institute. https://doi.org/10.21334/npolar.2014.a89b2682. https://data.npolar.no/dataset/a89b2682-e1f8-44b5-ab73-e6ba65f3a7a7.

ITOPF (2018). Shoreline Clean-Up and Response. https://www.itopf.org/knowledge-resources/documents-guides/response-techniques/shoreline-clean-up-and-response/

IUCN (2020). IUCN Red List of Threatened Species. Version 2020.1. Accessed 21 March 2020 www.iucnredlist.org

Jacobsen J, Asmund G (2000). TBT in marine sediments and blue mussels (*Mytilus edulis*) from central-west Greenland. Science of the Total Environment 245: 131-136. doi:10.1016/S0048-9697(99)00438-6

Jacobsen RB, Hedeholm RB, Robert D., Wheeland L (2018) Sustainable fisheries. Pp. 163-176 in: Adaptation Actions for a Changing Arctic. Perspectives from the Baffin Bay/Davis Strait Region. Arctic Monitoring and Assessment Programme (AMAP). Oslo, Norway.

Jambeck JR, Geyer R, Wilcox C, Siegler TR, Perryman M, Andrady A, Narayan R, Law KL (2015). Plastic waste inputs from land into the ocean. Science 347: 768-771. doi:10.1126/science.1260352

Jefferson T, Webber MA, Pitman RL (2008). Marine Mammals of the World: A Comprehensive Guide to Their Identification. Elsevier Inc. Isbn:1281984027, 0080557848, 0123838533, 9786611984021, 9780123838537

Jensen AS (1935). The Greenland halibut, *Reinhardtius hippoglossoides* (Walbaum): its development and migrations. No 6. Det Kgl Danske Videnskabernes Selskab. Skr Naturv Math Afd, Copenhagen.

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.

Jensen HM, Pedersen L, Burmeister AD, Hansen BW (1999a). Pelagic primary production during summer along 65 to 72°N off West Greenland. Polar Biology 21: 269-278. doi:10.1007/s003000050362

Jensen T, Palerud R, Olsgard F, Bakke SM (1999b). Spredning og effekter av syntetiske borevæsker i miljøet. (Dispersion and effects of synthetic drilling muds in the environment.). Rapport 99-3507. Norwegian Ministry of Petroleum and Industry.

Jensen LK, Carroll JL, 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. doi:10.1016/j.jembe.2005.12.001

Jensen MH, Nielsen TG, Dahllöf I (2008). Effects of pyrene on grazing and reproduction of *Calanus finmarchicus* and *Calanus glacialis* from Disko Bay, West Greenland. Aquatic Toxicology 87: 99-107. doi:10.1016/j.aquatox.2008.01.005

Jernelöv A (2010). The Threats from Oil Spills: Now, Then, and in the Future. Ambio 39: 353-366.

Jiang Z, Huang Y, Chen Q, Zeng J, Xu X (2012). Acute toxicity of crude oil water accommodated fraction on marine copepods: The relative importance of acclimatization temperature and body size. Marine Environmental Research 81: 12-17. doi:10.1016/j.marenvres.2012.08.003

JNCC (2010). JNCC guidelines for minimising the risk of injury and disturbance to marine mammals from seismic surveys. Joint Nature Conservation Council. Aberdeen.

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. OCS Study MMS 2008-006 Synthesis report. U.S. Dept. of the Interior, Minerals Management Service. Gulf of Mexico OCS Region, New Orleans, LA.

Johansen Ø (2008). Statistical oil drift simulations east of Greenland. SINTEF.

Johansen Ø, Rye H, Melbye AG, Jensen HV, Serigstad B, Knutsen T (2001). Experimental discharges of gas and oil at Helland Hansen, June 2000. SINTEF report No STF66 F00093. DeepSpill JIP.

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. Trondheim.

Johansen P, Pedersen HS, Asmund G, Rigét F (2006). Lead shot from hunting as a source of lead in human blood. Environmental Pollution 142: 93-97. doi:10.1016/j.envpol.2005.09.015

Johnsen AR, Christensen JH, Poulsen KG, Hansen LH, Ellegaard-Jensen L, Fritt-Rasmussen J (2019). A study of microbial crude oil degradation in water and sediment from the Greenland Sea. Scientific Report from DCE No 347. Nationalt Center for Miljø og Energi. Aarhus Universitet.

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. doi:10.1016/j.marpolbul.2009.10.014

Joye S, MacDonald I (2010). Offshore oceanic impacts from the BP oil spill. Nature Geoscience 3: 446. doi:10.1038/ngeo902

Joye SB (2015). Deepwater Horizon, 5 years on. Science 349: 592-593. doi:10.1126/science.aab4133

Juul-Pedersen T, Nielsen TG, 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. doi:10.3354/meps314239

Juul-Pedersen T, Michel C, Gosselin M, Seuthe L (2008). Seasonal changes in the sinking export of particulate material under first-year sea ice on the Mackenzie Shelf (western Canadian Arctic). Marine Ecology Progress Series 353: 13-25. doi:10.3354/meps07165

Juul-Pedersen T, Arendt KE, Mortensen J, Blicher ME, Søgaard DH, Rysgaard S (2015). Seasonal and interannual phytoplankton production in a sub-Arctic tidewater outlet glacier fjord, SW Greenland. Marine Ecology Progress Series 524: 27-38. doi:10.3354/meps11174

Jørgensen LL, Ljubin P, Skjoldal HR, Ingvaldsen RB, Anisimova N, Manushin I (2014). Distribution of benthic megafauna in the Barents Sea: baseline for an ecosystem approach to management. ICES Journal of Marine Science 72: 595-613. doi:10.1093/icesjms/fsu106

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, Hvingel C, Møller PR, Treble MA (2005). Identification and mapping of bottom fish assemblages in Davis Strait and southern Baffin Bay. Canadian Journal of Fisheries and Aquatic Sciences 62: 1833-1852. doi:10.1139/f05-101

Jørgensen LL, Ljubin P, Skjoldal HR, Ingvaldsen RB, Anisimova N, Manushin I (2014). Distribution of benthic megafauna in the Barents Sea: baseline for an ecosystem approach to management. ICES Journal of Marine Science 72: 595-613. doi:10.1093/icesjms/fsu106

Jørgensen L, Archambault P, Blicher M, Denisenko N, Guðmundsson G, Iken K, Roy V, Sørensen J, Anisimova N, Behe C, Bluhm B, Denisenko S, Metcalf V, Olafsdóttir S, Schiøtte T, Tendal O, Ravelo A, Kędra M, Piepenburg D (2017). State of the Arctic Marine Biodiversity Report. Conservation of Arctic Flora and Fauna, Akureyri Iceland. 'Benthos' in CAFF. doi:978-9935-431-63-9

Kampp K, Falk K, Pedersen CE (2000). Breeding density and population of little auks (*Alle alle*) in a Northwest Greenland colony. Polar Biology 23: 517-521. doi:10.1007/s003000000115

Kang HJ, Lee SY, Roh JY, Yim UH, Shim WJ, Kwon JH (2014). Prediction of ecotoxicity of heavy crude oil: Contribution of measured components. Environmental Science and Technology 48: 2962-2970. doi:10.1021/es404342k

Kanhai LDK, Gårdfeldt K, Lyashevska O, Hassellöv M, Thompson RC, O'Connor I (2018). Microplastics in sub-surface waters of the Arctic Central Basin. Marine Pollution Bulletin 130: 8-18. doi:10.1016/j.marpolbul.2018.03.011

Kapel FO (1979). Exploitation of large whales in West Greenland in the twentieth century. Unpublished Report No 29. International Whaling Commision.

Kapel FO (1985). On the occurrence of sei whales (*Balaenoptera borealis*) in West Greenland Waters. Report of the International Whaling Commission. Cambridge.

Kapel FO (1991). Grønlandssælernes fødevalg ved Vestgrønland. Unpublished Report. Grønlands Fiskeriundersøgelser. Copenhagen, Denmark.

Kapel FO (1995). Feeding ecology of harp and hooded seals in the Davis Strait: Baffin Bay region. pp.287-304

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. Greenland Survey, ASIAQ 2001 - 1. Bureau of Minerals and Petroleum (BMP) and Danish Meterological Institute (DMI).

Karnovsky NJ, Kwaśniewski S, W□sławski JM, Walkusz W, Beszczyńska-Möller A (2003). Foraging behavior of little auks in a heterogeneous environment. Marine Ecology Progress Series 253: 289-303. doi:10.3354/meps253289

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. doi:10.3354/meps07295

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. doi:10.1002/aqc.595

Kazanidis G, Vad J, Henry L-A, Neat F, Berx B, Georgoulas K and Roberts JM (2019). Distribution of Deep-Sea Sponge Aggregations in an Area of Multisectoral Activities and Changing Oceanic Conditions. Front. Mar. Sci. 6:163. doi: 10.3389/fmars.2019.00163

Kelly BP, Bengtson JL, Boveng PL, Cameron MF, Dahle SP, Jansen JK, Logerwell EA, Overland JE, Sabine CL, Waring GT, Wilder JM (2010). Status review of the ringed seal (Phoca hispida). U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-212.

Kenchington E, Link H, Roy V, Archambault P, Siferd T, Treble M, Wareham Hayes V (2011). Identification of Mega- and Macrobenthic Ecologically and Biologically Significant Areas (EBSAs) in the Hudson Bay Complex, the Western and Eastern Canadian Arctic. DFO Canadian Science Advisory Secretariat Research Document 071: vi + 52.

Kenchington E, Yashayaev I, Tendal OS, Jørgensbye H (2017). Water mass characteristics and associated fauna of a recently discovered *Lophelia pertusa* (Scleractinia: Anthozoa) reef in Greenlandic waters. Polar Biology 40: 321-337. doi:10.1007/s00300-016-1957-3

Kennedy J, Durif CMF, Florin A-B, Fréchet A, Gauthier J, Hüssy K, Jónsson SÞ, Ólafsson HG, Post SL, Hedeholm RB (2018). A brief history of lumpfishing, assessment, and management across the North Atlantic. Ices Journal of Marine Science 76: 181-191. doi:10.1093/icesjms/fsy146

Khan RA, Payne JF (2005). Influence of a crude oil dispersant, Corexit 9527, and dispersed oil on capelin (Mallotus villosus), Atlantic cod (*Gadus morhua*), longhorn sculpin (*Myoxocephalus octodecemspinosus*), and cunner (*Tautogolabrus adspersus*). Bulletin of Environmental Contamination and Toxicology 75: 50-56. doi:10.1007/s00128-005-0717-9

Kideys AE (2002). Fall and rise of the Black Sea ecosystem. Science 297: 1482-1484.

Kim TH, Yang CS, Oh JH, Ouchi K (2014). Analysis of the contribution of wind drift factor to oil slick movement under strong tidal condition: Hebei Spirit oil spill case. Plos One 9: doi:10.1371/journal.pone.0087393

Kingsley MCS (1998). The Number of ringed seals (*Phoca hispida*) in Baffin Bay and associated waters. Ringed Seals in the North Atlantic, Vol 1. NAMMCO Scientific Publications.

Kinze CC (2002) White-beaked dolphin, *Lagenorhynchus albirostris*, pp.1255-1258. in: Perrin W, Würsig B, Thewissen J (eds) Encyclopaedia of marine mammals. Academic Press, San Diego. doi:10.1016/B978-0-12-373553-9.00285-6

Kjellerup S, Dünweber M, Møller EF, Schiedek D, Oskarsson GJ, Rigét FF, Johansen KL, Mosbech A (2015). Vertical and horizontal distribution of zooplankton and polar cod in southern Baffin Bay (66-71°N) in September 2009. Polar Biology 38: 699-718. doi:10.1007/s00300-014-1633-4

Klima- og Miljødepartementet (2020). Helhetlige forvaltningsplaner for de norske havområderne. Meld. St. 20 (2019-2020). Melding til Stortinget. https://www.regjeringen.no/content assets/5570db2543234b8a9834606c33caa900/no/pdfs/stm201920200020000dddpdfs.pdf

Knol M (2011). The uncertainties of precaution: Zero discharges in the Barents Sea. Marine Policy 35: 399-404. doi:10.1016/j.marpol.2010.10.018

Kocan RM, Hose JE, Brown ED, Baker TT (1996). Pacific herring (*Clupea pallasi*) embryo sensitivity to Prudhoe Bay petroleum hydrocarbons: Laboratory evaluation and in situ exposure at oiled and unoiled sites in Prince William Sound. Canadian Journal of Fisheries and Aquatic Sciences 53: 2366-2375. doi:10.1139/f96-173

Kohlbach D, Graeve M, Lange BA, David C, Schaafsma FL, van Franeker JA, Vortkamp M, Brandt A, Flores H (2018). Dependency of Antarctic zooplankton species on ice algae-produced carbon suggests a sea ice-driven pelagic ecosystem during winter. Global Change Biology 24: 4667-4681. doi:10.1111/gcb.14392

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.

Kovacs KM (2016a). Cystophora cristata. The IUCN Red List of Threatened Species 2016: eT6204A45225150, Accessed 18 December http://dx.doi.org/10.2305/IUCN.UK.2016-1.RLTS.T6204A45225150.en

Kovacs KM (2016b). *Erignathus barbatus*. The IUCN Red List of Threatened Species, Accessed 06 September 2019 http://dx.doi.org/10.2305/IUCN.UK.2016-1.RLTS.T8010A45225428.en

Krause-Jensen D, Marbà N, Olesen B, Sejr MK, Christensen PB, Rodrigues J, Renaud PE, Balsby TJS, Rysgaard S (2012). Seasonal sea ice cover as principal driver of spatial and temporal variation in depth extension and annual production of kelp in Greenland. Global Change Biology 18: 2981-2994. doi:10.1111/j.1365-2486.2012.02765.x

Krause-Jensen D, Sejr MK, Bruhn A, Rasmussen MB, Christensen PB, Hansen JLS, Duarte CM, Bruntse G, Wegeberg S (2019). Deep penetration of kelps offshore along the west coast of Greenland. Frontiers in Marine Science 6: 375. doi:10.3389/fmars.2019.00375

Krause-Jensen D, Archambault P, Assis J, Bartsch I, Bischoff K, Filbee-Dexter K, Maximova O, Ragnarsdóttir SB, Sejr MK, Simakova U, Spiridonov V, Wegeberg S, Duarte CM (in prep.). Imprint of climate change on Arctic marine vegetation.

Krawczyk DW, Arendt KE, Juul-Pedersen T, Sejr MK, Blicher ME, Jakobsen HH (2015). Spatial and temporal distribution of planktonic protists in the East Greenland fjord and offshore waters. Marine Ecology Progress Series 538: 99-116. doi:10.3354/meps11439

Krawczyk DW, Zinglersen K, Al-Hamdani Z, Yesson C, Blicher ME, Arboe NH, Wagnholt J, Jensen JB, Hansen F, Edelvang K, Simon M (2019). MapHab - Mapping Benthic Habitats in Greenland. Best practice protocol. Technical report. No 108. Greenland Institute of Natural Resources. doi:87-91214-86-6

Kristensen M, Johnsen AR, Christensen JH (2015). Marine biodegradation of crude oil in temperate and Arctic water samples. Journal of Hazardous Materials 300: 75-83. doi:10.1016/j.jhazmat.2015.06.046

Krüger T, Rigét F, Skov H, Christensen JH, Bonefeld-Jørgensen, EC (2012). SAM-TREND Comparison of trends of persistent organic pollutants in Inuit, ringed seals and atmosphere in Greenland. Project report from Center for Arctic Health (CAH) Department of Public Health, Faculty of Health Aarhus University

Kvenvolden KA, Cooper CK (2003). Natural seepage of crude oil into the marine environment. Geo-marine Letters 23: 140-146. doi:10.1007/s00367-003-0135-0

Kyhn LA, Tougaard J, Sveegaard S (2011). Underwater noise from the drillship Stena Forth in Disko West, Baffin Bay, Greenland. NERI Technical Report No 838. National Environmental Research Institute.

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.

Kyhn LA, Wisniewska DM, Beedholm K, Tougaard J, Simon M, Mosbech A, Madsen PT (2019). Basin-wide contributions to the underwater soundscape by multiple seismic surveys with implications for marine mammals in Baffin Bay, Greenland. Marine Pollution Bulletin 138: 474-490. doi:10.1016/j.marpolbul.2018.11.038

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.

Labansen AL, Merkel F, Boertmann D, Nyeland J (2010). Status of the black-legged kittiwake (*Rissa tridactyla*) breeding population in Greenland, 2008. Polar Research 29: 391-403. doi:10.1111/j.1751-8369.2010.00169.x

Laidre KL, Heide-Jørgensen MP (2005). Winter feeding intensity of narwhals (*Monodon monoceros*). Marine Mammal Science 21: 45-57. doi:10.1111/j.1748-7692.2005.tb01207.x

Laidre KL, Heide-Jørgensen MP (2012). Spring partitioning of Disko Bay, West Greenland, by Arctic and Subarctic baleen whales. ICES Journal of Marine Science; doi:10.1093/icesjms/fss095

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. doi:10.3354/meps261269

Laidre KL, Heide-Jørgensen MP, Logdson ML, Hobbs RC, Heagerty P, Dietz R, Jørgensen OA, Treble MA (2004). Seasonal narwhal habitat associations in the high Arctic. Marine Biology 145: 821-831. doi:10.1007/s00227-004-1371-1

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. doi:10.3354/meps06995

Laidre KL, Heide-Jørgensen MP, Nyeland J, Mosbech A, Boertmann D (2008). Latitudinal gradients in sea ice and primary production determine Arctic seabird colony size in Greenland. Proceedings of the Royal Society B: Biological Sciences 275: 2695-2702. doi:10.1098/rspb.2008.0874

Laidre KL, Heagerty PJ, Heide-Jørgensen 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. doi:10.1093/icesjms/fsp191

Laidre KL, Heide-Jørgensen MP, Heagerty P, Cossio A, Bergström B, Simon M (2010). Spatial associations between large baleen whales and their prey in West Greenland. Marine Ecology Progress Series 402: 269-284. doi:10.3354/meps08423

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. doi:10.3354/meps08941

Laidre KL, Stern H, Kovacs KM, Lowry L, Moore SE, Regehr EV, Ferguson SH, Wiig Ø, Boveng P, Angliss RP, Born EW, Litovka D, Quakenbush L, Lydersen C, Vongraven D, Ugarte F (2015). Arctic marine mammal population status, sea ice habitat loss, and conservation recommendations for the 21st century. Conservation Biology 29: 724-737. doi:10.1111/cobi.12474

Laidre KL, Born EW, Atkinson SN, Wiig O, Andersen LW, Lunn NJ, Dyck M, Regehr EV, McGovern R, Heagerty P (2018a). Range contraction and increasing isolation of a polar bear subpopulation in an era of sea-ice loss. Ecol Evol 8: 2062-2075. doi:10.1002/ece3.3809

Laidre KL, Stern H, Born EW, Heagerty P, Atkinson S, Wiig O, Lunn NJ, Regehr E, McGovern R, Dyck M (2018b). Changes in winter and spring resource selection by polar bears *Ursus maritimus* in Baffin Bay over two decades of sea-ice loss. Endangered Species Research 36: 1-14. doi:10.3354/esr00886

Laidre KL, Atkinson S, Regehr EV, Stern HL, Born EW, Wiig Ø, Lunn NJ, Dyck M (2020). Interrelated ecological impacts of climate change on an apex predator. Ecological Applications 30: doi:10.1002/eap.2071

Laist DW (1986). Overview of the biological effects of lost and discarded plastic debris in the marine environment. Marine Pollution Bulletin 18: 319-326.

Laist DW (1997) Impacts of marine debris: entanglement of marine life in marine debris including a comprehensive list of species with entanglement and ingestion records, pp.432. in: Coe J.M, Rogers D.B. (eds.) (eds) Marine debris sources, impacts and solutions. Springer Verlag, New York.

Langen PL, Grenier P, Brown R (2018) Perspectives from the Baffin Bay/Davis Strait Region. Pp. 39-76 in: Adaptation Actions for a Changing Arctic. Perspectives from the Baffin Bay/Davis Strait Region. Arctic Monitoring and Assessment Programme (AMAP). Oslo, Norway.

Larsen F, Kapel FO (1981). Collection of Biological Material of Minke Whales in West Greenland, 1979. Report of the International Whaling Commission 31: 279-285.

Larsen ON, Wahlberg M, Christensen-Dalsgaard J (2020). Amphibious hearing in a diving bird, the great cormorant (Phalacrocorax carbo sinensis). Journal of Experimental Biology 223: doi:10.1242/jeb.217265

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. doi:10.1016/j.marpolbul.2011.03.041

Law KL (2017). Plastics in the Marine Environment. Annual Review of Marine Science 9: 205-229. doi:10.1146/annurev-marine-010816-060409

Law RJ, Moffat CF (2011) The Braer Oil Spill, 1993, pp.1119-1126. in: Fingas M (ed) Oil spill science and technology. Elsevier Inc. doi:10.1016/B978-1-85617-943-0.10036-X

Lawson JW (2005). Overviews: Beluga whale and noise. Joint Scientific Meeting Nuuk, Final report. JCNB/NAMMCO.

LeBlanc M., Gauthier S, Garbus, SE, Mosbech A, Fortier L. (2019). The co-distribution of Arctic cod and its seabird predators across the marginal ice zone in Baffin Bay. Elem Sci Anth 7: 1. DOI: https://doi.org/10.1525/elementa.339

Lee K, Neff J (2011). Produced water: Environmental Risk and Advances in Mitigation Technologies. Springer, New York, USA.

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, pp.319-342. in: Armsworthy SL (ed) Offshore oil and gas environmental effects monitoring Approaches and technologies. Batelle Press, Columbus, Ohio.

Lee RF, Hagen W, Kattner G (2006). Lipid storage in marine zooplankton. Marine Ecology Progress Series 307: 273-306. doi:10.3354/meps307273

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.

Lemcke S, Holding J, Møller EF, Thyrring J, Gustavson K, Juul-Pedersen T, Sejr MK (2018). Acute oil exposure reduces physiological process rates in Arctic phyto- and zooplankton. Ecotoxicology 28: 26-36. doi:10.1007/s10646-018-1995-4

Lemming NE (2019). Ecology of harbour porpoises in Greenland - extreme living in the light of other populations? PhD, Aarhus University

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. doi:10.1016/j.scitotenv.2009.10.038

Leu E, Mundy CJ, Assmy P, Campbell K, Gabrielsen TM, Gosselin M, Juul-Pedersen T, Gradinger (2015). Arctic spring awakening – Steering principles behind the phenology of vernal ice algal blooms. Progress in Oceanography 139: 151–170, http://dx.doi.org/10.1016/j.pocean.2015.07.012

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.

Lewis A, Daling PS (2007a). Evaluation of dispersant spray systems and platforms for use on spilled oil in seas with ice present. SINTEF report A 16088. SINTEF Materials and Chemistry, Marine Environmental Technology.

Lewis A, Daling PS (2007b). A review of studies of oil spill dispersant effectiveness in Arctic conditions. SINTEF report A 16086. SINTEF Materials and Chemistry, Marine Environmental Technology.

Lewis M, Pryor R (2013). Toxicities of oils, dispersants and dispersed oils to algae and aquatic plants: Review and database value to resource sustainability. Environmental Pollution 180: 345-367. doi:10.1016/j.envpol.2013.05.001

Lewis K M, van Dijken GL, Arrigo KR (2020). Changes in phytoplankton concentration now drive increased Arctic Ocean primary production. Science, 369(6500): 198-202. doi:10.1126/science.aay8380

LGL (2005). Husky delineation/exploration drilling program for Jeanne d'Arc Basin area environmental assessment. LGL Report SA845. LGL Limited, Canning and Pitt Associates, Inc., PAL Environmental Services. St. John's.

Li Y, Hu C, Quigg A, Gao H (2019). Potential influence of the Deepwater Horizon oil spill on phytoplankton primary productivity in the northern Gulf of Mexico. Environmental Research Letters 14: 094018. doi:10.1088/1748-9326/ab3735

Lin Q, Mendelssohn IA, Graham SA, Hou A, Fleeger JW, Deis DR (2016). Response of salt marshes to oiling from the Deepwater Horizon spill: Implications for plant growth, soil surface-erosion, and shoreline stability. Science of the Total Environment 557-558: 369-377. doi:10.1016/j.scitotenv.2016.03.049

Lindeberg MR, Maselko J, Heintz RA, Fugate CJ, Holland L (2018). Conditions of persistent oil on beaches in Prince William Sound 26 years after the Exxon Valdez spill. Deep-sea Research Part Ii: Topical Studies in Oceanography 147: 9-19. doi:10.1016/j.dsr2.2017.07.011

Lippert H, Iken K, Rachor E, Wiencke C (2001). Macrofauna associated with macroalgae in the Kongsfjord (Spitsbergen). Polar Biology 24: 512-522. doi:10.1007/s003000100250

Litz JA, Baran MA, Bowen-Stevens SR, Carmichael RH, Colegrove KM, Garrison LP, Fire SE, Fougeres EM, Hardy R, Holmes S, Jones W, Mase-Guthrie BE, Odell DK, Rosel PE, Saliki JT, Shannon DK, Shippee SF, Smith SM, Stratton EM, Tumlin MC, Whitehead HR, Worthy GAJ, Rowles TK (2014). Review of historical unusual mortality events (UMEs) in the Gulf of Mexico (1990-2009): Providing context for the multi-year northern Gulf of Mexico cetacean UME declared in 2010. Diseases of Aquatic Organisms 112: 161-175. doi:10.3354/dao02807

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.

Lockyer C, Heide-Jørgensen MP, Jensen J, Walton MJ (2003). Life history and ecology of harbour porpoises (Phocoena phocoena, L.) from West Greenland. NAMMCO Scientific Publications 5: 177-194.

Long M, Bossi R, Bonefeld-Jørgensen EC (2012). Level and temporal trend of perfluoroalkyl acids in Greenlandic Inuit. Int. J. Circumpolar Health, 71 p. 17998. doi: 10.3402/ijch.v71i0.17998

Long M, Knudsen, A-KS, Pedersen HS, Bonefeld-Jørgensen EC (2015). Food intake and serum persistent organic pollutants in the Greenlandic pregnant women: The ACCEPT sub-study. Science of the Total Environment 529:198-212.

Long S, Sparrow-Scinocca B, Blicher M, Hammeken Arboe N, Fuhrmann M, Kemp K, Nygaard R, Zinglersen K, Yesson C (2020). Identification of a soft coral garden candidate vulnerable marine ecosystem (VME) using video imagery, Davis Strait, west Greenland. Frontiers in Marine Science: 460. https://doi.org/10.3389/fmars.2020.00460

Lovell JM, Findlay MM, Moate RM, Yan HY (2005). The hearing abilities of the prawn *Palaemon serratus*. Comparative Biochemistry and Physiology - a Molecular and Integrative Physiology 140: 89-100. doi:10.1016/j.cbpb.2004.11.003

Lowry, L. (2016a). *Odobenus rosmarus*. The IUCN Red List of Threatened Species 2016: e.T15106A45228501.https://dx.doi.org/10.2305/IUCN.UK.2016-1.RLTS.T15106A45228501.en. Downloaded on 15 July 2020

Lowry, L. (2016b). Phoca vitulina. The IUCN Red List of Threatened Species 2016: e.T17013A45229114.https://dx.doi.org/10.2305/IUCN.UK.2016-1.RLTS.T17013A45229114.en. Downloaded on 15 July 2020.

Lowry L, Laidre K, Reeves R (2017). *Monodon monoceros*. The IUCN Red List of Threatened Species, Accessed 06 September 2019 http://dx.doi.org/10.2305/IUCN.UK.2017-3.RLTS.T13704A50367651.en

Lowther AD, Kovacs KM, Griffiths D, Lydersen C (2015). Identification of motivational state in adult male Atlantic walruses inferred from changes in movement and diving behavior. Marine Mammal Science 31: 1291-1313. doi:10.1111/mms.12224

Lubchenco J, McNutt MK, Dreyfus G, Murawski SA, Kennedy DM, Anastas PT, Chu S, Hunter T (2012). Science in support of the Deepwater Horizon response. Proceedings of the National Academy of Sciences of the United States of America 109: 20212-20221.

Lund-Hansen LC, Hawes I, Holtegaard Nielsen M, Dahllöf I, Sorrell BK (2018). Summer meltwater and spring sea ice primary production, light climate and nutrients in an Arctic estuary, Kangerlussuaq, west Greenland. Arctic, Antarctic, and Alpine Research 50: doi:10.1080/15230430.2017.1414468

Lund-Hansen LC, Bendtsen J, Stratmann T, Tonboe R, Olsen SM, Markager S, Sorrell BK (2020). Will low primary production rates in the Amundsen Basin (Arctic Ocean) remain low in a future ice-free setting, and what governs this production? Journal of Marine Systems 205: doi:10.1016/j.jmarsys.2019.103287

Lusher AL, Tirelli V, O'Connor I, Officer R (2015). Microplastics in Arctic polar waters: The first reported values of particles in surface and sub-surface samples. Scientific Reports 5: doi:10.1038/srep14947

Lyngs P (2003). Migration and winter ranges of birds in Greenland; an analysis of ringing recoveries. Dansk Ornitologisk Forenings Tidskrift 97: 92-100.

Lyrholm T, Gyllensten U (1998). Global matrilineal population structure in sperm whales as indicated by mitochondrial DNA sequences. Proceedings of the Royal Society 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. Fisken og Havet. No 2. Havforskningsinstituttet. Bergen.

Madsen SD, Nielsen TG, Hansen BW (2001). Annual population development and production by *Calanus finmarchicus*, *C. glacialis* and *C. hyperboreus* in Disko Bay, western Greenland. Marine Biology 139: 75-93. doi:10.1007/s002270100552

Madsen PT, Møhl B, Nielsen BK, Wahlberg M (2002a). Male sperm whale behaviour during exposures to distant seismic survey pulses. Aquatic Mammals 28: 231-240.

Madsen PT, Wahlberg M, Møhl B (2002b). Male sperm whale (*Physeter macrocephalus*) acoustics in a high-latitude habitat: implications for echolocation and communication. Behavioral Ecology and Sociobiology 53: 31-41. doi:10.1007/s00265-002-0548-1

Madsen PT, Johnson M, Miller PJO, Aguilar Soto N, Lynch J, Tyack P (2006). Quantitative measures of air-gun pulses recorded on sperm whales (*Physeter macrocephalus*) using acoustic tags during controlled exposure experiments. 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. doi:10.1007/s00227-008-1007-y

Malmquist HJ (2004). Poster A2: paper 8 presented. ACIA International Symposium on Climate Change in the Arctic, 9-12 November Reykjavik, Iceland.

Mankoff KD, Colgan, W., Solgaard A et al. (2019). Greenland Ice Sheet solid ice discharge from 1986 through 2017. Earth Syst. Sci. Data, 11, 769-786

Mankoff KD, Solgaard A, Colgan W et al. (2020). Greenland Ice Sheet solid ice discharge from 1986 through March 2020. Earth Syst. Sci. Data, 12, 1367-1383. https://doi.org/10.5194/essd-12-1367-2020

Marbà N, Krause-Jensen D, Olesen B, Christensen PB, Merzouk A, Rodrigues J, Wegeberg S, Wilce RT (2017). Climate change stimulates the growth of the intertidal macroalgae *Ascophyllum nodosum* near the northern distribution limit. Ambio 46: 119-131. doi:10.1007/s13280-016-0873-7

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. doi:10.1017/S0025315400048426

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. doi:10.3354/meps07273

Mayoral EG, Olsen M, Hedeholm R, Post SL, Eg Nielsen E, Bekkevold D (2016). Genetic structure of West Greenland populations of lumpfish *Cyclopterus lumpus*. Journal of Fish Biology 89: 2625-2642. doi:10.1111/jfb.13167

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: 0195. doi:10.1071/AJ99048

McCauley RD, Fewtrell J, Popper AN (2003). High intensity anthropogenic sound damages fish ears. Journal of the Acoustical Society of America 113: 638-642. doi:10.1121/1.1527962

McCauley RD, Day RD, Swadling KM, Fitzgibbon QP, Watson RA, Semmens JM (2017). Widely used marine seismic survey air gun operations negatively impact zooplankton. Nature Ecology and Evolution 1: doi:10.1038/s41559-017-0195

McCay DF (2003). Development and application of damage assessment modeling: Example assessment for the North Cape oil spill. Marine Pollution Bulletin 47: 341-359. doi:10.1016/S0025-326X(03)00208-X

McCay DPF, Gibson M, Cobb JS (2003). Scaling restoration of American lobsters: combined demographic and discounting model for an exploited species. Marine Ecology Progress Series 264: 197-212.

McClain CR, Nunnally C, Benfield MC (2019). Persistent and substantial impacts of the Deepwater Horizon oil spill on deep-sea megafauna. Royal Society Open Science 6: 191164. doi:10.1098/rsos.191164

McDonald MA, Hildebrand JA, Mesnick S (2009). Worldwide decline in tonal frequencies of blue whale songs. Endangered Species Research 9: 13-21. doi:10.3354/esr00217

McNutt MK, Chu S, Lubchenco J, Hunter T, Dreyfus G, Murawski SA, Kennedy DM (2012). Applications of science and engineering to quantify and control the Deepwater Horizon oil spill. Proceedings of the National Academy of Sciences of the United States of America 109: 20222-20228. doi:10.1073/pnas.1214389109

Meier S, Klungsøyr J, Svardal A (2002). Alkylerte fenolers hormonelle innvirkning på torsk. Unpublished Report. Havforskningsinstituttet. Bergen.

Meire L, Søgaard DH, Mortensen J, Meysman FJR, Soetaert K, Arendt KE, Juul-Pedersen T, Blicher ME, Rysgaard S (2015). Glacial meltwater and primary production are drivers of strong CO2 uptake in fjord and coastal waters adjacent to the Greenland Ice Sheet. Biogeosciences 12: 2347-2363. doi:10.5194/bg-12-2347-2015

Meire L, Mortensen J, Meire P, Juul-Pedersen T, Sejr MK, Rysgaard S, Nygaard R, Huybrechts P, Meysman FJR (2017). Marine-terminating glaciers sustain high productivity in Greenland fjords. Global Change Biology 23: 5344-5357. doi:10.1111/gcb.13801

Melbye AG, Brakstad OG, Hokstad JN, Gregersen IK, Hansen BH, Booth AM, Rowland SJ, Tollefsen KE (2009). Chemical and toxicological characterization of an unresolved complex mixture-rich biodegraded crude oil. Environmental Toxicology and Chemistry 28: 1815-1824. doi:10.1897/08-545.1

Melle W, Serigstad B, Ellertsen B (2001). Environmental risk of deep water oil drilling- A preliminary analysis. Rapport nr 1/2001. Senter for marint miljø, Havforskningsinstituttet. Bergen.

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. doi:10.1007/s00442-006-0612-z

Meredith M, Sommerkorn M, Cassotta S, Derksen C, Ekaykin A, Hollowed A, Kofinas G, Mackintosh A, Melbourne-Thomas J, Muelbert MMC, Ottersen G, Pritchard H, Schuur EAG (2019). Polar Regions. Pp.203-321. in: Pörtner H-O, Roberts DC, Masson-Delmotte V, Zhai P, Tignor M, Poloczanska E, Mintenbeck K, Alegría A, Nicolai M, Okem A, Petzold J, Rama B, Weyer NM (eds) IPCC Special Report on the Ocean and Cryosphere in a Changing Climate.

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. Technical Report No 73. Greenland Institute of Natural Resources. Nuuk.

Merkel FR (2010). Evidence of recent population recovery in common eiders breeding in western Greenland. Journal of Wildlife Management 74: 1869-1874. doi:10.2193/2009-189

Merkel FR, Christensen T (2008). Seabird harvest in Greenland. Pp. 41-49 in MerkelFR & Barry T (eds) Seabird harvest in the Arctic. CAFF International Secretariat, Circumpolar Seabird Group (CBird). CAFF Technical Report, Nr. 16.

Merkel FR, Johansen KL (2011). Light-induced bird strikes on vessels in Southwest Greenland. Marine Pollution Bulletin 62: 2330-2336. doi:10.1016/j.marpolbul.2011.08.040

Merkel FR, Tremblay J-E (2018). Living resources. Pp. 133-138 in Adaptation Actions for a Changing Arctic. Perspectives from the Baffin Bay/Davis Strait Region. Arctic Monitoring and Assessment Programme (AMAP). Oslo, Norway.

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. doi:10.1007/s00300-006-0176-8

Merkel F, Labansen AL, Boertmann D, Mosbech A, Egevang C, Falk K, Linnebjerg JF, Frederiksen M, Kampp K (2014). Declining trends in the majority of Greenland's thick-billed murre (*Uria lomvia*) colonies 1981–2011. Polar Biology 37: 1061-1071. doi:10.1007/s00300-014-1500-3

Merkel F, Boertmann D, Falk K, Frederiksen M, Johansen K, Labansen AL, Linnebjerg JF, Mosbech A, Sonne C (2016). Why is the last Thick-billed Murre *Uria lomvia* colony in central West Greenland heading for extinction? Bird Conservation International 26: 177-191. doi:10.1017/s0959270915000040

Merkel FR, Johansen KL, Nielsen RD, Petersen IK, Sterup J, Mosbech A (2019). Wintering seabirds in south-west Greenland, 2017. Polar Research 38: doi:10.33265/polar.v38.3462

Merkel FR, Boertmann D, Mosbech A (2021). Davis Strait – an updated strategic environmental impact assessment of oil and gas activities in the eastern Davis Strait. Scientific Report from DCE – Danish Centre for Environment and Energy No. xxx, xx pp. http://dce2.au.dk/pub/TRxxx.pdf

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. doi:10.3354/ame030057

Middelbo AB, Møller EF, Arendt KE, Thyrring J, Sejr MK (2019). Spatial, seasonal and inter-annual variation in abundance and carbon turnover of small copepods in Young Sound, Northeast Greenland. Polar Biology 42: 179-193. doi:10.1007/s00300-018-2416-0

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 DM, Rysgaard S, Glud RN (2008). Microalgal composition and primary production in Arctic sea ice: A seasonal study from Kobbefjord (Kangerluarsunnguaq), West Greenland. Marine Ecology Progress Series 368: 65-74. doi:10.3354/meps07627

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 (2005a) Monitoring seismic effects on marine mammals – Southeastern Beaufort Sea 2001-2002, pp.511-542. in: (eds) Aea (ed) Offshore oil and gas environmental effects monitoring Approaches and technologies. Batelle Press, Columbus, Ohio.

Miller PJO, Johnson MP, Tyack PL, Madsen PT, Watwood SL (2005b). Controlled seismic airgun exposures: effects on the movement and foraging behavior of sperm whales. Proceedings: Twenty-third Gulf of Mexico information transfer meeting, January 2005 New Orleans, LA.

Miller PJO, Kvadsheim PH, Lam FPA, Tyack PL, Curé C, DeRuiter SL, Kleivane L, Sivle LD, Van Ijsselmuide SP, Visser F, Wensveen PJ, Von Benda-Beckmann AM, Martín López LM, Narazaki T, Hooker SK (2015). First indications that northern bottlenose whales are sensitive to behavioural disturbance from anthropogenic noise. Royal Society Open Science 2: 140484. doi:10.1098/rsos.140484

Minton G, Reeves R, Braulik G (2018). *Globicephala melas*. The IUCN Red List of Threatened Species, Accessed 08 May 2019 http://dx.doi.org/10.2305/IUCN.UK.2018-2.RLTS.T9250A50356171.en

Molnar JL, Gamboa RL, Revenga C, Spalding MD (2008). Assessing the global threat of invasive species to marine biodiversity. Frontiers in Ecology and the Environment 6: 485-492. doi:10.1890/070064

Montagna PA, Baguley JG, Cooksey C, Hartwell I, Hyde LJ, Hyland JL, Kalke RD, Kracker LM, Reuscher M, Rhodes ACE (2013). Deep-Sea Benthic Footprint of the Deepwater Horizon Blowout. Plos One 8: doi:10.1371/journal.pone.0070540

Moore RC, Loseto L, Noel M, Etemadifar A, Brewster JD, MacPhee S, Bendell L, Ross PS (2020). Microplastics in beluga whales (*Delphinapterus leucas*) from the Eastern Beaufort Sea. Marine Pollution Bulletin 150: doi:10.1016/j.marpolbul.2019.110723

Morandin LA, O'Hara PD (2014). Fish oil disrupts seabird feather microstructure and waterproofing. Science of the Total Environment 496: 257-263. doi:10.1016/j.scitotenv.2014.07.025

Morgana S, Ghigliotti L, Estévez-Calvar N, Stifanese R, Wieckzorek A, Doyle T, Christiansen JS, Faimali M, Garaventa F (2018). Microplastics in the Arctic: A case study with subsurface water and fish samples off Northeast Greenland. Environmental Pollution 242: 1078-1086. doi:10.1016/j.envpol.2018.08.001

Morris CJ, Cote D, Martin B, Kehler D (2018). Effects of 2D seismic on the snow crab fishery. Fisheries Research 197: 67-77. doi:10.1016/j.fishres.2017.09.012

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. doi:10.1007/s00227-003-1280-8

Mortensen J, Lennert K, Bendtsen J, Rysgaard S (2011). Heat sources for glacial melt in a subarctic fjord (Godthåbsfjord) in contact with Greenland Ice Sheet. Journal of Geophysical Research 116: C01013. https://doi.org/10.1029/2010JC006528.

Mosbech A (1997). Assessment of seabird vulnerability to oil spill in eastern Davis Strait. Proceedings from the Fifth International Conference on Effects of Oil on Wildlife. University of California.

Mosbech A (2002). Potential environmental impacts of oil spills in Greenland. An assessment of information status and research needs. NERI Technical report No 415. National Environmental Research Institute (NERI). Roskilde, Denmark.

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. doi:10.3402/polar.v18i1.6554

Mosbech A, D. B, Nymand J, Rigét F, M. A (1998). The Marine Environment in Southwest Greenland. Biological resources, resource use and sensitivity to oil spill. NERI Technical Report No 236. National Environmental Research Institute (NERI). Roskilde, Denmark.

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 (2004). Environmental oil spill sensitivity atlas for the West Greenland (68°-72° N) coastal zone. NERI Technical Report No 494. National Environmental Research Institute (NERI). Roskilde, Denmark.

Mosbech A, Danø RS, Merkel F, Sonne C, Gilchrist G, Flagstad A (2006) Use of satellite telemetry to locate key habitats for king eiders *Somateria spectabilis* in West Greenland, pp.769-776. in: Boere GC, Galbraith CA, Stroud DA (eds) Waterbirds around the world A global overview of the conservation, management and research of the world's waterbird flyways. Edinburgh Stationery Office. Link

Mosbech A, Boertmann D, Jespersen M (2007a). Strategic Environmental Impact Assessment of hydrocarbon activities in the disko West area. NERI technical report No 618. Danmarks Miljøundersøgelser. Aarhus Universitet.

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. NERI Technical Report No 629. Danmarks Miljøundersøgelser, Aarhus Universitet.

Mosbech A, Merkel FR, Boertmann D, Falk K, Frederiksen M, Johansen KL, Sonne C (2009). Thick-billed Murre studies in Disko Bay (Ritenbenk), West Greenland. NERI Technical Report No 749. National Environmental Research Institute, Aarhus University.

Mosbech A, Johansen K, Lyngs P (2017) Tracking of Little auks: migration routes and identification of moulting and wintering areas using geolocation data loggers, pp.108. in: Boertmann D, Mosbech A (eds) An updated strategic Environmental Impact Assessment of petroleum activities in the Greenland part of Baffin Bay – Scientific Report from DCE – No 218. Danish Centre for Environment and Energy, Aarhus University.

Mosbech A, Boertmann D, Aastrup P, Kyhn LA, Gustavson K, Nymand J (2019). Mineral Resources Strategy – environmental contribution. Scientific recommendations from DCE and GINR. Memo from DCE. Danish Centre for Environment and Energy and the Greenland Institute of Natural Resources.

Motyka RJ, Truffer M, Fahnestock M, Mortensen J, Rysgaard S, Howat I (2011). Submarine melting of the 1985 Jakobshavn Isbræ floating tongue and the triggering of the current retreat. Journal of Geophysical Research: Earth Surface 116: doi:10.1029/2009jf001632

Mullin KD, McDonald T, Wells RS, Balmer BC, Speakman T, Sinclair C, Zolman ES, Hornsby F, McBride SM, Wilkinson KA, Schwacke LH (2017). Density, abundance, survival, and ranging patterns of common bottlenose dolphins (*Tursiops truncatus*) in Mississippi Sound following the Deepwater Horizon oil spill. Plos One 12: doi:10.1371/journal.pone.0186265

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, 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, Nielsen JG (1998). Havfisk og fiskeri i Nordvesteuropa. Gads forlag, Copenhagen.

Muus B, Salomonsen F, Vibe C (1990). Grønlands Fauna. Gyldendal, Copenhagen.

Møhl B, Wahlberg M, Madsen PT, Heerfordt A, Lund A (2003). The monopulsed nature of sperm whale clicks. The Journal of the Acoustical Society of America 114: 1143-1154.

Møller PR (2001). A new zoarcid, *Lycodes mcallisteri*, from eastern Arctic Canada (Teleostei: Perciformes). Ichthyological Research 48: 111-116. doi:10.1007/s10228-001-8125-6

Møller PR, Jørgensen OA (2000). Distribution and abundance of eelpouts (Pisces, Zoarcidae) off West Greenland. Sarsia 85: 23-48. doi:10.1080/00364827.2000.10414553

Møller EF, Nielsen TG (2019). Borealization of Arctic zooplankton—smaller and less fat zooplankton species in Disko Bay, Western Greenland. Limnology and Oceanography. doi:10.1002/lno.11380

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, Sünksen K, Jørgensen OA (2010). A checklist of the fish fauna of Greenland waters. Zootaxa. 1-84.

Møller EF, Lambert Johansen K, Agersted MD, Rigét F, Clausen DS, Larsen J, Lyngs P, Middelbo A, Mosbech A (2018). Zooplankton phenology may explain the North Water polynya's importance as a breeding area for little auks. Marine Ecology Progress Series 605: 207-223. doi:10.3354/meps12745

Nahrgang J, Camus L, Gonzalez P, Goksøyr A, Christiansen JS, Hop H (2009). PAH biomarker responses in polar cod (*Boreogadus saida*) exposed to benzo(a)pyrene. Aquatic Toxicology 94: 309-319. doi:10.1016/j.aquatox.2009.07.017

Nahrgang, J., Storhaug E, Murzina SA, Delmas O, Nemova NN, Berge J (2016). Aspects of reproductive biology of wild-caught polar cod (*Boreogadus saida*) from Svalbard waters. Polar Biology 39: 1155-1164. doi:10.1007/s00300-015-1837-2

Nakken O (1992). 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 (2018). Report of the NAMMCO Scientific Working Group on Walrus, October 2018. NAMMCO Scientific Publicatons. North Atlantic Marine Mammal Commission.

NAMMCO (2019). Report of the Scientific Committee 26th Meeting. October 29 – November 1. órshavn Faroe Islands.

NAMMCO/JCNB (2015). Report of the Joint Meeting of the NAMMCO scientific working group on the population status of narwhal and beluga in the North Atlantic and the Canada. Greenland Joint Commission on Conservation and Management of Narwhal and Beluga Scientific Group. Annex 2 in: Report of the 22nd Meeting of the NAMMCO Scientific Committee. pp. 94–16. http://nammco.no/assets/Publications/Scientific-Committee-Reports/SC-22-Final-Report.pdf.

National Research Council (2003). Cumulative Environmental Effects of Oil and Gas Activities on Alaska's North Slope. The National Academes Press. Washington, D.C.

Nazareth J, Steensboe J (1998). Physical environment of eastern Davis Strait and northeastern Labrador Sea. DMI Technical Report No 97. Mineral Resources Administration for Greenland (MRA) and Danish Meteorological Institute.

Neff JM (1987) Biological effects of drilling fluids, drill cuttings and produced water, pp.469-538. in: Boesch DF, Rabalais NN (eds) Long-term Environmental Effects of Offshore Oil and Gas Development. Elsevier Applied Science, London and New York.

Neff JM (2002). Bioaccumulation in Marine Organisms: Effect of Contaminants from Oil Well Produced Water. Elsevier. Isbn:0080437168, 1281053945, 0080527841, 9786611053949

NERI (2010). Notat med en vurdering af ansøgninger til Baffin Bay udbudsrunden 2010. Memo of 27 Oct. 2010. National Environmental Research Institute.

Nielsen J (1961). Contributions to the biology of the salmonidae in Greenland I-IV. Meddelelser om Grønland 159: 1-77.

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 JW, Kliem N, Jespersen M, Christiansen BM (2006). Oil drift and fate modelling at Disko Bay. DMI Technical Report 06-06. Danish Meteorological Institute. Denmark.

Nielsen JW, Murawski J, Kliem N (2008). Oil drift and fate modelling off NE and NW Greenland. DMI Technical report 08-12. Danish Meteorological Institute.

Nielsen NH, Laidre K, Larsen RS, Heide-Jorgensen MP (2015). Identification of Potential Foraging Areas for Bowhead Whales in Baffin Bay and Adjacent Waters. Arctic 68: 169-179.

Nielsen NH, Teilmann J, Sveegaard S, Hansen RG, Sinding MHS, Dietz R, Heide-Jørgensen MP (2018). Oceanic movements, site fidelity and deep diving in harbour porpoises from Greenland show limited similarities to animals from the North Sea. Marine Ecology Progress Series 597: 259-272. doi:10.3354/meps12588

Nielsen OK, Plejdrup MS, Winther M, Nielsen M, Gyldenkærne S, Mikkelsen MH, Albrektsen R, Thomsen M, Hjelgaard K, Fauser P, Bruun HG, Johannsen VK, Nord-Larsen T, Vesterdal L, Callesen I, Caspersen OH, Scott-Bentsen N, Rasmussen E, Petersen SB, Olsen TM, Hansen MG (2019). Denmark's National Inventory Report 2019. Emission Inventories 1990-2017 - Submitted under the United Nations Framework Convention on Climate Change and the Kyoto Protocol. DCE Scientific Report No 318. Danish Centre for Environment and Energy. Aarhus University.

NIRB (2019a). Nunavut Impact Review Board Final Report for the Strategic Environmental Assessment in Baffin Bay and Davis Strait NIRB File No. 17SN034. Vol. 1. https://www.nirb.ca/publications/Strategic%20Environmental%20Assessment/first%20row-first%20file%20-190731-17SN034-Final%20SEA%20Report-Volume%201-OPAE.pdf

NIRB (2019b). Nunavut Impact Review Board Final Report for the Strategic Environmental Assessment in Baffin Bay and Davis Strait NIRB File No. 17SN034. Vol. 3. https://www.nirb.ca/publications/Strategic%20Environmental%20Assessment/first%20row-third%20file-190731-17SN034-Final%20SEA%20Report-Volume%203-OPAE.pdf

Nixon Z, Michel J (2018). A Review of distribution and quantity of lingering subsurface oil from the Exxon Valdez Oil Spill. Deep-sea Research Part Ii: Topical Studies in Oceanography 147: 20-26. doi:10.1016/j.dsr2.2017.07.009

NMFS (2002). Biological opinion. Endangered Species Act-Section 7. Consultation and Operation of the Liberty Oil Production Island. Consultation No F/AKR/2001/00889. National Marine Fisheries Service. Anchorage.

NMFS (2003). Taking marine mammals incidental to conducting oil and gas exploration activities in the Gulf of Mexico. Fedl Register. No 68. National Marine Fisheries Service.

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.

NORCOR (1975). The interaction of crude oil with Arctic sea ice. Technical report No 27. Canada Department of the Environment. Victoria, British Colombia.

Norsk olje & gass (2014). Facts and development trends. Environmental report. Norwegian Oil and Gas Assosiation.

Norsk olje & gass (2018). Environmental work by the oil and gas industry facts and development trends. Environmental report 2018. Norwegian Oil and Gas Assosiation.

Nowacek DP, Thorne LH, Johnston DW, Tyack PL (2007). Responses of cetaceans to anthropogenic noise. Mammal Review 37: 81-115. doi:10.1111/j.1365-2907.2007.00104.x

NOAA (2010). A draft supplemental environmental impact statement for the Exxon Valdez oil spill restoration plan. US National Oceanic and Atmosphaeric Administration.

NOAA (2011). Deepwater Horizon/BP Oil Spill Information. Accessed May 15 http://sero.nmfs.noaa.gov/deepwater_horizon_oil_spill.htm

Norsk Polarinstitutt (2020). Høringsuttalelse om 25. konsesjonsrunde. https://www.regjeringen.no/contentassets/edfa73397d034b71b945ddda9d1dff47/norsk-polarinstitutt.pdf?uid=Norsk_Polarinstitutt

Nørregaard RD, Gustavson K, Møller EF, Strand J, Tairova Z, Mosbech A (2015). Ecotoxicological investigation of the effect of accumulation of PAH and possible impact of dispersant in resting high arctic copepod Calanus hyperboreus. Aquatic Toxicology 167: 1-11. doi:10.1016/j.aquatox.2015.07.006

Obbard RW (2018). Microplastics in Polar Regions: The role of long range transport. Current Opinion in Environmental Science and Health 1: 24-29. doi:10.1016/j.coesh.2017.10.004

Obbard RW, Sadri S, Wong YQ, Khitun AA, Baker I, Thompson RC (2014). Global warming releases microplastic legacy frozen in Arctic Sea ice. Earths Future 2: 315-320. doi:10.1002/2014ef000240

OED (2006). Sameksistens mellom fiskerinæringen og oljevirksomheten i området Lofoten. Barentshavet innenfor rammen af en bærekraftig utvikling. Olje- og enenergidepartementet. Oslo.

Olaguer, E. 2017. Atmospheric Impacts of the Oil and Gas Industry. Elsevier.

Olsen GH, Sva E, Carroll JL, 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. doi:10.1016/j.aquatox.2007.03.012

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. doi:10.1016/j.marenvres.2008.02.063

Olsen GH, Smit MGD, Carroll JL, Jæger I, Smith T, Camus L (2011). Arctic versus temperate comparison of risk assessment metrics for 2-methyl-naphthalene. Marine Environmental Research 72: 179-187. doi:10.1016/j.marenvres.2011.08.003

Olsgard F, Gray JS (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. DMU.

Oren K, Kovacs KM, Yoccoz NG, Lydersen C (2018). Assessing site-use and sources of disturbance at walrus haul-outs using monitoring cameras. Polar Biology 41: 1737-1750. doi:10.1007/s00300-018-2313-6

OSPAR (2009). Overview of the impacts of anthropogenic underwater sound in the marine environment. Biodiversity Series. https://tethys.pnnl.gov/sites/default/files/publications/Anthropogenic_Underwater_Sound_in_the_Marine_Environment.pdf

Overrein Ø (2002). Virkninger av motorferdsel på fauna og vegetasjon. Rapportserie nr 119. Norsk Polarinstitutt, Tromsø.

Oziel L, Massicotte P, Randelhoff A, Ferland J, Vladoiu A, Lacour L, Galindo V, Lambert-Girard S, Dumont D, Cuypers Y, Bouruet-Aubertot P, Mundy CJ, Ehn J, Becu G, Marec C, Forget MH, Garcia N, Coupel P, Raimbault P, Houssais MN, Babin M (2019). Environmental factors influencing the seasonal dynamics of spring algal blooms in and beneath sea ice in western Baffin Bay. Elementa-science of the Anthropocene 7: doi:10.1525/elementa.372

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.

Page D, Boehm P, Brown J, Gundlach E, Neff J (2013) Oil in the environment, pp.116-143. in: Wiens J (ed) Legacies and lessons of the Exxon Valdez oil spill. Cambridge University Press.

Palsbøll PJ, 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. doi:10.1111/j.1365-294x.1997.tb00146.x

PAME (2009). Arctic Council, Arctic offshore oil and gas guidelines. Protection of the Arctic Marine Environment. Arctic Council. Akureyri.

PAME (2019). Desktop Study on Marine Litter including Microplastics in the Arctic (May 2019).

PAME (2020). Status of Offshore Oil and Gas Activities and Regulatory Frameworks in the Arctic. Pree-Meeting Document. Link

Panasenko LD, Sobolova MS (1980). Food interrelations between the Barents Sea capelin and polar cod. ICES Council Meeting 1980:G:23. pp.15

Panti C, Baini M, Lusher A, Hernandez-Milan G, Bravo Rebolledo EL, Unger B, Syberg K, Simmonds MP, Fossi MC (2019). Marine litter: One of the major threats for marine mammals. Outcomes from the European Cetacean Society workshop. pp.72-79

Parga Martínez KB, Tekman MB, Bergmann M (2020). Temporal Trends in Marine Litter at Three Stations of the HAUSGARTEN Observatory in the Arctic Deep Sea. Frontiers in Marine Science 7: doi:10.3389/fmars.2020.00321

Paris CB, Berenshtein I, Trillo ML, Faillettaz R, Olascoaga MJ, Aman ZM, Schlueter M, Joye SB (2018). BP Gulf Science Data Reveals Ineffectual Subsea Dispersant Injection for the Macondo Blowout. Frontiers in Marine Science 5: doi:10.3389/fmars.2018.00389

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. doi:10.1016/j.fishres.2006.03.023

Parsons DG (2005). Predators of northern shrimp, *Pandalus borealis* (Pandalidae), throughout the North Atlantic. Mar. Biol. Res. 1:59-67.

Parsons ECM, Wright AJ, Gore MA (2008). The nature of Humpback Whale (*Megaptera novaeangliae*) song. Journal of Marine Animals and Their Ecology 1: 22-31.

Pascoe S, Innes JP (2018). Economic Impacts of the Development of an Offshore Oil and Gas Industry on Fishing Industries: A Review of Experiences and Assessment Methods. Reviews in Fisheries Science and Aquaculture 26: 350-370. doi:10.1080/23308249.2018.1436521

Pasparakis C, Esbaugh AJ, Burggren W, Grosell M (2019). Impacts of deepwater horizon oil on fish. Comparative Biochemistry and Physiology Part - C: Toxicology and Pharmacology 224: doi:10.1016/j.cbpc.2019.06.002

Passow U, Ziervogel K (2016). Marine snow sedimented oil released during the Deepwater Horizon spill. Oceanography 29: 118-125. doi:10.5670/oceanog.2016.76

Patenaude NJ, Richardson WJ, Smultea MA, Koski WR, Miller GW, WÃ¼Rsig B, Greene CR (2002). Aircraft sound and disturbance to bowhead and beluga whales during spring migration in the Alaskan Beaufort Sea. Marine Mammal Science 18: 309-335. doi:10.1111/j.1748-7692.2002.tb01040.x

Pawłowska J, Włodarska-Kowalczuk M, Zajączkowski M, Nygård H, Berge J (2011). Seasonal variability of meio- and macrobenthic standing stocks and diversity in an Arctic fjord (Adventfjorden, Spitsbergen). Polar Biology. 1-13.

Payne K, Payne RS (1985). Large scale changes over 19 years in songs of humpback whales in Bermuda. Zeitschrift für Tierpsychologie 68: 89-114.

Peacock E, Taylor MK, Laake J, Stirling I (2013). Population ecology of polar bears in Davis Strait, Canada and Greenland. The Journal of Wildlife Management 77: 463-476. doi:10.1002/jwmg.489

Pedersen SA (2005). Nordatlantiske havøkosystemer under forandring, effekter af klima, havstrømme og fiskeri. DFU-rapport 157/05.

Pedersen SA, Kanneworff P (1995). Fish on the West Greenland shrimp grounds, 1988-1992. ICES Journal of Marine Science 52: 165-182.

Pedersen PM, Kristiansen A (1992). *Stictyosiphon arcticus* (Fucophyceae, Stictyosiphonaceae) a new species from Greenland, North Norway, and Baffin Island. Nordic Journal of Botany 12: 461-464. doi:10.1111/j.1756-1051.1992.tb01328.x

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, Stenberg C (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. doi:10.2960/j.v30.a2

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. doi:10.1016/j.jmarsys.2004.11.004

Pedersen LT, Tonboe RT, Jensen MB, Dybkjær G, Nissen M, Rasmussen J, Ø. OB, Skourup H, Saldo R, Forsberg R (2011). Kanumas MET/ICE. OCEAN Overview Report 2011. DMI & DTU-Space.

Peeken I, Primpke S, Beyer B, Gütermann J, Katlein C, Krumpen T, Bergmann M, Hehemann L, Gerdts G (2018). Arctic sea ice is an important temporal sink and means of transport for microplastic. Nature Communications 9: 1505. doi:10.1038/s41467-018-03825-5

Pérez C, Velando A, Munilla I, López-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 42: 707-713.

Perovich D, Meier W, Tschudi M, Farrell S, Gerland S, Hendricks S, (2017). Sea Ice. – Arctic report card: Update for 2015. https://arctic.noaa.gov/Report-Card/Report-Card-2015/ArtMID/5037/ArticleID/217/Sea-Ice

Perovich D, Meier W, Tschudi M, Farrell S, Hendricks S, Gerland S, Kaleschke L, Ricker R, Tian-Kunze X, Webster M, Wood K (2019). Sea Ice. – Arctic report card: Update for 2019. https://arctic.noaa.gov/Report-Card/Report-Card-2019/ArtMID/7916/ArticleID/841/Sea-Ice

Petersen DG, Dahllöf I (2007). Combined effects of pyrene and UV-light on algae and bacteria in an arctic sediment. Ecotoxicology 16: 371-377. doi:10.1007/s10646-007-0139-z

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. doi:10.1021/es071854n

Peterson CH, Rice SD, Short JW, Esler D, Bodkin JL, Ballachey BE, Irons DB (2003). Long-Term Ecosystem Response to the Exxon Valdez Oil Spill. Science 302: 2082-2086. doi:10.1126/science.1084282

Piatt JF, Ford RG (1996). How many seabirds were killed by the Exxon Valdez oil spill? American Fisheries Society. pp.712-719

Piepenburg D (2005). Recent research on Arctic benthos: Common notions need to be revised. Polar Biology 28: 733-755. doi:10.1007/s00300-005-0013-5

Piepenburg D, Ambrose WG, Brandt A, Renaud PE, Ahrens MJ, Jensen P (1997). Benthic community patterns reflect water column processes in the Northeast Water polynya (Greenland). Journal of Marine Systems 10: 467-482.

Pike D, Hansen R, Desportes G (2019). Sighting Surveys in the North Atlantic; 30 years of counting whales. NAMMCO Scientific Publications 11. https://doi.org/10.7557/3.11

Pilegaard K, Rasmussen L (1989). Atmosfærisk tungmetal deposition i Danmark, Island, Grønland og Nordtyskland 1985 moniteret ved analyser af mos. Risø-M-2754, Forskningscenter Risø, Marts 1989.

Polmear R, Stark JS, Roberts D, McMinn A (2015). The effects of oil pollution on Antarctic benthic diatom communities over 5 years. Marine Pollution Bulletin 90: 33-40. doi:10.1016/j.marpolbul.2014.11.035

Pomerleau C, Ferguson SH, Walkusz W (2011). Stomach contents of bowhead whales (*Balaena mysticetus*) from four locations in the Canadian Arctic. Polar Biology 34: 615-620. doi:10.1007/s00300-010-0914-9

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. doi:10.5751/ES-02720-130247

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.

Potter S, Buist I, Trudel K, Dickins D, Owens E (2012). Spill Response in Arctic Offshore. Programme on Oil Spill Recovery in Ice. Prepared for the American Petroleum Institute and the Joint Industry.

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, Potential Environmental impacts of oil spills in Greenland. An assessment of informations status and research needs. NERI Technical Report No 415.

Provencher JF, Bond AL, Hedd A, Montevecchi WA, Muzaffar SB, Courchesne SJ, Gilchrist HG, Jamieson SE, Merkel FR, Falk K, Durinck J, Mallory ML (2014). Prevalence of marine debris in marine birds from the North Atlantic. Marine Pollution Bulletin 84: 411-417. doi:10.1016/j.marpolbul.2014.04.044

Provencher JF, Bond AL, Avery-Gomm S, Borrelle SB, Bravo Rebolledo EL, Hammer S, Kühn S, Lavers JL, Mallory ML, Trevail A, Van Franeker JA (2017). Quantifying ingested debris in marine megafauna: A review and recommendations for standardization. Analytical Methods 9: 1454-1469. doi:10.1039/c6ay02419j

Provencher JF, Vermaire JC, Avery-Gomm S, Braune BM, Mallory ML (2018). Garbage in guano? Microplastic debris found in faecal precursors of seabirds known to ingest plastics. Science of the Total Environment 644: 1477-1484. doi:10.1016/j.scitotenv.2018.07.101

Przeslawski R, Huang Z, Anderson J, Carroll AG, Edmunds M, Hurt L, Williams S (2018). Multiple field-based methods to assess the potential impacts of seismic surveys on scallops. Marine Pollution Bulletin 129: 750-761. doi:10.1016/j.marpolbul.2017.10.066

Quillfeldt CHv (2017). Miljøverdier og sårbarhet i iskantsonen, Iskantsonen, rapport fra NP og HI, 30.06.17, p. 256 pp. file:///C:/Users/au223141/Downloads/Kortrapport47.pdf

Quillfeldt CHv, Hegseth EN, Johnsen G, Sakshaug E, Syvertsen EE (2009) Ice algae, pp.285-303. in: Sakshaug E, Johnsen G, Kovacs K (eds) Ecosystem Barents Sea. Tapir Academic Press, Trondheim.

Randelhoff A, Oziel L, Massicotte P, Bécu G, Galí M, Lacour L, Dumont D, Vladoiu A, Marec C, Bruyant F, Houssais MN, Tremblay JÉ, Deslongchamps G, Babin M (2019). The evolution of light and vertical mixing across a phytoplankton ice-edge bloom. Elementa 7: doi:10.1525/elementa.357

Rankin S, Barlow J (2007). Vocalizations of the sei whale *Balaenoptera borealis* off the Hawaiian islands. Bioacoustics 16: 137-145. doi:10.1080/09524622.2007.9753572

Rasmussen MH (1999). Sound production, behaviour and distribution of the White Beaked Dolphin. Master Thesis, Odense University

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 C (1994). Cumulative effects assessment: a tool for sustainable development. Impact Assessment 12: 319-331. doi:10.1080/07349165.1994.9725869

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 R, Pitman RL, Ford JKB (2017). Orcinus orca. The IUCN Red List of Threatened Species, Accessed 06 September 2019 http://dx.doi.org/10.2305/IUCN.UK.2017-3.RLTS.T15421A50368125.en

Reeves RR, Ljungblad DK, Clarke JT (1984). Bowhead Whales and acoustic seismic surveys in the Beaufort Sea. Polar Record 22: 271-280. doi:10.1017/S0032247400005398

Reeves RR, Smeenk C, Kinze CC, Brownell RL, Lien J (1999) White-beaked dolphin - *Lagenorhynchus albirostris* (Gray, 1846), pp.1–30. in: Ridgway SH, Harrison SR (eds) Handbook of marine mammals, Vol 6. Academic Press, London.

Regehr, EV, Wilson RR, Rode, KD, Runge, MC Stern HL (2017). Harvesting wildlife affected by climate change: a modelling and management approach for polar bears. Journal of Applied Ecology 54: 1534-1543.

Reijnders PJH, Brasseur SMJM, Meesters EHWG (2010). Earlier pupping in harbour seals, Phoca vitulina. Biology Letters 6: 854-857. doi:10.1098/rsbl.2010.0468

Rekdal SL, Hansen RG, Borchers D, Bachmann L, Laidre KL, Wiig Ø, Nielsen NH, Fossette S, Tervo O, Heide-Jørgensen MP (2014). Trends in bowhead whales in West Greenland: Aerial surveysvs. genetic capture-recapture analyses. Marine Mammal Science 31: 133-154. doi:10.1111/mms.12150

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.

Renaud PE, Løkken TS, Jørgensen LL, Berge J, Johnson BJ (2015). Macroalgal detritus and food-web subsidies along an Arctic fjord depth-gradient. Frontiers in Marine Science 2: doi:10.3389/fmars.2015.00031

Renaud PE, Daase M, Banas NS, Gabrielsen TM, Søreide JE, Varpe O, Cottier F, Falk-Petersen S, Halsband C, Vogedes D, Heggland K, Berge J, Andersen K (2018). Pelagic food-webs in a changing Arctic: A trait-based perspective suggests a mode of resilience. Ices Journal of Marine Science 75: 1871-1881. doi:10.1093/icesjms/fsy063

Renaud PE, Wallhead P, Kotta J, Włodarska-Kowalczuk M, Bellerby RGJ, Rätsep M, Slagstad D, Kukliński P (2019). Arctic Sensitivity? Suitable Habitat for Benthic Taxa Is Surprisingly Robust to Climate Change. Frontiers in Marine Science 6: 10.3389/fmars.2019.00538. doi:10.3389/fmars.2019.0053

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.

Ribergaard MH, Kliem N, Jespersen M (2006). HYCOM for the North Atlantic Ocean with special emphasis on West Greenland Waters. DMI Technical Report No 06-07. Danish Meteorological Institute (DMI), National Environmental Research Institute (NERI). Copenhagen, Denmark.

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. doi:10.1016/j.csr.2004.05.011

Rice DW (1989) Sperm whale. *Physeter macrocephalus* Linnaeus, pp.177-233. in: Ridgway SH, Harrison SR (eds) Handbook of Marine Mammals, Vol 4. Academic Press, London.

Rice S, Peterson C (2018). Foreword: The evolution from species-specific damage assessment to ecosystem centric studies over the multi-decade period following the Exxon Valdez oil spill. Deep-sea Research Part Ii: Topical Studies in Oceanography 147: 79-86. doi:10.1016/j.dsr2.2018.01.001

Rice SD, Spies RB, Wolfe DA, Wright BA (1996). Proceedings of the Exxon Valdez Oil Spill Symposium. American Fisheries Society.

Richardson WJ, Greene CRJ, Malme CI, Thomson DH (1995). Marine mammals and noise. Academic Press, San Diego 1: 576.

Richardson WJ, Wursig B, Greene CR (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. doi:10.1121/1.393384

Richardson WJ, Hickie JP, Davis RA, Thomson DH (1989a). Effects of offshore petroleum operations on cold water marine mammals: A literature review. Report prepared by LGL Ltd Publication No 4485. American Petroleum Institute (API). Health and Environmental Sciences Department. King City, Ontario, Canada.

Richardson WJ, Würsig B, Greene CR (1989b). Reactions of bowhead whales, *Balaena mysticetus*, to drilling and dredging noise in the Canadian Beaufort Sea. Marine Environmental Research 29: 135-160. doi:10.1016/0141-1136(90)90032-J

Rigét F, Böcher J (1998) The fresh water environment, pp.221-236. in: Born E, Böcher J (eds) The ecology of Greenland. Ilinniusiorfik, Nuuk.

Rigét F, Bossi R, Sonne C, Vorkamp K, Dietz R (2013a). Trends of perfluorochemicals in Greenland ringed seals and polar bears: Indications of shifts to decreasing trends. Chemosphere 93: 1607-1614. doi:https://doi.org/10.1016/j.chemosphere.2013.08.015

Rigét F, Vorkamp K, Hobson KA, Muir DCG, Dietz R (2013b). Temporal trends of selected POPs and the potential influence of climate variability in a Greenland ringed seal population. Environmental Sciences: Processes and Impacts 15: 1706-1716. doi:10.1039/c3em00189j

Rigét F, Vorkamp K, Bossi R, Sonne C, Letcher RJ, Dietz R (2015). Twenty years of monitoring of persistent organic pollutants in Greenland biota. A review. Environmental Pollution 217:1-10. DOI 10.1016/j.envpol.2015.11.006.

Rigét F, Bignert A, Braune B, Dam M, Dietz R, Evans M, Green N, Gunnlaugsdóttir H, Hoydal KS, Kucklick J (2019). Temporal trends of persistent organic pollutants in Arctic marine and freshwater biota. Science of the total environment 649: 99-110.

Risch D, Clark CW, Corkeron PJ, Elepfandt A, Kovacs KM, Lydersen C, Stirling I, Van Parijs SM (2007). Vocalizations of male bearded seals, *Erignathus barbatus*: Classification and geographical variation. Animal Behaviour 73: 747-762. doi:10.1016/j.anbehav.2006.06.012

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, Gaseo N, Duhamel G (2007). Marine mammals and demersal longline fishery interactions in crozet and kerguelen exclusive economic zones: An assessment of depredation levels. Commission for the Conservation of Antarctic Marine Living Resources Science 14: 67-82.

Roe HSJ (1969). Food and feeding habits of sperm whales (*Physeter catodon* L) taken off west coast of iceland. ICES Journal of Marine Science 33: 93-102.

Rojano-Donate L, McDonald BI, Wisniewska DM, Johnson M, Teilmann J, Wahlberg M, Hojer-Kristensen J, Madsen PT (2018). High field metabolic rates of wild harbour porpoises. J Exp Biol 221: doi:10.1242/jeb.185827

Rojas-Alva U, Fritt-Rasmussen J, Jomaas G (2020). Experimental study of thickening effectiveness of two herders for in-situ burning of crude oils on water. Cold Regions Science and Technology 175: doi:10.1016/j.coldregions.2020.103083

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 (2010) Catch history and status of the harbour seal (*Phoca vitulina*) in Greenland, pp.159-172. in: Desportes G, Bjørge A, Rosing-Asvid A, Waring G (eds) Harbour seals in the North Atlantic and the Baltic. NAMMCO Scientific Publications 8.

Rosing-Asvid A (2011). Status of harbor seals and grey seals in Greenland. NAMMCO Working Group Paper on Coastal Seals. NAMMCO.

Ross SL (1992). Evaluation of the behaviour and cleanup of offshore oil-well blowout spills in west Greenland. Environmental Research Limited, Ottawa. 87.

Ross WG (1993) Commercial whaling in the North Atlantic sector, pp.511-561. 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.

Rozas LP, Minello TJ, Miles MS (2014). Effect of Deepwater Horizon Oil on Growth Rates of Juvenile Penaeid Shrimps. Estuaries and Coasts 37: 1403-1414. doi:10.1007/s12237-013-9766-1

Ryals BM, Rubel EW (1988). Hair cell regeneration after acoustic trauma in adult coturnix quail. Science 240: 1774-1776. doi:10.1126/science.3381101

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. Unpublished Report. Sintef.

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, Kühl M, Glud RN, Hansen JW (2001). Biomass, production and horizontal patchiness of sea ice algae in a high-Arctic fjord (Young Sound, NE Greenland). Marine Ecology Progress Series 223: 15-26. doi:10.3354/meps223015

Rysgaard S, Boone W, Carlson D, Sejr MK, Bendtsen J, Juul‐Pedersen T, Lund H, Meire L, Mortensen J (2020). An Updated View on Water Masses on the pan‐West Greenland Continental Shelf and Their Link to Proglacial Fjords. Journal of Geophysical Research: Oceans 125: doi:10.1029/2019jc015564

Rätz HJ (1999). Structures and changes of the demersal fish assemblage off Greenland, 1982-96. Nafo Scientific Council Studies 0: 1-15.

Røe Utvik T, Johnsen S (1999). Bioavailability of polycyclic aromatic hydrocarbons in the North Sea. Environmental Science and Technology 33: 1963-1969. doi:10.1021/es9804215

Saint-Beat B, Fath BD, Aubry C, Colombet J, Dinasquet J, Fortier L, Galindo V, Grondin P-L, Joux F, Lalande C, LeBlanc M, Raimbault P, Sime-Ngando T, Tremblay J-E, Vaulot D, Maps F, Babin M (2020). Contrasting pelagic ecosystem functioning in eastern and western Baffin Bay revealed by trophic network modeling. Elementa-science of the Anthropocene 8: doi:10.1525/elementa.397

Sainte-Marie B, Sévigny 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. doi:10.1139/f96-287

Salaberria I, Brakstad OG, Olsen AJ, Nordtug T, Hansen BH (2014). Endocrine and AhR-CYP1A pathway responses to the water-soluble fraction of oil in zebrafish (Danio rerio Hamilton). pp.506-515

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: 281-294. doi:10.3354/meps183281

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

Scheibye K, Christensen JH, Johnsen AR (2017). Biodegradation of crude oil in Arctic subsurface water from the Disko Bay (Greenland) is limited. Environmental Pollution 223: 73-80. doi:10.1016/j.envpol.2016.12.032

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. doi:10.1121/1.1835508

Schick RS, Urban DL (2000). Spatial components of bowhead whale (*Balaena mysticetus*) distribution in the Alaskan Beaufort Sea. Canadian Journal of Fisheries and Aquatic Sciences 57: 2193-2200. doi:10.1139/f00-196

Schlining K, von Thun S, Kuhnz L, Schlining B, Lundsten L, Jacobsen Stout N, Chaney L, Connor J (2013). Debris in the deep: Using a 22-year video annotation database to survey marine litter in Monterey Canyon, central California, USA. Deep-sea Research Part I: Oceanographic Research Papers 79: 96-105. doi:10.1016/j.dsr.2013.05.006

Schmid M, Piepenburg D (1993). The benthos zonation of the Disko Fjord, West Greenland. Meddelelser om Grønland 37: 1-21.

Schmidt-Etkin D (2011) Spill occurrences: A world overview, pp.7-47. in: Fingas M (ed) Oil spill science and technology. Elsevier.

Schreiber EA, Burger J (2002). Biology of marine Birds. CRC Press.

Schwacke LH, Smith CR, Townsend FI, Wells RS, Hart LB, Balmer BC, Collier TK, De Guise S, Fry MM, Guillette LJ, Lamb SV, Lane SM, McFee WE, Place NJ, Tumlin MC, Ylitalo GM, Zolman ES, Rowles TK (2014). Health of common bottlenose dolphins (*Tursiops truncatus*) in Barataria Bay, Louisiana, following the Deepwater Horizon oil spill. Environmental Science and Technology 48: 93-103. doi:10.1021/es403610f

Sejr M, Sand M, Jensen K, Petersen J, Christensen P, Rysgaard S (2002). Growth and production of *Hiatella arctica* (Bivalvia) in a High-Arctic fjord (Young Sound, Northeast Greenland). Marine Ecology Progress Series 244: 163-169.

Sejr MK, Jensen KT, Rysgaard S (2000). Macrozoobenthic community structure in a high-arctic East Greenland fjord. Polar Biology 23: 792-801.

Sejr MK, Nielsen TG, Rysgaard S, Risgaard-Petersen N, Sturluson M, Blicher ME (2007). Fate of pelagic organic carbon and importance of pelagic-benthic coupling in a shallow cove in Disko Bay, West Greenland. Marine Ecology Progress Series 341: 75-88. doi:10.3354/meps341075

Sejr M, Włodarska-Kowalczuk M, Legeżyńska J, Blicher M (2010a). Macrobenthic species composition and diversity in the Godthaabsfjord system, SW Greenland. Polar Biology 33: 421-431.

Sejr MK, Batty P, A.B. J, Blicher ME, Hansen J, Rysgaard S (2010b). Survey of macrobenthic invertebrates in the eastern Baffin Bay including estimates of biogeochemical activity and PAH levels of the sediment. National Environmental Research Institute (NERI). Silkeborg, Denmark.

Sergy GA, Blackall PJ (1987). Design and Conclusions of the Baffin Island Oil Spill Project. Arctic 40: 1-9. doi:10.14430/arctic1797

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. doi:10.1016/j.marpolbul.2005.09.030

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.

Shigenaka G (2014). Twenty-Five Years after the Exxon Valdez Oil Spill. NOAA's Scientific Support, Monitoring, and Research. NOAA Office of Response and Restoration. Seattle.

Short JW (2017). Advances in Understanding the Fate and Effects of Oil from Accidental Spills in the United States Beginning with the Exxon Valdez. Archives of Environmental Contamination and Toxicology 73: 5-11. doi:10.1007/s00244-016-0359-4

Short JW, Rice SD, Heintz RA, Carls MG, Moles A (2003). Long-term effects of crude oil on developing fish: Lessons from the Exxon Valdez oil spill. Energy Sources 25: 509-517. doi:10.1080/00908310390195589

Shumway SE, OPerkins HC, Schick DF, Stickney AP (1985). Synopsis of biological data of the pink shrimp Pandalus borealis (Krøyer, 1838). Technical Report of the National Marine Fisheries Service No 30. NOAA.

Siegstad H, Neve PB, Heide-Jørgensen MP, Härkönen T (1998) Diet of the Ringed Seal (Phoca hispida) in Greenland, pp.229-241, in: Heide-Jørgensen MP, Lydersen C (eds) Ringed Seals in the North Atlantic, Vol 1. NAMMCO scientific publications.

Simon M (2009). The sounds of whales and their food: Baleen whales, their foraging behaviour, ecology and habitat use in an arctic habitat. Ph.D. Thesis Ph.D., 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. doi:10.1080/0036420310001688

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, McGregor PK, Ugarte F (2007b). The relationship between the acoustic behaviour and surface activity of killer whales (*Orcinus orca*) that feed on herring (*Clupea harengus*). Acta Ethologica 10: 47-53. doi:10.1007/s10211-007-0029-7

Simon M, Wahlberg M, Miller LA (2007c). Echolocation clicks from killer whales (*Orcinus orca*) feeding on herring (*Clupea harengus*) (L). Journal of the Acoustical Society of America 121: 749-752. doi:10.1121/1.2404922

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. doi:10.1121/1.3495946

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. doi:10.1007/ s00227-005-0172-5

Singer MM, Aurand D, Bragin GE, Clark JR, Coelho GM, Sowby ML, Tjeerdema RS (2000). Standardization of the preparation and quantitation of water-accommodated fractions of petroleum for toxicity testing. Marine Pollution Bulletin 40: 1007-1016. doi:10.1016/s0025-326x(00)00045-x

Širović A, Hildebrand JA, Wiggins SM (2007). Blue and fin whale call source levels and propagation range in the Southern Ocean. Journal of the Acoustical Society of America 122: 1208-1215. doi:10.1121/1.2749452

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. doi:10.1139/z96-103

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.

Skognes K (1999). Exploratory drillings at the Fylla field southwest of Greenland: Far field drift and fate of potential surface and seabed blowouts. SINTEF Report.

Skottene E, Tarrant AM, Olsen AJ, Altin DAG, Hansen BH, Choquet M, Olsen RE, Jenssen BM (2019). A crude awakening: Effects of crude oil on lipid metabolism in calanoid copepods terminating diapause. Biological Bulletin 237: 90-110. doi:10.1086/705234

SL Ross Environmental Research Ltd (2015). Reaserch summary: Herding surfactants to contract and thicken oil spills for in situ burning in arctic waters. Oill Spill Preparedness. Arctic Oil Spill Response Technology Joint Industry Programme (JIP).

Slabbekoorn H, Dalen J, de Haan D, Winter HV, Radford C, Ainslie MA, Heaney KD, van Kooten T, Thomas L, Harwood J (2019). Population-level consequences of seismic surveys on fishes: An interdisciplinary challenge. Fish and Fisheries 20: 653-685. doi:10.1111/faf.12367

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. doi:10.1016/j.fishres.2003.09.046

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, pp.527-598. in: L. AW (ed) Artic Monitoring and Assessment Programme. Elsevier Inc. doi:10.1016/B978-0-08-092595-0.50008-8

Smith WO, Barber DG (2007). Polynyas: Windows to the World. Elsevier Science BV Isbn:04229894

Smultea MA, Wursig B (1995). Behavioral reactions of bottlenose dolphins to the Mega Borg oil spill, Gulf of Mexico 1990. Aquatic Mammals 21: 171-181.

Snyder RA, Ederington-Hagy M, Hileman F, Moss JA, Amick L, Carruth R, Head M, Marks J, Tominack S, Jeffrey WH (2014). Polycyclic aromatic hydrocarbon concentrations across the Florida Panhandle continental shelf and slope after the BP MC 252 well failure. Marine Pollution Bulletin 89: 201-208. doi:10.1016/j.marpolbul.2014.09.057

Sonne C, Gustavson K, Rigét FF, Dietz R, Birkved M, Letcher RJ, Bossi R, Vorkamp K, Born EW, Petersen G (2009). Reproductive performance in East Greenland polar bears (*Ursus maritimus*) may be affected by organohalogen contaminants as shown by physiologically-based pharmacokinetic (PBPK) modelling. Chemosphere 77: 1558-1568. doi:10.1016/j.chemosphere.2009.09.044

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. doi:10.1016/j.chemosphere.2009.06.049

Southall BL, Bowles AE, Ellison WT, Finneran JJ, Gentry RL, Greene CR, Kastak D, Ketten DR, Miller JH, Nachtigall PE, Richardson WJ, Thomas JA, Tyack PL (2007). Marine mammal noise exposure criteria: Initial scientific recommendations. Aquatic Mammals 33: 411-521.

Speer L, Nelson R, Casier R, Gavrilo M, von Quillfeldt C, Cleary J, Halpin P, Hooper, P. (2017). Natural Marine World Heritage in the Arctic Ocean. Report of an expert workshop and review process. Gland, Switzerland: IUCN. 112p Link

Spraker TR, Lowry LF, Frost KJ (1994) Gross necropsy and histopathological lesions found in harbor seals, pp.281-311. in: Loughlin TR (ed) Marine mammals and the 'Exxon Valdez'. Academic Press, Inc, San Diego, CA.

Spreen G, Kaleschke L, Heygster G (2008), Sea ice remote sensing using AMSR-E 89 GHz channels J. Geophys. Res. 113: C02S03, doi:10.1029/2005JC003384.

Sreeram MP, Menon NR (2005). Histopathological changes in the hepatopancreas of the penaeid shrimp *Metapenaeus dobsoni* exposed to petroleum hydrocarbons. Journal of Marine Biological Association of India 47: 160–168.

St. Aubin DJ (1990) Phyisiologic and toxic effects on pinnipeds, pp.103-127. in: Geraci JR, D.J. SA (eds) Sea mammals and oil Confronting the risks. Academic Press.

Stafford KM, Moore SE, Laidre KL, Heide-Jørgensen MP (2008). Bowhead whale springtime song off West Greenland. Journal of the Acoustical Society of America 124: 3315-3323. doi:10.1121/1.2980443

Statoil (2004). Environmental statement for the Statfjord late life. Statoil. Stavanger.

Stein R, Macdonald R (2004). The Organic Carbon Cycle in the Arctic Ocean. Springer-Verlag, Berlin, Heidelberg, New York.

Stenberg C, Ribergaard MH, Boje J, Sundby S (2016). Larval drift and settling of Greenland halibut (*R. hippoglossoides* Walbaum) in Northwest Atlantic with special focus on Greenlandic waters.

Stenson GB, Myers RA, Warren WG, Ni IH (1996). Pup production of hooded seals (Cystophora cristata) in the Northwest Atlantic. NAFO Scientific Council Studies 26: 105-114.

Stevick PT, Allen J, Clapham PJ, Katona SK, Larsen F, Lien J, Mattila DK, Palsboll PJ, Sears R, Sigurjonsson J, Smith TD, Vikingsson G, Oien N, Hammond P (2006). Population spatial structuring on the feeding grounds in North Atlantic humpback whales (*Megaptera novaeangliae*). Journal of Zoology 270: 244-255. doi:10.1111/j.1469-7998.2006.00128.x

Stewart REA, Born EW, Dietz R, Heide-Jørgensen MP, Rigét FF, Laidre K, Jensen MV, Knutsen LØ, Fossette S, Dunn JB (2014). Abundance of Atlantic walrus in Western Nares Strait, Baffin Bay Stock, during summer. Nammco Scientific Publications 9: doi:10.7557/3.2611

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.

Stimpert AK, Wiley DN, Au WWL, Johnson MP, Arsenault R (2007). 'Megapclicks': Acoustic click trains and buzzes produced during night-time foraging of humpback whales (*Megaptera novaeangliae*). Biology Letters 3: 467-470. doi:10.1098/rsbl.2007.0281

Stirling I (1988). Attraction of polar bears *Ursus maritimus* to offshore drilling sites in the eastern Beaufort Sea. Polar Record 24: doi:10.1017/S0032247400022282

Stirling I (1990) Polar bears and oil: ecologic perspectives, pp.223-234. in: Geraci JR, St. Aubin DJ (eds) Sea Mammals and Oil: Confronting the Risks. Academic Press, San Diego, USA.

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.

Stirling I, Thomas J (2003). Relationships between underwater vocalizations and mating systems in phocid seals. Aquatic Mammals 29: 227-246. doi:10.1578/016754203101024176

Stjernholm M, Boertmann D, Mosbech A, Nymand J, Merkel FR, Myrup M, Siegstad H, Clausen DS, Potter S (2011). Environmental Oil Spill Sensitivity Atlas for the Northern West Greenland (72°-75° N) Coastal Zone. NERI Technical Report No 828. National Environmental Research Institute, Aarhus University.

Storm L, Pedersen SA (2003). Development and drift of northern shrimp larvae (*Pandalus borealis*) at West Greenland. Marine Biology 143: 1083-1093.

Stout SA, Payne JR (2016). Chemical composition of floating and sunken in-situ burn residues from the Deepwater Horizon oil spill. Marine Pollution Bulletin 108: 186-202. doi:10.1016/j.marpolbul.2016.04.031

Strand J, Asmund G (2003). Tributyltin accumulation and effects in marine molluscs from West Greenland. Environmental Pollution 123: 31-37. doi:10.1016/S0269-7491(02)00361-5

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.

Strand J, Bach L, Cusa M, Lenz R (2018). Importance of local sources versus long-range transport if marine litter in Arctic Greenland. Poster session at Sixth Marine Debris Conference, San Diego, California, USA, March 12-16,2018.

Straneo F, Saucier F (2008). The outflow from Hudson Strait and its contribution to the Labrador Current. Deep-sea Research Part I: Oceanographic Research Papers 55: 926-946. doi:10.1016/j.dsr.2008.03.012

Stroeve J, Meier WN (2018). Sea Ice Trends and Climatologies from SMMR and SSM/I-SSMIS, Version 3. Boulder, Colorado USA. NASA National Snow and Ice Data Center Distributed Active Archive Center. doi: https://doi.org/10.5067/IJ0T7HFHB9Y6. [Sep 04 2020].

Strøm H, Boertmann D, Gavrilo MV, Gillchrist HG, Gilg O, Mallory M, Mosbech A, Yannic G (2019). Ivory Gull: Status, Trends and New Knowledge. Arctic Report Card: Update for 2019.

Sundet JH (2014). The snow crab (*Chionoecetes opilio*) in the Barents Sea. Workshop on king- and snow crabs in the Barents Sea. Institute of Marine Research. Tromsø.

Sundet JH, Herzke D, Jenssen M (2016). Forekomst og kilder av mikroplastikk i sediment, og konsekvenser for bunnlevende fisk og evertebrater på Svalbard. Sluttrapport No 13. Svalbards Miljøvernfond. Norway.

Sunnanå K (2005) Rognkjeks, pp.128-130. 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.

Sutherland DA, Pickart RS (2008). The East Greenland Coastal Current: Structure, variability, and forcing. Progress in Oceanography 78: 58-77. doi:10.1016/j.pocean.2007.09.006

Swalethorp R, Kjellerup S, Dünweber M, Nielsen TG, Møller EF, Rysgaard S, Hansen BW (2011). Grazing, egg production, and biochemical evidence of differences in the life strategies of *Calanus finmarchicus*, *C. glacialis* and *C. hyperboreus* in Disko Bay, western Greenland. Marine Ecology Progress Series 429: 125-144. doi:10.3354/meps09065

Sweet ST, Kennicutt MC, Klein AG (2015) The gounding of the Bahía Paraíso, Arthur Harbor, Antarctica: Distribution and fate of oil spill releted hydrocarbons, pp.547-556. in: M. F (ed) Handbook of oil spill science and technology. John Wiley and Sons Inc.

SWG (2016). Re-Assessment of the Baffin Bay and Kane Basin Polar Bear Subpopulations. Final Report to the Canada-Greenland Joint Commission on Polar Bear. Environment and Climate Change Canada.

Systad GH, Bustnes JO, Erikstad KE (2000). Behavioral responses to decreasing day length in wintering sea ducks. Auk, 117: 33-40. Doi 10.1642/0004-8038(2000)117[0033:Brtddl]2.0.Co;2

Söderkvist J, Nielsen TG, Jespersen M (2006). Physical and biological oceanography in West Greenland waters with emphasis on shrimp and fish larvae distribution. NERI Technical Report No 581. National Environmental Research Institute (NERI), University of Aarhus. Roskilde, Denmark.

Søgaard DH, Kristensen M, Rysgaard S, Glud RN, Hansen PJ, Hilligsøe KM (2010). Autotrophic and heterotrophic activity in Arctic first-year sea ice: seasonal study from Malene Bight, SW Greenland. Marine Ecology Progress Series 419: 31-45. doi:10.3354/meps08845

Søgaard DH, Thomas DN, Rysgaard S, Glud RN, Norman L, Kaartokallio H, Juul-Pedersen T, Geilfus N-X (2013). The relative contributions of biological and abiotic processes to carbon dynamics in subarctic sea ice. Polar Biology 36: 1761-1777. doi:10.1007/s00300-013-1396-3

Sørensen EF, Simonsen V (1988). Genetic differentiation among populations of capelin Mallotus villosus from the West Coast of Greenland. Journal of Applied Ichthyology 4: 23-28. doi:10.1111/j.1439-0426.1988.tb00544.x

Tairova Z, Frantzen M, Mosbech A, Arukwe A, Gustavson K (2019). Effects of water accommodated fraction of physically and chemically dispersed heavy fuel oil on beach spawning capelin (*Mallotus villosus*). Marine Environmental Research 147: 62-71. doi:10.1016/j.marenvres.2019.03.010

Tasker ML, Stone CJ (2006). The effects of seismic airguns on cetaceans in UK waters. Journal of Cetacean Research and Management 8: 255-263.

Taylor MK, Akeeagok S, Andriashek D, Barbour W, Born EW, Calvert W, Cluff HD, Ferguson S, 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. doi:10.1139/cjz-79-4-690

Taylor MK, Laake J, McLoughlin PD, Born EW, Cluff HD, Ferguson SH, Rosing-Asvid A, Schweinsburg R, Messier F (2005). Demography and viability of a hunted population of polar bears. Arctic 58: 203-214.

Taylor BL, Baird R, Barlow J, Dawson SM, Ford J, Mead JG, Notarbartolo di Sciara G, Wade P, Pitman RL (2008). *Hyperoodon ampullatus*. The IUCN Red List of Threatened Species, https://dx.doi.org/10.2305/IUCN.UK.2008.RLTS.T10707A3208523.en

Taylor BL, Baird R, Barlow J, Dawson SM, Ford J, Mead JG, Notarbartolo di Sciara G, Wade P, Pitman RL (2019). *Physeter macrocephalus*. The IUCN Red List of Threatened Species, https://dx.doi.org/10.2305/IUCN.UK.2008.RLTS.T41755A160983555.en

Tedesco L, Vichi M, Scoccimarro E (2019). Sea-ice algal phenology in a warmer Arctic. Science Advances 5: eaav4830. doi:10.1126/sciadv.aav4830

Teilmann J, Dietz R (1998). Status of the harbour porpoise in Greenland. Polar Biology 19: 211-220.

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. doi:10.1016/j.jembe.2007.10.010

Tendal O, Schiøtte T (2003). Report on Greenland marine benthic animals, diversity and geographic distribution. Internal report to the Danish Environment Agency. No 361.

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. doi:10.1121/1.3158941

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. doi:10.1089/ees.2010.0276

Thompson PM, Brookes KL, Graham IM, Barton TR, Needham K, Bradbury G, Merchant ND (2013). Short-term disturbance by a commercial two-dimensional seismic survey does not lead to long-term displacement of harbour porpoises. Proceedings Biological Sciences / the Royal Society 280: 20132001. doi:10.1098/rspb.2013.2001

Thompson PO, Cummings WC, Ha SJ (1986). Sounds source levels and associated behavior of humpback whales Megaptera-Novaeangliae southeast alaska USA. Journal of the Acoustical Society of America 80: 735-740.

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. doi:10.1121/1.1349537

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, pp.87-112. in: Halberg KA (ed) Arctic Biology Field Course, Qeqartarsuaq 2006. Copenhagen University.

Thyrring J, Juhl BK, Holmstrup M, Blicher ME, Sejr MK (2015a). Does acute lead (Pb) contamination influence membrane fatty acid composition and freeze tolerance in intertidal blue mussels in arctic Greenland? Ecotoxicology 24: 2036-2042. doi:10.1007/s10646-015-1539-0

Thyrring J, Rysgaard S, Blicher M, Sejr M (2015b). Metabolic cold adaptation and aerobic performance of blue mussels (*Mytilus edulis*) along a temperature gradient into the High Arctic region. Marine Biology 162: 35-243. doi:10.1007/s00227-014-2575-7

Thyrring J, Blicher ME, Sørensen JG, Wegeberg S, Sejr MK (2017a). Rising air temperatures will increase intertidal mussel abundance in the Arctic. Marine Ecology Progress Series 584: 91-104.

Thyrring J, Bundgaard A, Sejr MK (2017b). Seasonal acclimation and latitudinal adaptation are of the same magnitude in *Mytilus edulis* and *Mytilus trossulus* mitochondrial respiration. Polar Biology 40: 1885-1891. doi:10.1007/s00300-016-2064-1

Thyrring J, Tremblay R, Sejr M (2019). Local cold adaption increases the thermal window of temperate mussels in the Arctic. Conservation physiology 7: coz098. doi:10.1093/conphys/coz098

Thyrring J, Wegeberg S, Blicher ME, Krause-Jensen D, Høgslund S, Olesen B, Wiktor J, Mouritsen KN, Sejr MK (in prep.). Quantification of latitudinal patterns in intertidal community structure reveal ecosystem dynamics and resilience to climate change in West Greenland.

Todd S, Stevick P, Lien J, Marques F, Ketten D (1996). Behavioural effects of exposure to underwater explosions in humpback whales (*Megaptera novaeangliae*). Canadian Journal of Zoology 74: 1661-1672. doi:10.1139/z96-184

Toxværd K, Pančić M, Eide HO, Søreide JE, Lacroix C, Le Floch S, Hjorth M, Nielsen TG (2018a). Effects of oil spill response technologies on the physiological performance of the Arctic copepod *Calanus glacialis*. Aquatic Toxicology 199: 65-76. doi:10.1016/j.aquatox.2018.03.032

Toxværd KU, Dinh KV, Henriksen O, Hjorth M, Nielsen TG (2018b). Impact of Pyrene exposure during overwintering of the Arctic Copepod *Calanus glacialis*. Environmental Science and Technology 52: 10328-10336. doi:10.1021/acs.est.8b03327

Trannum HC, Bakke T (2012). The environmental effects of the Deepwater Horizon oil spill, focus on effects on fish and effects of dispersants. Report. No 6283. Norwegian Institute for Water Research.

Trannum HC, Nilsson HC, Schaanning MT, Øxnevad S (2010). Effects of sedimentation from water-based drill cuttings and natural sediment on benthic macrofaunal community structure and ecosystem processes. Journal of Experimental Marine Biology and Ecology 383: 111-121. doi:10.1016/j.jembe.2009.12.004

Tremblay J-E, Sejr M (2018) Marine ecosystems. Pp. 139-152 in: Adaptation Actions for a Changing Arctic. Perspectives from the Baffin Bay/Davis Strait Region. Arctic Monitoring and Assessment Programme (AMAP). Oslo, Norway.

Turner JT (2002). Zooplankton fecal pellets, marine snow and sinking phytoplankton blooms. Aquatic Microbial Ecology 27: 57-102. doi:10.3354/ame027057

UNEP (2011). UNEP Year Book 2011. Emerging issues in our global environment. United Nations Environment Programme. Nairobi, Kenya.

UNEP (2013). Global Mercury Assessment 2013. Sources, Emissions, Releases and Environmental Transport. UNEP Chemical Branch. Geneva, Switzerland.

UNEP (2014). UNEP Year Book 2014. Emerging issues update. United Nations Environment Programme. Nairobi, Kenya.

Urick RJ (1983). Principles of underwater sound. McGraw-Hill. Isbn:0070660875

USFWS (United States Fish and Wildlife Service) (2008). Endangered and threatened wildlife and plants; determination of threatened status for the polar bear (*Ursus maritimus*) throughout its range; final rule. Federal Register 72: 28212-28303. https://www.govinfo.gov/app/details/FR-2008-05-15/E8-11105

Vad J, Kazanidis G, Henry L-A, Jones DOB, Tendal OS, Christiansen S, Henry TB, Roberts JM 2018. Chapter Two – Potential impacts of offshore oil and gas activities on deep-sea sponges and the habitats they form. Advances in Marine Biology 79: 33-60. hhttps://doi.org/10.1016/bs.amb.2018.01.001

Vad J, Dunnett F, Liu F, Montagner CC, Roberts JM, Henry TB (2020) Soaking up the oil: Biological impacts of dispersants and crude oil on the sponge *Halichondria panicea*. Chemosphere 257: 127109. https://doi.org/10.1016/j.chemosphere.2020.127109

Valeur HH, Hansen C, Hansen KQ, Rasmussen L, Thingvad N (1996). Weather, sea and ice conditions in eastern Baffin Bay, offshore Northwest Greenland. A review. DMI Technical Report No 96-12. Danish Meteorological Institute. Copenhagen.

van Eenennaam JS, Rahsepar S, Radović JR, Oldenburg TBP, Wonink J, Langenhoff AAM, Murk AJ, Foekema EM (2018). Marine snow increases the adverse effects of oil on benthic invertebrates. Marine Pollution Bulletin 126: 339-348. doi:10.1016/j.marpolbul.2017.11.028

Van Leeuwe MA, Tedesco L, Arrigo KR, Assmy P, Campbell K, Meiners KM, Rintala JM, Selz V, Thomas DN, Stefels J (2018). Microalgal community structure and primary production in Arctic and Antarctic sea ice: A synthesis. Elementa 6: 4. doi:10.1525/elementa.267

Van Sebille E, Wilcox C, Lebreton L, Maximenko N, Hardesty BD, Van Franeker JA, Eriksen M, Siegel D, Galgani F, Law KL (2015). A global inventory of small floating plastic debris. Environmental Research Letters 10: 124006. doi:10.1088/1748-9326/10/12/124006

Venn-Watson S, Colegrove KM, Litz J, Kinsel M, Terio K, Saliki J, Fire S, Carmichael R, Chevis C, Hatchett W, Pitchford J, Tumlin M, Field C, Smith S, Ewing R, Fauquier D, Lovewell G, Whitehead H, Rotstein D, McFee W, Fougeres E, Rowles T (2015a). Adrenal gland and lung lesions in Gulf of Mexico common bottlenose dolphins (*Tursiops truncatus*) found dead following the Deepwater Horizon oil spill. Plos One 10: doi:10.1371/journal.pone.0126538

Venn-Watson S, Garrison L, Litz J, Fougeres E, Mase B, Rappucci G, Stratton E, Carmichael R, Odell D, Shannon D, Shippee S, Smith S, Staggs L, Tumlin M, Whitehead H, Rowles T (2015b). Demographic clusters identified within the northern Gulf of Mexico common bottlenose dolphin (*Tursiops truncatus*) unusual mortality event: January 2010 - June 2013. Plos One 10: doi:10.1371/journal.pone.0117248

Vergeynst L, Wegeberg S, Aamand J, Lassen P, Gosewinkel U, Fritt-Rasmussen J, Gustavson K, Mosbech A (2018). Biodegradation of marine oil spills in the Arctic with a Greenland perspective. Science of the Total Environment 626: 1243-1258. doi:10.1016/j.scitotenv.2018.01.173

Versteegh EAA, Blicher ME, Mortensen J, Rysgaard S, Als TD, Wanamaker AD (2012). Oxygen isotope ratios in the shell of *Mytilus edulis*: archives of glacier meltwater in Greenland? Biogeosciences 9: 5231-5241. doi:10.5194/bg-9-5231-2012

Vibe C (1939). Preliminary investigations on shallow water animal communities in the Upernavik- and Thule-districts (Northwest Greenland). Meddelelser om Grønland, Bioscience 124: 1-42.

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 150: 1-115.

Vilhjálmsson H (1994). The Icelandic Capelin Stock: Capelin, Mallotus villosus (Muller) in the Iceland, Greenland-Jan Mayen area. Journal of the Marine Research Institute 13: 1-281.

Vilhjálmsson H (2002). Capelin biology and ecology: Capelin (*Mallotus villosus*) in the Iceland-East Greenland-Jan Mayen ecosystem. ICES Journal of Marine Science 59: 870-883. doi:10.1006/jmsc.2002.1233

Villadsgaard A, Wahlberg M, Tougaard J (2007). Echolocation signals of wild harbour porpoises, Phocoena phocoena. Journal of Experimental Biology 210: 56-64.

Villumsen A, Ottosen LM (2006). Heavy metal and TBT contamination in the sediment around Sisimiut, Greenland. The Greenlandic Environment, Pollution and Solutions. Department of Civil Engineering, Technical University of Denmark. Lyngby.

Vincent CG, Nilson RM, Hanna RE (1985). Vocalization and coordinated feeding behavior of the humpback whale megaptera-novaeangliae in southeastern Alaska USA. Scientific Reports of the Whales Research Institute Tokyo.

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 (In Norwegian with summary in English). Havforskningsinstituttet. Bergen.

Vongraven D, Aars J, Amstrup S, Atkinson SN, Belikov S, Born EW, Debruyn TD, Derocher AE, Durner G, Gill M, Lunn N, Obbard ME, Omelak J, Ovsyanikov N, Peacock E, Richardson E, Sahanatien V, Stirling I, Wiig Ø (2012). A circumpolar monitoring framework for polar bears. Ursus 23: 1-66. doi:10.2192/URSUS-D-11-00026.1

Wang M, Overland JE (2009). A sea ice free summer Arctic within 30 years? Geophysical Research Letters 36: L07502. doi:10.1029/2009GL037820

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. doi:10.1016/s0278-4343(00)00122-9

Ware C, Berge J, Jelmert A, Olsen SM, Pellissier L, Wisz M, Kriticos D, Semenov G, Kwaśniewski S, Alsos IG (2016). Biological introduction risks from shipping in a warming Arctic. Journal of Applied Ecology 53: 340-349. doi:10.1111/1365-2664.12566

Wassmann P, Ratkova TN, Andreassen I, Vernet M, Pedersen G, Rey F (2002). 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. doi:10.1111/j.1365-2486.2010.02311.x

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.

Wegeberg S (2007). Er tang en ny marin ressource i Grønland? Vand Og Jord 14: 117-120.

Wegeberg S (2012) Macrophytes, pp.74-80. in: Merkel F, Boertmann D, Mosbech A, Ugarte F (eds) The Davis Strait A preliminary strategic environmental impact assessment of hydrocarbon activities in the eastern Davis Strait. Scientific report from DCE – Danish Centre for Environment and Energy No 15.

Wegeberg S (2013) Benthic flora, pp.70-80. in: Boertmann D, Mosbech A, Schiedek D, Dünweber M (eds) Disko West A strategic environmental impact assessment of hydrocarbon activities. Scientific report from DCE – Danish Centre for Environment and Energy No 71.

Wegeberg S, Boertmann D (2016). Disko Island and Nuussuaq Peninsula, West Greenland. A strategic environmental impact assessment of petroleum exploration and exploitation. Scientific Report. No 199. DCE - Danish Centre for Environment and Energy. Aarhus University. http://dce2.au.dk/pub/SR199.pdf

Wegeberg S, Geertz-Hansen O (2020) Benthic Flora, pp.59-67. in: Boertmann D, Blockley D, Mosbech A (eds) Greenland Sea – an updated strategic environmental assessment of petroleum activities Scientific Report from DCE- Danish Centre for Environment and Energy No 375.

Wegeberg S, Gustavson K (2019). Barite-bound mercury in marine sediments; potential release and bioavailability under Arctic conditions. Scientific Report. No 288. Danish Centre for Environment and Energy. Aarhus University.

Wegeberg S, Rigét F, Gustavson K, Mosbech A (2016a). Store Hellefiskebanke, Grønland. Miljøvurdering af oliespild samt potentialet for oliespildsbekæmpelse. Videnskabelig rapport fra DCE. No 216. DCE - Nationalt Center for Miljø og Energi. https://dce2.au.dk/pub/SR216.pdf

Wegeberg S, Rigét F, Boertmann D, Gustavson K, Nymand J, Mosbecg A (2016b). Vedr. miljøvurdering af olieaktiviteter og -spild i Naternaq-blokken, St. Hellefiskebanke. Notat fra DCE-Nationalt Center for Miljø og Energi og Grønlands Naturinstitut.

Wegeberg S, Fritt-Rasmussen J, Boertmann D (2017). Oil spill response in Greenland: Net Environmental Benefit Analysis, NEBA, and environmental monitoring. Scientific Report from DCE - Danish Centre for Environment and Energy No 221. http://dce2.au.dk/pub/SR221.pdf

Wegeberg S, Johnsen A, Aamand J, Lassen P, Gosewinkel U, Fritt-Rasmussen J, Rigét F, Gustavson K, Mosbech A (2018a). Arctic marine potential of microbial oil degradation. DCE Scientific Report No 271. Danish Centre for Environment and Energy. Aarhus University.

Wegeberg S, Johnsen A, Aamund J, Lassen P, Gosewinkel U, Fritt-Rasmussen J, Rigét F, Gustavson K, Mosbech A (2018b). Arctic marine potential of microbial oil degradation. Aarhus University, DCE – Danish Centre for Environment and Energy. Roskilde, Denmark.

Wegeberg S, Hansson SV, van Beest FM, Fritt-Rasmussen J, Gustavson K (2020a). Smooth or smothering? The self-cleaning potential and photosynthetic effects of oil spill on arctic macro-algae Fucus distichus. Marine Pollution Bulletin 150: doi:10.1016/j.marpolbul.2019.110604

Wegeberg S, Linnebjerg JF, Wiktor J, Geertz-Hansen O (2020b). Box 3.1: Submerged vegetation communities along the coast of Northeast Greenland. Greenland Sea – an updated strategic environmental impact assessment of petroleum activities. DCE – Danish Centre for Environment and Energy. Aarhus University.

Wenzel FW, Allen J, Berrow S, Hazevoet CJ, Jann B, Seton RE, Steiner L, Stevick P, Suárez PL, 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. doi:10.1578/AM.35.4.2009.502

Werner S, Budziak A, van Franeker J, Galgani F, Hanke G, Maes T, Matiddi M, Nilsson P, Oosterbaan L, Priestland E, Thompson R, Veiga J, Vlachogianni T (2016). Harm caused by Marine Litter. MSFD GES TG Marine Litter - Thematic Report. Technical report; EUR 28317 EN. JRC. doi:10.2788/690366

Werth AJ (2001). How do mysticetes remove prey trapped in baleen? Bulletin of the Museum of Comparative Zoology 156: 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.

White HK, Hsing PY, Cho W, Shank TM, Cordes EE, Quattrini AM, Nelson RK, Camilli R, Demopoulos AWJ, German CR, Brooks JM, Roberts HH, Shedd W, Reddy CM, Fisher CR (2012). Impact of the Deepwater Horizon oil spill on a deep-water coral community in the Gulf of Mexico. Proceedings of the National Academy of Sciences of the United States of America 109: 20303-20308. doi:10.1073/pnas.1118029109

Whitehead H (2003). Sperm whales social evolution in the ocean. The University of Chicago Press.

Whitehead A (2013). Interactions between Oil-Spill Pollutants and Natural Stressors Can Compound Ecotoxicological Effects. Integrative and Comparative Biology 53: 635-647.

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. doi:10.1139/f05-178

Whitehead H, Weilgart L, Mann J, Connor RC, Tyack PL, Whitehead H (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.

Whitehead A, Dubansky B, Bodinier C, Garcia TI, Miles S, Pilley C, Raghunathan V, Roach JL, Walker N, Walter RB, Rice CD, Galvez F (2012). Genomic and physiological footprint of the Deepwater Horizon oil spill on resident marsh fishes (vol 109, pg 20298, 2012). Proceedings of the National Academy of Sciences of the United States of America 109: 20775-20775. doi:10.1073/pnas.1118844109

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, 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.

Wiens JA (2013). Oil in the environment: Legacies and lessons of the Exxon Valdez oil spill. Cambridge University Press. Isbn:9781107614697, 9781107027176, 9781139225335

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. doi:10.1016/S0025-326X(01)00096-0

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. doi:10.1016/S0006-3207(03)00191-5

Wiig Ø, Belikov SE, Bultonov AN, Garner GW (1996). Selection of marine mammal Valued Ecosystem Components and description of impact hypotheses in the Northern Sea Route Area. Working paper, NO 40, II43. INSOP.

Wiig Ø, Amstrup S, Atwood T, Laidre K, Lunn N, Obbard M, Regehr E, Thiemann G (2015). *Ursus maritimus*. The IUCN Red List of Threatened Species 2015: eT22823A14871490, Accessed 18 December http://dx.doi.org/10.2305/IUCN.UK.2015-4.RLTS.T22823A14871490.en

Wilson RR, Perham C, French-McCay DP, Balouskus R (2018). Potential impacts of offshore oil spills on polar bears in the Chukchi Sea. Environmental Pollution 235: 652-659. doi:10.1016/j.envpol.2017.12.057

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. doi:10.1139/Z04-168

Witting L, Born EW (2005). An assessment of Greenland walrus populations. ICES Journal of Marine Science 62: 266-284. doi:10.1016/j.icesjms.2004.11.001

Witting L, Born EW (2014). Population dynamics of walruses in Greenland. Nammco Scientific Publications 9: doi:10.7557/3.2612

Wlodarska-Kowalczuk M, Kendall MA, Marcin Weslawski J, Klages M, Soltwedel T (2004). Depth gradients of benthic standing stock and diversity on the continental margin at a high-latitude ice-free site (off Spitsbergen, 79°N). Deep-sea Research Part I: Oceanographic Research Papers 51: 1903-1914. doi:10.1016/j.dsr.2004.07.013

Wlodarska-Kowalczuk M, Pearson T, Kendall M (2005). Benthic response to chronic natural physical disturbance by glacial sedimentation in an Arctic fjord. Marine Ecology Progress Series 303: 31-41.

Woodall LC, Sanchez-Vidal A, Canals M, Paterson GLJ, Coppock R, Sleight V, Calafat A, Rogers AD, Narayanaswamy BE, Thompson RC (2014). The deep sea is a major sink for microplastic debris. Royal Society Open Science 1: 140317. doi:10.1098/rsos.140317

Word JQ (2013). Environmental Impacts of Arctic Oil Spills and Arctic Spill Response Technologies Literature Review and Recommendations. Arctic Oil Spill Response Technology Joint Industry Programme.

Wright SL, Thompson RC, Galloway TS (2013). The physical impacts of microplastics on marine organisms: A review. Environmental Pollution (1987) 178: 483-492. doi:10.1016/j.envpol.2013.02.031

Yesson C, Fisher J, Gorham T, Turner C, Hammeken Arboe N, Blicher M, Kemp K (2016). The impact of trawling on the epibenthic megafauna of the west Greenland shelf. Ices Journal of Marine Science https://doiorg/101093/icesjms/fsw206. doi:https://doi.org/10.1093/icesjms/fsw206

Yesson C, Simon P, Chemshirova I, Gorham T, Turner CJ, Hammeken Arboe N, Blicher ME, Kemp KM (2015). Community composition of epibenthic megafauna on the West Greenland Shelf. Polar Biology. 1-12. doi:10.1007/s00300-015-1768-y

Yurkowski DJ, Semeniuk CAD, Harwood LA, Rosing-Asvid A, Dietz R, Brown TM, Clackett S, Grgicak-Mannion A, Fisk AT, Ferguson SH (2016). Influence of sea ice phenology on the movement ecology of ringed seals across their latitudinal range. Marine Ecology Progress Series 562: 237-250. doi:10.3354/meps11950

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.

Ørberg SB, Krause-Jensen D, Meire L, Sejr MK (2018a). Subtidal benthic recruitment in a sub-Arctic glacial fjord system: Temporal and spatial variability and potential drivers. Polar Biology 41: 2627-2634. doi:10.1007/s00300-018-2390-6

Ørberg SB, Krause-Jensen D, Mouritsen KN, Olesen B, Marbà N, Larsen MH, Blicher ME, Sejr MK (2018b). Canopy-Forming Macroalgae Facilitate Recolonization of Sub-Arctic Intertidal Fauna and Reduce Temperature Extremes. Frontiers in Marine Science 5: doi:10.3389/fmars.2018.00332

Øritsland NA, Engelhardt FR, Juck FA, Hurst RJ, Watts PD (1981). Effect of crude oil on polar bears. Environmental studies 24: 268.

Østby C, Nordstrøm L, Moe KA (2003). Konsekvenser av seismisk aktivitet. ULB delutredning 18. Alpha Miljørådgivning. Oslo.

Årthun M, Eldevik T, Viste E et al. (2017) Skillful prediction of northern climate provided by the ocean. Nature Communications 8: 15875. https://doi.org/10.1038/ncomms15875

11 Annex A

Names of animals (vertebrates) mentioned in the report

BIRDS	Aves	Fugle	Timmisat
Vernacular name (alphabetical)	**Scientific name**	**Dansk navn**	**Kalaallisut taaguutaat**
Arctic tern	*Sterna paradisaea*	Havterne	Imeqqutaalaq
Atlantic puffin	*Fratercula arctica*	Lunde	Qilanngaq
Black guillemot	*Cepphus grille*	Tejst	Serfaq
Black-legged kittiwake	*Rissa tridactyla*	Ride	Taateraaq
Brent goose	*Branta bernicla*	Knortegås	Nerlernat Canadaiittut
Common eider	*Somateria mollissima*	Ederfugl	Miteq siorartooq
Great cormorant	*Phalacrocorax carbo*	Storskarv	Oqaatsoq
Glaucous gull	*Larus hyperboreus*	Gråmåge	Naajarujussuaq
Great northern diver	*Gavia immer*	Islom	Tuullik
Gyrfalcon	*Falco rusticolus*	Jagtfalk	Kissaviarsuk
Harlequin duck	*Histrionicus histrionicus*	Strømand	Toornarviarsuk
Iceland gull	*Larus glaucoides*	Hvidvinget måge	Naajarnaq
Ivory gull	*Pagophila eburnean*	Ismåge	Naajavaarsuk
King eider	*Somateria spectabilis*	Kongeederfugl	Miteq siorakitsoq
Little auk	*Alle alle*	Søkonge	ppaliarsuk
Long-tailed duck	*Clangula hyemalis*	Havlit	Alleq
Mallard	*Anas plathyrrhynchos*	Gråand	Qeerlutooq
Northern fulmar	*Fulmarus glacialis*	Mallemuk	Qaqulluk
Razorbill	*Alca torda*	Alk	Apparluk
Red phalarope	*Phalaropus fulicarius*	Thorshane	Kajuaraq
Red-breasted merganser	*Mergus serrator*	Toppet skallesluger	Paaq
Red-necked phalarope	*Phalaropus lobatus*	Odinshane	Naluumasortoq
Red-throated diver	*Gavia stellata*	Rødstrubet lom	Qarsaaq
Ross's gull	*Rhodosthetia rosea*	Rosenmåge	Naajannguaq
Sabine's gull	*Xema sabini*	Sabinemåge	Taateraarnaq
Snow goose	*Anser caerulescens*	Snegås	Kangoq
Thick-billed murre	*Uria lomvia*	Polarlomvie	Appa
White-fronted goose	*Anser albifrons*	Blisgås	Nerleq
White-tailed eagle	*Haliaeetus albicilla*	Havørn	Nattoralik

MAMMALS	Mammalia	Pattedyr	Uumasut miluumasut
Vernacular name (alphabetical)	**Scientific name**	**Dansk navn**	**Kalaallisut taaguutaat**
Bearded seal	*Erignathus barbatus*	Remmesæl	Ussuk
Blue whale	*Balaenoptera musculus*	Blåhval	Tunnulik
Bowhead whale	*Balaena mysticetus*	Grønlandshval	Arfivik
Fin whale	*Balaenoptera physalus*	Finhval	Tikaagulliusaaq
Harbour seal	*Phoca vitulina*	Spættet/spraglet sæl	Qasigiaq
Harbour porpoise	*Phocoena phocoena*	Marsvin	Niisa
Harp seal	*Pagophilus groenlandicus*	Grønlandssæl	Aataaq/allattooq
Hooded seal	*Cystophora cristata*	Klapmyds	Natsersuaq
Humpback whale	*Megaptera novaeanglia*	Pukkelhval	Qipoqqaq
Killer whale	*Orcinus orca*	Spækhukker	Aarluk
Long-finned pilot whale	*Globicephala melas*	Grindehval	Niisarnaq
Minke Whale	*Balaenoptera acutorostrata*	Vågehval (sildepisker)	Tikaagullik
Narwhal	*Monodon Monoceros*	Narhval	Qilalugaq qernertaq
Northern bottlenose whale	*Hyperoodon ampullatus*	Døgling	Anarnak
Polar bear	*Ursus maritimus*	Isbjørn	Nanoq
Ringed seal	*Pusa hispida*	Ringsæl	Natseq
Sei whale	*Baleanoptera borealis*	Sejhval	Tunnullit ilaa
Sperm whale	*Physeter macrocephalus*	Kaskelot	Kigutilissuaq
White whale/beluga	*Delphinapterus leucas*	Hvidhval	Qilalugaq qaqortaq
Walrus	*Odobenus rosmarus*	Hvalros	Aaveq
White-beaked dolphin	*Lagenorhynchus albirostris*	Hvidnæse	Aarluarsuk

FISH	Pisces	Fisk	
Vernacular name (alphabetical)	**Scientific name**	**Dansk navn**	**Kalaallisut taaguutaat**
Amberjack	*Seriola sp.*	Ravfisk	?
Arctic char	*Salvelinus alpinus*	Fjeldørred	Eqaluk
Atlantic cod	*Gadus morhua*	Torsk	Saarullik
Atlantic halibut	*Hippoglossus hippoglossus*	Helleflynder	Nataarnaq
Atlantic herring	*Clupea harengus*	Sild	Ammassassuaq
Atlantic mackerel	*Scomber scombrus*	Makrel	Avaleraasartooq
Bluefin tuna	*Thunnus thynnus*	Blåfinnet tun	Tunfiskit
Capelin	*Mallotus villosus*	Lodde	Ammassak
Greenland halibut	*Reinhardtius hippoglossoides*	Hellefisk	Qaleralik
Greenland shark	*Microcephalus somniosus*	Grønlandshaj	Eqalussuaq
Ling	*Molva molva*	Almindelig lange	Saarullik atamasoq
Lumpfish	*Cyclopterus lumpus*	Stenbider	Nipisa
Monkfisk	*Lophius piscatorius*	Havtaske	?
Pacific herring	*Clupea pallasii*	Stillehavssild	Ammassassuaq
Polar cod	*Boreogadus saida*	Polartorsk	Eqalugaq
Redfish	*Sebastes spp.*	Rødfisk	Suluppaagaq
Roughhead grenadier	*Macrourus berglax*	Skolæst	Tupissut
Saithe	*Pollachius virens*	Sej	Saarulliusaaq
Sandeel	*Ammodytes spp.*	Tobis	Putooruttoq avannarleq
Sculpin	*Myxocephalus scorpius*	Ulk	Kanajoq
Spotted wolffish	*Anarchichas minor*	Plettet havkat	Qeeraq milattooq
Tusk	*Brosme brosme*	Brosme	Tinguttooq
Yellowfin tuna	*Thunnus albacares*	Gulfinnet tun	?
Zebrafish	*Danio rerio*	Zebrafisk	?

12 Annex B

Abbreviations and acronyms

AAW	Arctic Atlantic Water
AMAP	Arctic Monitoring and Assessment Programme, working group under Arctic Council
AMSA	Arctic Marine Shipping Assessment
AMSR	Advanced Microwave Scanning Radiometer
ANS	Aquatic Nuisance Species
API	American Petroleum Institute gravity
APNN	Ministry of Fisheries, Hunting and Agriculture, Greenland Government
AR	Assessment report
AU	Aarhus University
AVISO	Archiving, Validation and Interpretation of Satellite Oceanographic data
BACI	Before-After-Control-Impact
BAT	Best Available Technique
bbl	Barrel of oil
BC	Black carbon
BCB	Bering-Chukchi-Beaufort Sea
BEP	Best Environmental Practice
BFR	Brominated flame retardants
BIOS	Baffin Island Oil Spill study
BMP	Bureau of Mineral and Petroleum, Greenland Government, today Mineral Licence and Safety Authority (Greenland Government) and Ministry of Foreign Affairs and Energy
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
C	Carbon
CBMP	Circumpolar Biodoversity Monitoring Programme
CEFE	Centre d'Ecologie Fonctionelle Evolutive, France
CFR	Chlorinated flame retardants
chl. a	Chlorophyll a
CI	Confidence interval
CMIP	Coupled Model Intercomparison Project
CRI	Cuttings Re-Injecting
COSRVA	Circumpolar Oil Spill Response Viability Analysis
COY	Cub Of the Year
CRI	Cuttings Re-Injecting
CTD	Conductivity Temperature Depth
CU	University of Copenhagen
CV	Coefficient of Variance
CW	Southwest Greenland Coastal Water
DCE	Danish Centre for Environment and Energy
DDC-CO	Dechlorane Plus
DDT	Dichloro-Diphenyl-Trichloro-ethane
df	Degrees of freedom
DFO	Dept. Fisheries and Oceans Canada
DFHA	Department of Fishery, Hunting and Agriculture
DMI	Danish Meteorological Institute
DPC	Danish Polar Centre
dw	Dry weight
EAC	Environmental Assessment Criteria
EAMRA	Environmental Agency for Mineral Resources Activities, Greenland Government
EBSA	Ecologically or Biologically Significant Areas
ECWG	Eastern Canada-West Greenland population of bowhead whales
EDCS	Endocrine-disrupting chemicals
EEZ	Exclusive Economic Zone
EIA	Environmental Impact Assessment
EOF	Extractable organofluorine
EOS	Environment & Oil Spill Response
EPA	U.S. Environmental Protection Agency
ERL-ERM	Effects Range Low and Effects Range Medium
FPSO	Floating Production, Storage and Offloading unit
FR	Flame retardant
GAPS	Global Atmospheric Passive Sampling
GBS	Gravity Based Structure
GC-MS	Gas chromatography–mass spectrometry
GCM	General Circulation Models

GEBCO	General Bathymetric Chart of the Oceans
GEUS	Geological Survey of Denmark and Greenland
GINR	Greenland Institute of Natural Resources
gww	Grammes, wet weight
HBCCD	Hexabromocyclododecane
HCB	Hexachlorobenzene
HCH	Hexachlorocyclohexane
HFO	Heavy Fuel Oil
Hg	Mercury
HOCNF	Harmonized Offshore Chemical Notification Format (OSPAR)
HSE	Health, Safety and Environment
ICES	International Council for the Exploration of the Sea
IMO	International Maritime Organization
IO PAN	Institute of Oceanology of the Polish Academy of Sciences
IPY	International Polar Year
IWC	International Whaling Commission
JAMP	Joint Assessment & Monitoring Programme (OSPAR)
JCNB	Canada/Greenland Joint Commission on Conservation and Management of Narwhal and Beluga
JNCC	Joint Nature Conservation Committee (UK)
Kt	kilotonnes
LIENS	Littoral, Environment and Societé, France
LRTAP	Convention on Long-Range Transboundary Air Pollution
LSFO	Low Sulphur Fuel Oil
lw	lipid weight
MARPOL	International Convention for the Prevention of Pollution from Ships
MIK net	Mid-water ring net
MIZ	Marginal Ice Zone
MLD	Mixed Layer Depth
MLSA	Mineral Licence and Safety Authority (Greenland Government)
MMO	Marine Mammals Observer
MMSO	Marine Mammals and Seabird Observer
MOS	Marine Oil Snow
MPM	most probable number
MSC	Marine Stewardship Council
NAO	North Atlantic Oscillation
NAFO	The Northwest Atlantic Fisheries Organisation
NEBA	Net Environmental Benefit Analysis
NEG	Northeast Greenland
NERI	National Environmental Research Institute
NEW	Northeast Water Polynya
NHMO	Natural History Museum, Oslo
NGO	Non-Governmental Organisation
NHM	Natural History Museum, Denmark
NIC	US National Ice Center
NMDA	N-methyl-D-aspartate
NOW	North Water Polynya
NPP	Net Primary Production
NSIDC	National Snow and Ice Data Center, USA
OBM	Oil based drilling mud
OC	Organochlorines
OCH	Organohalogen contaminants
OSPAR	Oslo-Paris Convention for the protection of the marine environment of the Northeast Atlantic
OT	Organotin
OUV	Outstanding Universal Value
PAH	Polycyclic Aromatic Hydrocarbons
PAM	Passive Acoustic Monitoring
PBDE	Polybrominated diphenyl ethers
PCB	Polychlorinated biphenyls
PCN	Polychlorinated napthalenes
pCO_2	Partial CO_2 pressure
PFAS	Per- and polyfluoroalkyl substances
PFC	Perfluorinated compounds
PFNA	Perfluorononanoic acid
PFOA	Perfluorooctanoic acid
PFOS	Perfluorooctane sulfonate
PLONOR	OSPARs list over substances which Pose Little Or No Risk to the Environment
PNEC	Predicted No Effect Concentration
POP	Persistent Organic Pollutants
pp	Peak to peak (in units for sound pressure levels)
ppm	Parts per million

ppb	Parts per billion
PROBAS	the Danish product registre
PSSA	Particular Sensitive Sea Areas
PSW	Polar Surface Waters
PTS	Permanent elevation in hearing threshold shift
RAW	Return Atlantic Water
RCP	Representative Concentration Pathway
rms	Root mean squared
RoHS	Restriction of Hazardous Substances Directive
RQ	Risk Quotient
RSF	Resource Selection Functions
S	Salinity
SBM	Synthetic based drilling mud
SCCP	Short-chained chlorinated paraffins
sd	Standard deviation
SE	Standard error
SEIA	Strategic Environmental Impact Assessment
SIMA	Spill Impact Mitigation Assessment
SINTEF	Stiftelsen for industriell og teknisk forskning (The Foundation for Scientific and Industrial Research at the Norwegian Institute of Technology)
SM	Synthetic drilling mud
SSDI	Sub-sea dispersant injection
SSOR	Subsurface Oil Reservoirs
SVHC	Substances of Very High Concern
SVM	Support Vector Machine model
T	Temperature
TAB	Thule Air Base
TAC	Total Allowable Catch
TBT	Tributyltin
TEK	Traditional Ecological Knowledge
TOPAZ	The MyOcean Arctic Forecasting Center, Norway
TPAH	Total polycyclic aromatic hydrocarbons (TPAH)
TPH	Total Petroleum Hydrocarbons
TPT	Triphenyltin
TTS	Temporary elevation in hearing threshold
uPDW	upper Polar Deep Water
UNECE	The United Nations Economic Commission for Europe
UNESCO	United Nations Educational, Scientific and Cultural Organization
USCG	United States Coast Guard
USEPA	United States Environmental Protection Agency
US-NMFS	US National Marine Fisheries Service
uSPMW	upper Subpolar Mode Water
UW	University of Washington
VEC	Valued Ecosystem Components
VME	Vulnerable Marine Ecosystems
VOC	Volatile Organic Compounds
VSP	Vertical Seismic Profile
WAF	Water-accommodated fraction
WBM	Water based drilling mud
WG-SBI	West Greenland-Southeast Baffin Island population of walrus
WSF	Water Soluble Fraction
ww	Wet weight
ZSL	Zoological Society of London

13 Annex C

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 model results show the oil drift without any oil spill response applied.

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 tons released each day over 10 days, in total 30,000 tons) and an instantaneous spill where 15,000 tons 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 tons 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 blowout. 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).

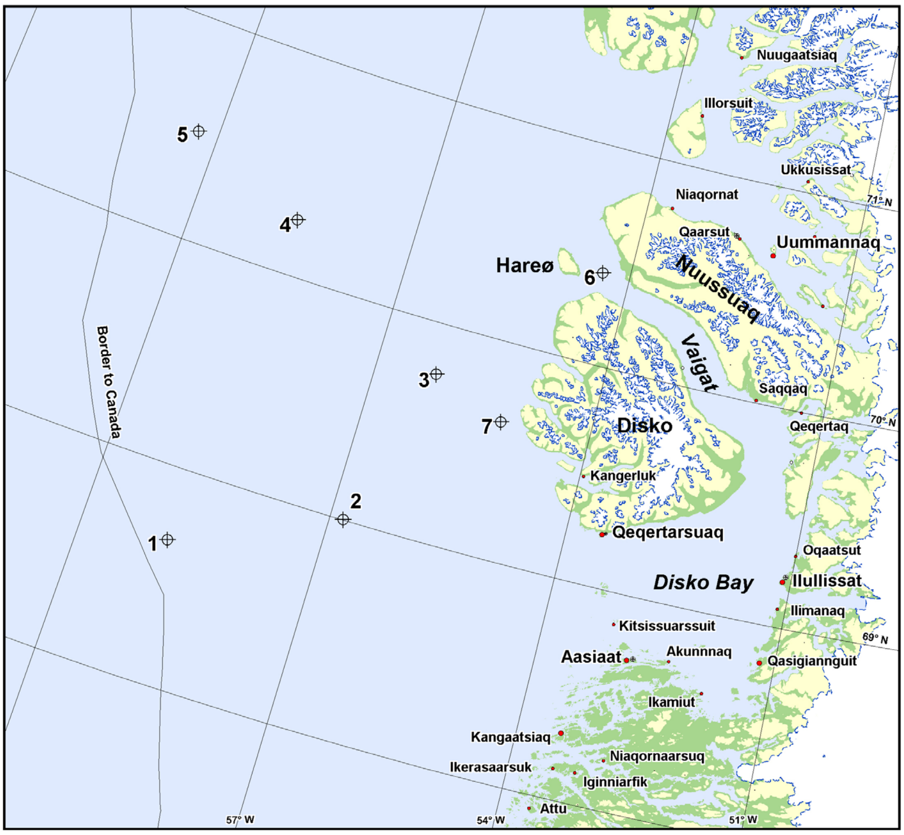


Figure 1. The seven spill locations, towns and settlements in the region.

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 bottom releases, oil may settle on the seabed, 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 and spill site in time and space (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 tons 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 affected by of the oil spills modelled for 30 days, and not the maximum area covered at a specific time after the spill.

The described scenarios do not include oil spill recovery. The effects of such actions have been estimated for Southwest Greenland with the best available technology in 1992 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.

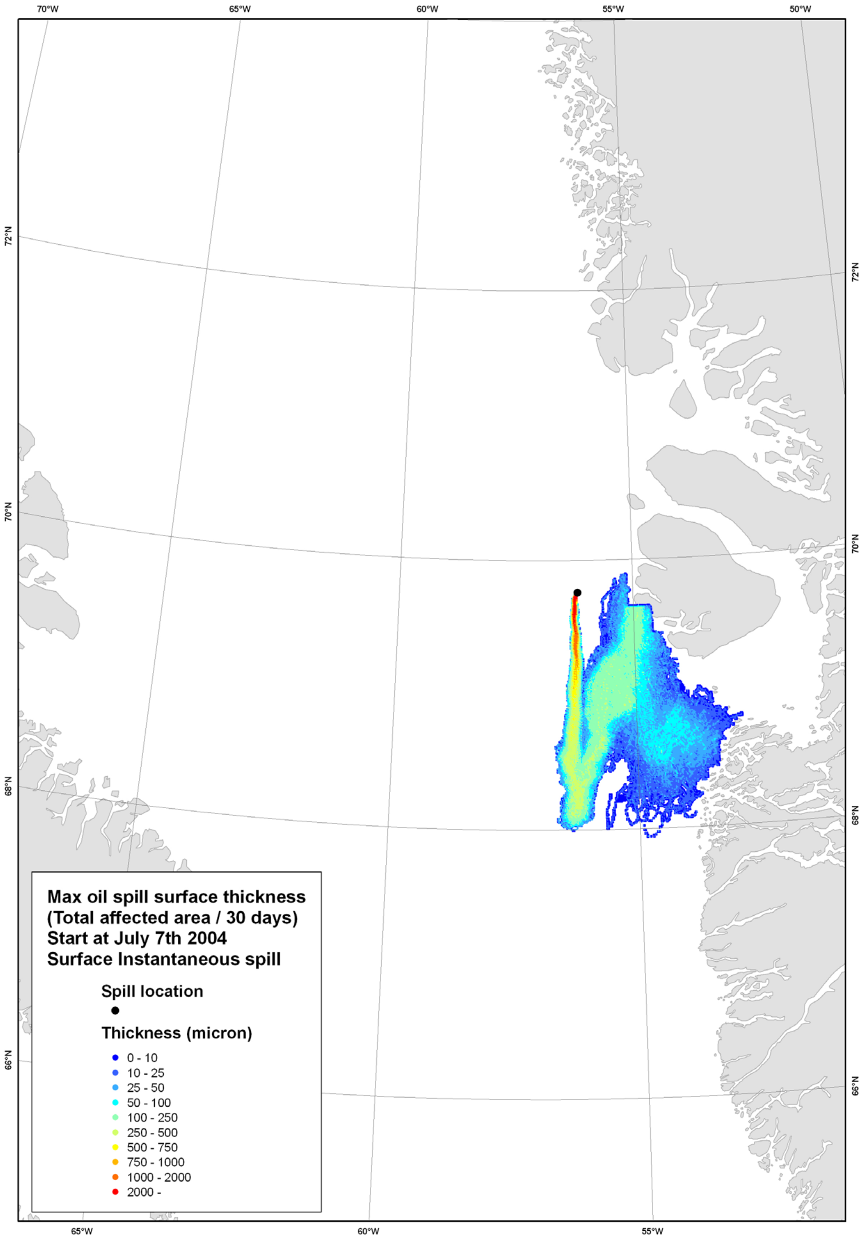
Impacts are classified as none, low, moderate, and high, or in a few cases – mainly fishery – they have been quantified.

In Table 1, the scenarios are summarised.

Spill scenario 1

15,000 tons of 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 km2, and more than 1500 km coastline is exposed for oil settlement.

Figure 2. Spill scenario 1. This is part of Figure 39 in the DMI report (Nielsen et 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).



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 30 and 31 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 has not been studied in the affected areas, but generally, the West Greenland coast has rich and diverse benthos communities.

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 5 in main report).

Shoreline sensitivity: The affected shorelines include all sensitivity classes; shorelines with moderate sensitivity are the most frequent (Figure 93 in main report).

Offshore sensitivity: The affected offshore areas are classified as having extreme sensitivity to oil spills in the summer period (Figure 94 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 tons) and snow crab (annual average catch 2002-2005 was 750 tons) takes place almost throughout the region swept by the oil spill.

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.

Seabirds: High and for some species very slowly reversible. The important breeding colonies of Atlantic puffin and 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 offshore 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 shorelines (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.

Commercial fisheries: High and reversible. Although the populations of northern 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 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 sediment and 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.

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 mortality, with long-term effects on the population as the result. Long coastlines of western Disko and Nuussuaq will be contaminated with oil. The northwards drift of oil will also sweep the important northern 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 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 starts 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 the subsurface concentration will be low, reducing the risk for impacts on both primary production and plankton.

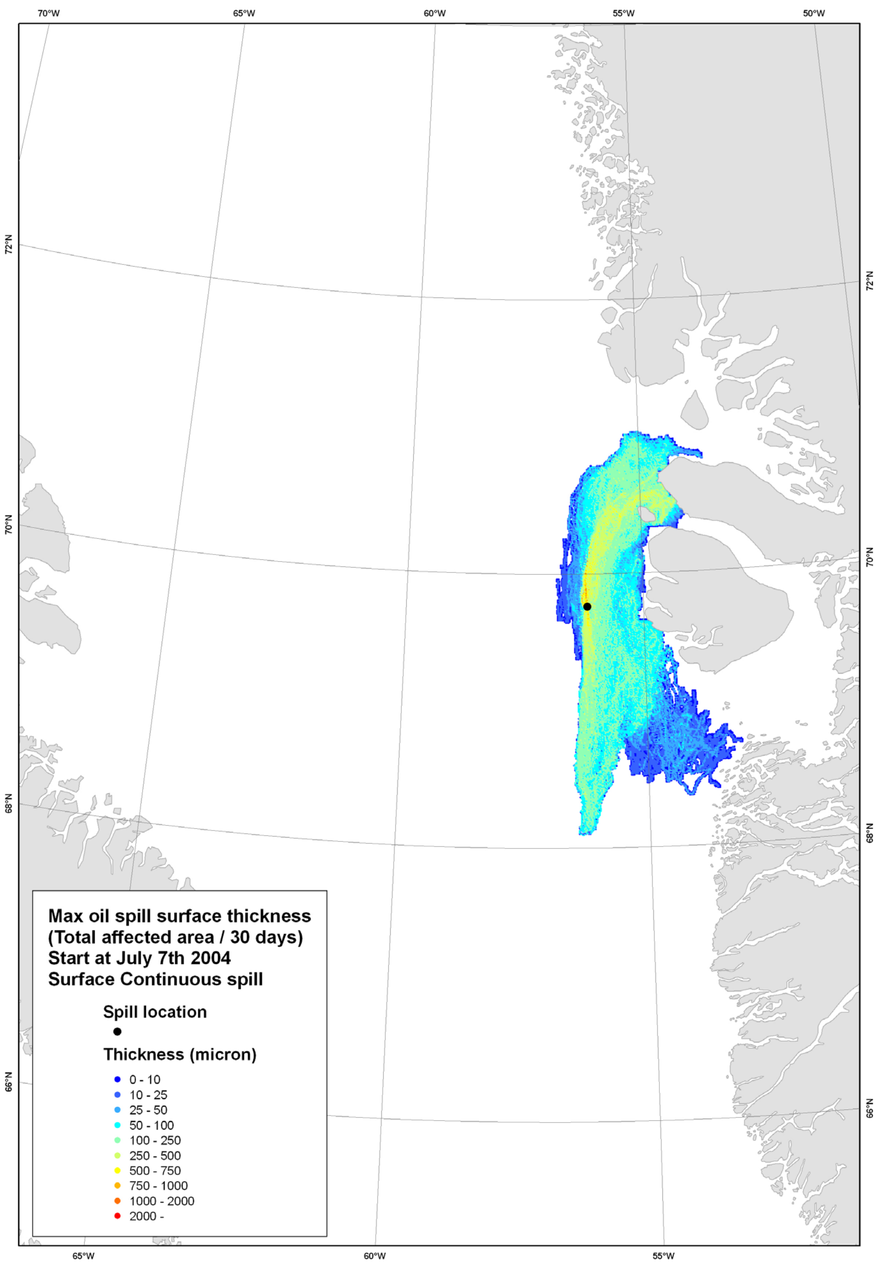


Figure 3. Spill scenario 1, alternative with a continuous spill. This is part of Figure 39 in the DMI report (Nielsen et al. 2006), showing maximum surface layer thickness and entire area swept by a continuous oil spill at location 3 for wind period 1.

Spill scenario 2

15,000 tons of 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 after the spill 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.

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 5).

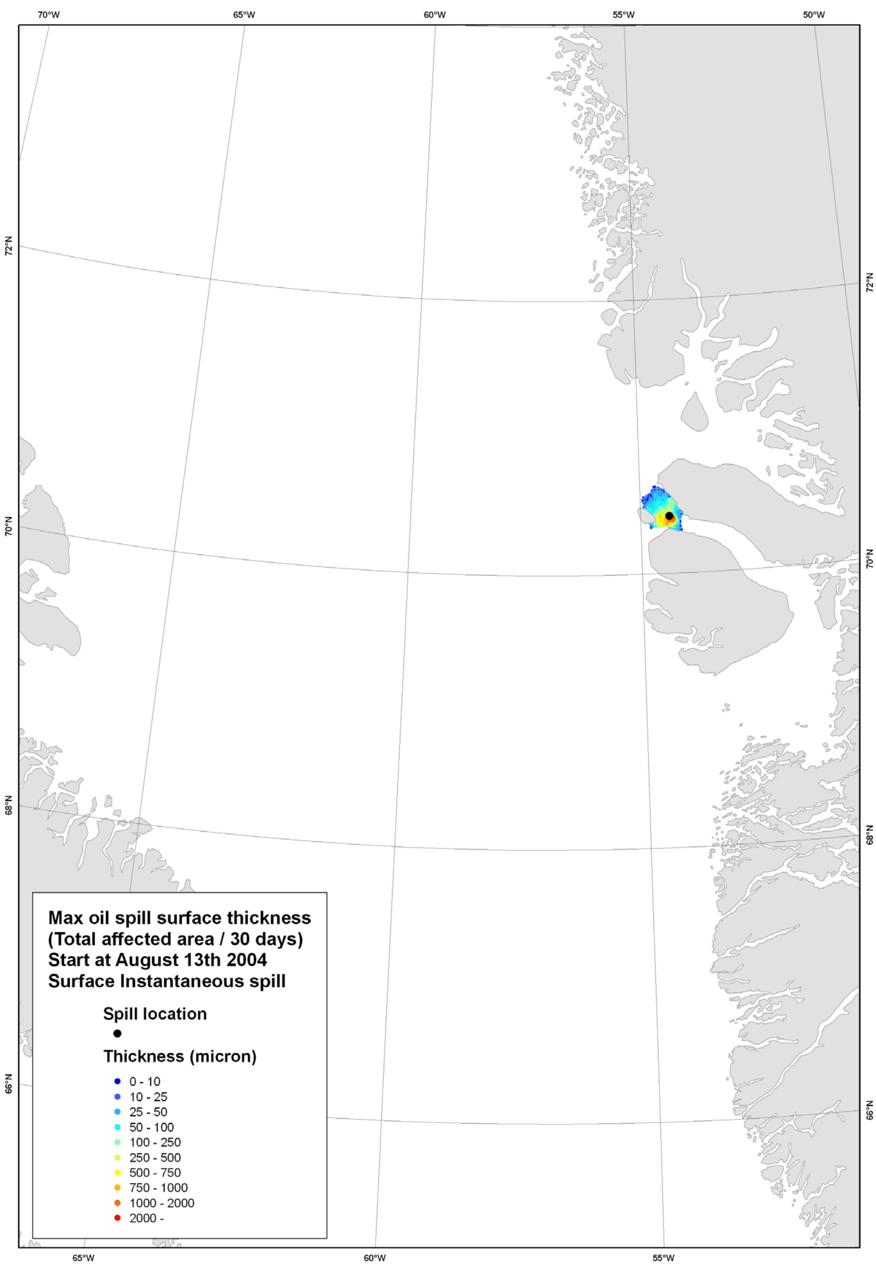


Figure 4. Spill scenario 2. This is part of Figure 48 in the DMI report (Nielsen et al. 2006), showing maximum surface layer thickness for an instantaneous and entire area swept by an oil spill at location 6 for wind period 2 (starting on Aug. 13th 2004).

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 affected by the oil spill.

Shoreline sensitivity: Most of the affected shorelines of Vaigat are classified as having high sensitivity to oil spills. The shorelines of Hareø are classified as having low sensitivity (Figure 93 in main report).

Offshore sensitivity: The outer Vaigat is classified as having high sensitivity to oil spills in August and September (Figure 94 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, because of the long distances.

Commercial fisheries: Northern 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 tons, while the crab fishery landed 30 tons 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 5), most of the birds have passed the affected area when the oil is spilled. However, in late breeding seasons the migration may be delayed and could 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 northern 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 and sediment 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 is a risk for long-term effects from stranded and preserved oil in boulder beaches.

Spill scenario 3

30,000 tons of 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 release during melt in spring. The affected area covers app. 22,000 km2 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.

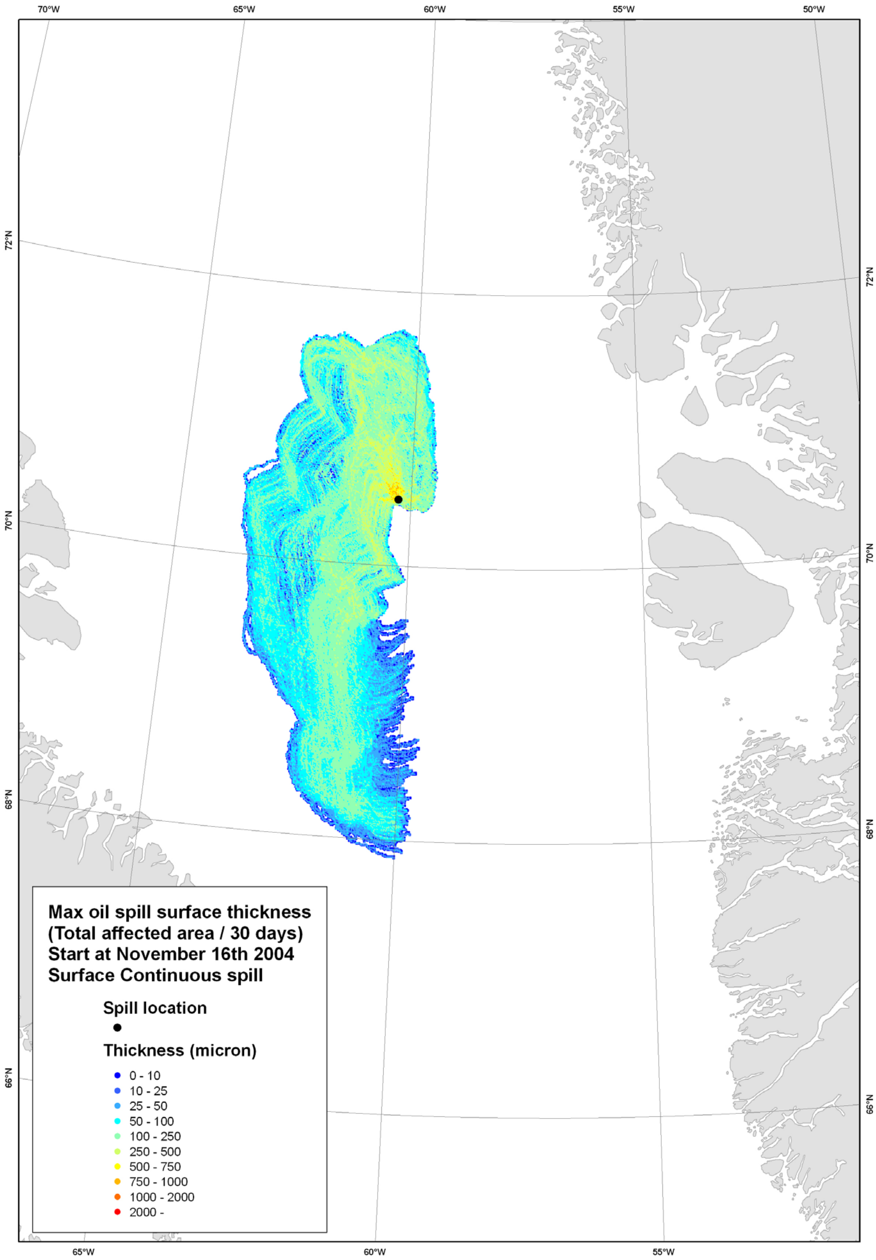
Seabirds: Substantial numbers of thick-billed murres migrate through the affected area during the autumn; however, most birds probably have passed through by mid-November. Fulmars also occur, but due to the late season probably in low numbers.

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.

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.

Figure 5. Spill scenario 3. This is part of Figure 46 in the DMI report (Nielsen et 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 Nov. 16th 2004).



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 94 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 how large of the population is difficult to estimate.

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, as long as the oil is on the surface, due to the deep waters.

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 melt. This may affect the primary production in the marginal ice zone far from the spill site, and oil may be released 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 be negligible.

Long-term effects

Probably none. However, an increased mortality on discrete narwhal populations may have a long-term effect as Greenland narwhal populations are exposed to hunting mortality.

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 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. Satellite tracking and seabird-at-sea surveys have revealed thick-billed murre concentrations in the area in autumn, while the little auks appear to move southwards closer to the Canadian coast than to the Greenlandic. Substantial numbers of thick-billed murres may be affected by a spill in September. 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.

Spill scenario 4

15,000 tons of 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

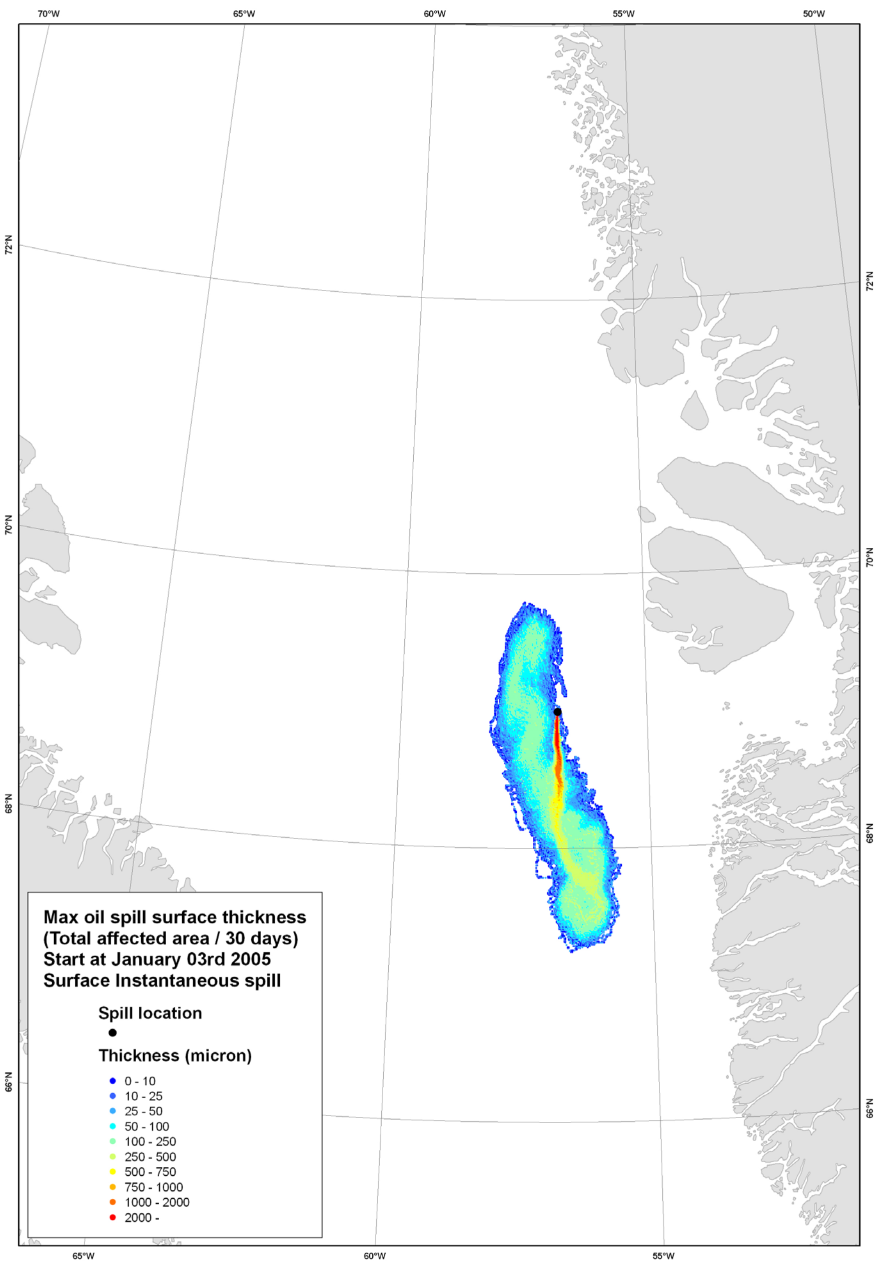


Figure 6. Spill scenario 4. This is part of Figure 37 in the DMI report (Nielsen et al. 2006), showing maximum surface layer thickness and entire area swept by an instantaneous oil spill at location 2 for wind period 4 (starting at Jan. 3rd 2005).

released far from the spill location when the ice melts in spring. Ice edges close to the spill location in open waters 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. However, the spill will approach a very important winter habitat for king eiders, where more than 1 million 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 94 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 northern shrimp fisheries takes place in the affected area. The annual average catch in the area was in 1995-2004 app. 5000 tons. 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 probably not affect the population as a whole. The oil will affect a very important winter habitat for walrus. In spring 2012, app. 1400 walruses were estimated in the region here. How these will respond to an oil spill is unknown. This population is subject to hunting and cumulative effects may be expected.

Seabirds: Low, due to the absence of seabirds. However, 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 (Frederiksen & Mosbech 2016).

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 tons of oil are 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 km2 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

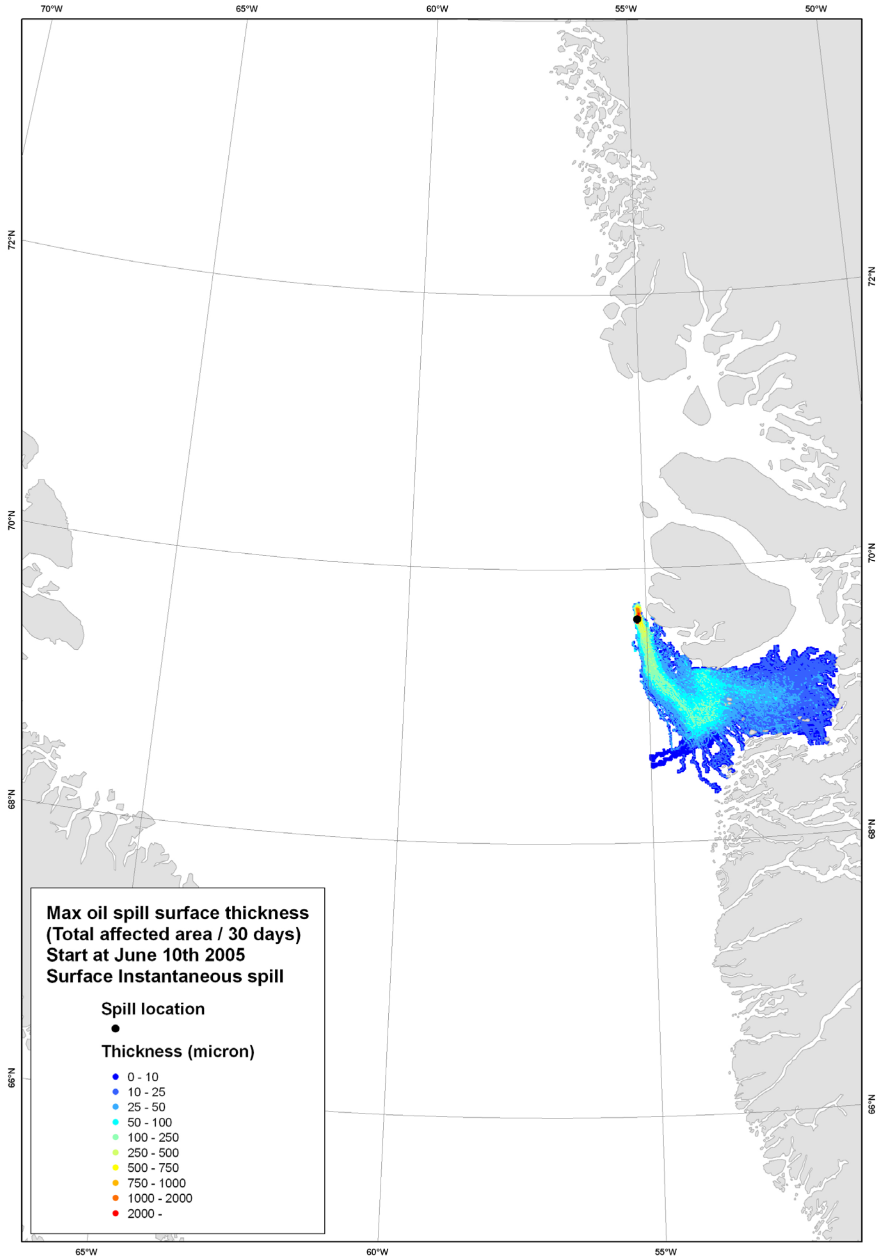
Marine mammals: Minke, fin and humpback whales, harbour porpoises and seals, mainly harp seals.

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: The benthic communities are rich and diverse.

Figure 7. Spill scenario 5. This is part of Figure 53 in the DMI report (Nielsen et 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 10th June 2005).



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 fronts and upwelling sites (Söderkvist et al. 2006). The most conspicuous and predictable of these 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 93 in main report).

Offshore sensitivity: The affected offshore areas are classified as having an extreme sensitivity to oil spills in summer (Figure 94 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 tons) and for deep sea shrimp (average annual catch 1995-2004 were app. 6000 tons) and snow crab (annual average catches 2002-2005 were 550 tons) in the Disko Bay.

Impacts

Marine mammals: Low, as no important concentrations areas are known and because seals and whales generally are little vulnerable 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, and affecting mainly Arctic char which may be forced to migrate through contaminated 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.

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, but it will be substantial.

Long-term effects:

Oil caught in boulder and sediment 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 tons of 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 northwest, and will not hit the coast (Figure 8). It will affect 25,000-30,000 km². However, the oil spill drift model does not take the presence of

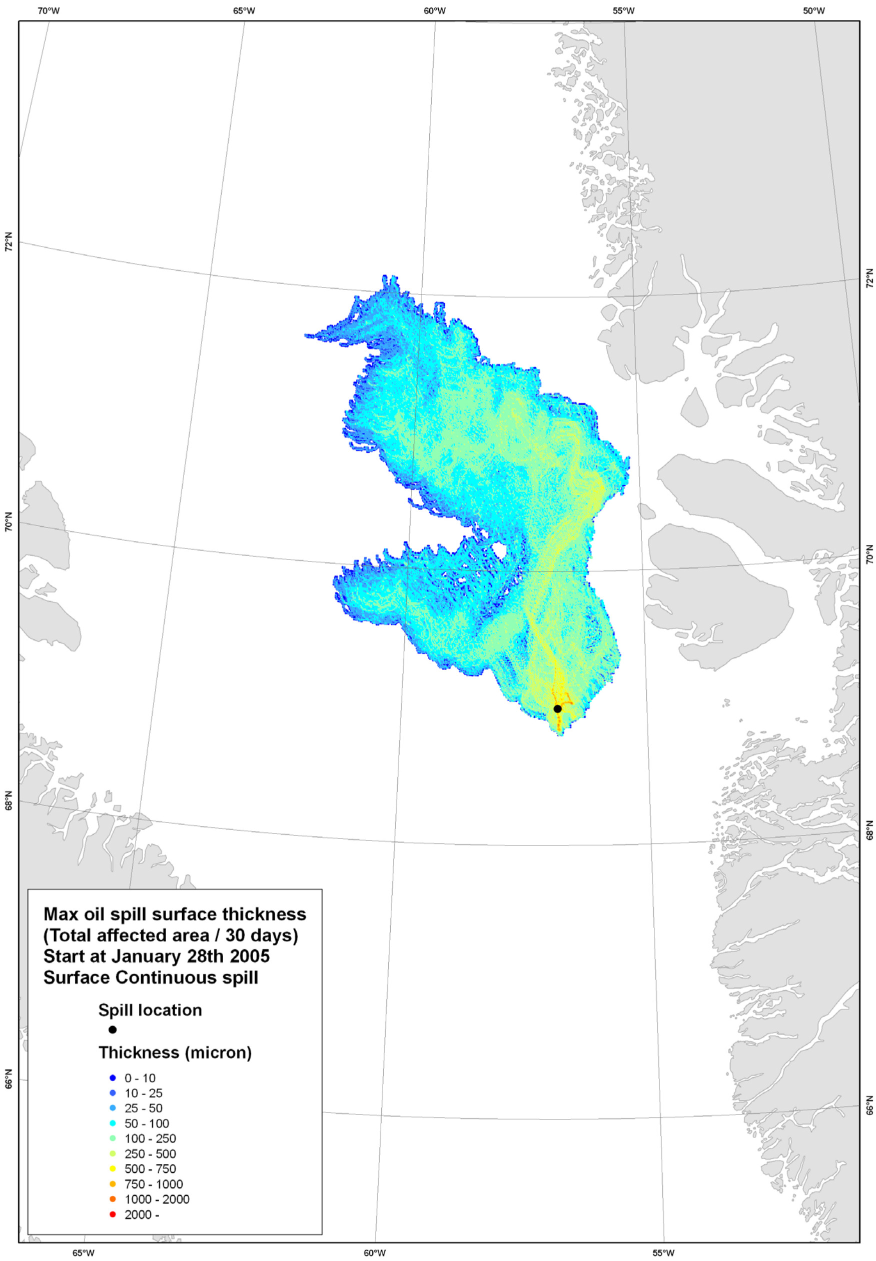


Figure 8. Spill scenario 6. This is part of Figure 38 in the DMI report (Nielsen et al. 2006), showing maximum surface layer thickness and entire area swept by a continuous oil spill at location 2 in wind period 6 (starting on 28th Jan. 2005).

sea ice into account, and it 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.

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 93 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 94 in main report).

Local use: Citizens at least from Qeqertarsuaq, Uummannaq, Illorsuit, Niaqornat and Kangerluk hunt narwhals, white whales and walrus in 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 northern 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, 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.

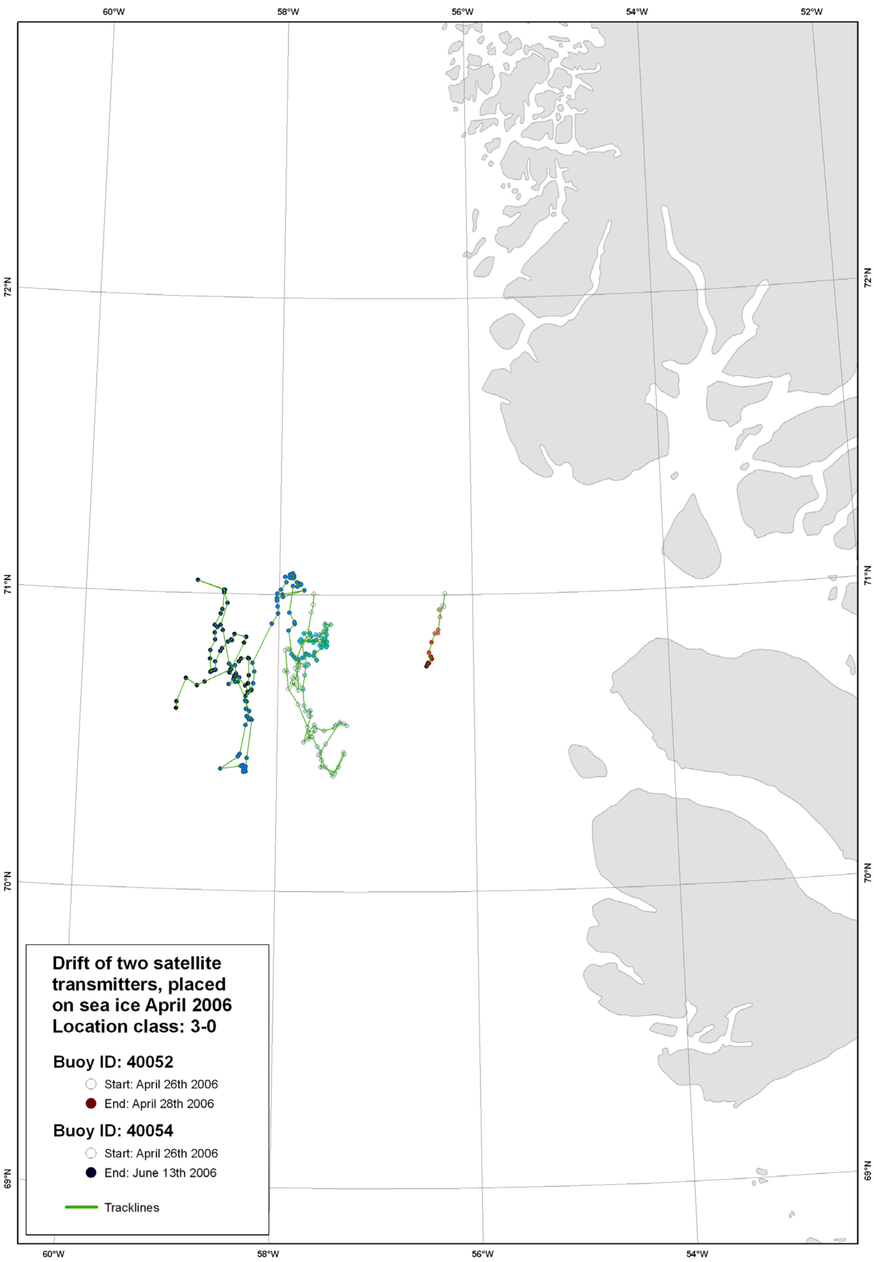
Scenario 6 transposed to August and September

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. One of the parent birds follows these. 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 5 indicate however, that the murres from the colony at Ritenbenk are spread over very large areas, reducing the risk of massive mortality. However, 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 northern 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 tons of oil is released at spill site 4 (135 km west of Hareø and 98

Figure 9. Drift pattern of two satellite transmitters placed on sea ice on 27th April 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).



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.

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 hunt marine mammals in the area.

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 unknown but 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 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. However, 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 unknown and effects under the ice and in the marginal ice zone may 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.

Frederiksen, M., Mosbech, M. 2016. Risikovurdering for kongeederfugle på Store Hellefiskebanke. Pp. 64-67 in Store Hellefiskebanke, Grønland. Miljøvurdering af oliespild samt potentialet for oliespildsbekæmpelse. – Videnskabelig rapport No 216. fra DCE - Nationalt Center for Miljø og Energi. https://dce2.au.dk/pub/SR216.pdf

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.

14 Annex D

The Store Hellefiskebanke and Disko Bay area

These two areas were recommended to be kept free of oil and gas activities in the DCE/GINR contribution to the oil and gas strategy 2020-2024 (Mosbech et al. 2019). The recommendation was based on the biological and ecological importance of the areas, which are of high value and significance, and they are described in several reports from DCE/GINR:

Two reports by Christensen et al. (2015, 2016) included them as areas of 'particular biological and ecological importance' and as 'Particular Sensitive Sea Areas' (see also Figures 61 and 59 in main report).

An analysis of oil spill effects and response methods concluded that oils spill response possibilities were limited in the Store Hellefiskebanke-area (Wegeberg et al. 2016a).

A memo from 2016 also characterised the Store Hellefiskebanke as "a particularly sensitive area in relation to oil exploration and exploitation" (Wegeberg et al. 2016b).

The biological and ecological importance of the area is based on the:
- high biodiversity which include internationally threatened (red listed) and vulnerable species (Table 9):
  - walrus, very important winter habitat,
  - narwhal, very important winter habitat,
  - white whale, very important winter habitat,
  - polar bear, in the winter season,
  - bowhead whales, spring concentrations,
  - king eider, very important winter habitat,
  - seabirds breeding concentrations – the bird cliff at Ritenbenk and the islands of Kitsissut (Grønne Ejlande).
- high biological production in spring.

These VEC's (Valuable Ecosystem Components) are all vulnerable to especially large oil spills, and populations such as the wintering walruses and the wintering king eiders are in risk of being severely decimated with long recovery times for the populations if their habitats are hit by a large oil spill. Moreover, Wegeberg et al. (2016a) showed that during a large oil spill, a high proportion of the copepods could be exposed to toxic concentrations of oil in the water column, and that the large population of wintering king eider population could be seriously affected (on population level) by a spill.

The oil spill sensitivity map covering the areas (Clausen et al. 2012), designate the waters off the outer coasts as extremely vulnerable to oil spills all four seasons and the inner Disko Bay as extremely vulnerable to oil spills in summer and autumn (Figure 94 in main report).

Finally, the area provides important ecosystem services in form of large fisheries for northern shrimp and Greenland halibut (Figures 71, 72 in main report).

References

Christensen T, Mosbech A, Geertz-Hansen O, Johansen KL, Wegeberg S, Boertmann D, Clausen DS, Zinglersen KB, Linnebjerg JF (2015). Analyse af mulig økosystembaseret tilgang til forvaltning af skibstrafik i Disko Bugt og Store Hellefiskebanke. DCE Teknisk rapport nr 61. Nationalt Center for Miljø og Energi. Aarhus Universitet.

Christensen T, Aastrup P, Boye T, Boertmann D, Hedeholm R, Johansen KL, Merkel F, Rosing-Asvid A, Bay C, Blicher M, Clausen DS, Ugarte F, Arendt K, Burmeister A, Topp-Jørgensen E, Retzel A, Hammeksen N, Falk K, Frederiksen M, Bjerrum M, Mosbech A (2016). Biologiske interesseområder i Vest- og Sydøstgrønland. Kortlægning af vigtige biologiske områder. Teknisk rapport fra DCE nr 89. Nationalt Center for Miljø og Energi. Aarhus Universitet.

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 Scientific Report No 44. Danish Centre for Environment and Energy.

Mosbech A, Boertmann D, Aastrup P, Kyhn LA, Gustavson K, Nymand J (2019). Mineral Resources Strategy – environmental contribution Scientific recommendations from DCE and GINR. Memo from DCE. Danish Centre for Environment and Energy and the Greenland Institute of Natural Resources.

Wegeberg S, Rigét F, Gustavson K, Mosbech A (2016a). Store Hellefiskebanke, Grønland. Miljøvurdering af oliespild samt potentialet for oliespildsbekæmpelse. Videnskabelig rapport fra DCE. No 216. DCE - Nationalt Center for Miljø og Energi. https://dce2.au.dk/pub/SR216.pdf

Wegeberg S, Riget F, Boertmann D, Gustavson K, Nymand J, Mosbech A (2016b). Vedr. miljøvurdering af olieaktiviteter og -spild i Naternaq-blokken, St. Hellefiskebanke. Notat fra DCE-Nationalt Center for Miljø og Energi og Grønlands Naturinstitut.

DISKO WEST
– AN UPDATED STRATEGIC ENVIRONMENTAL IMPACT ASSESSMENT OF OIL AND GAS ACTIVITIES

This report is an updated strategic environmental impact assessment of activities related to exploration, development and exploitation of oil and gas in the sea west of central Greenland, between 67° and 72° N – the Disko West licencing round area. The previous version from 2013 needed an update before the area was openend for 'open door' applications in 2021. The report includes new research results from the area. The first part of the report gives an overview of the biology and ecology in the assessment area, followed by an evaluation of potential impacts from activities related to exploration and exploitation of oil and gas. Based on the presence of especially valuable (in an ecological sense), sensitive (to oil spills) coast lines and presence of sea ice in winter, the report recommends to consider not to open the Disko West assessment area for oil and gas activities within the present strategy period (2020-2024).

ISBN: 978-87-7156-587-4
ISSN: 2245-0203