# THE 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. 439 2021

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# Data sheet

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Abstract: This report is an updated strategic environmental impact assessment of activities related to exploration, development and exploitation of oil and gas in the eastern part of the Davis Strait between 62° and 67° N – the Davis Strait licensing round area. The previous version from 2012 needed an update. The report includes new research results from the area and a new assessment. 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. The report further compares the general level of environmental risk for oil activities in seasonally ice covered areas in Eastern Davis Strait with the criteria recently implemented by Norway in the updated Barents Sea Management Plan. DCE/GINR recommends to consider further area restrictions for oil licensing within the present strategy period (2020-2024).

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# 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 (EAMRA) by October 2020. The report conclude that if the high environmental Norwegian standards are applied in the assessment area, oil licensing should be restricted 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 an update of the strategic environmental impact assessment (SEIA) of oil and gas exploration and exploitation activities in the Davis Strait licence round area. The first edition was issued in 2012 in relation to a licencing round. One licence block is currently granted within the licence area.

# Summary and conclusions

This document is an udated Strategic Environmental Impact Assessment (SEIA) of activities related to exploration, development and exploitation of oil and gas in the eastern Davis Strait (Merkel et al. 2012). The covered area is referred to as the Davis Strait assessment area and is situated between 62° N in the south and 67° N in the north and extends to the border of the *Exclusive Economical Zone* (EEZ) (Fig 1.1.1). The update is justified by the plan to open the area for 'open door' applications in November 2020.

The report has been prepared by DCE - Danish Centre for Environment and Energy and the 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 updated is based on published and unpublished sources made available since the first SEIA report in 2012.

The purpose of the SEIA is to provide updated information to support the decision process concerning potential future exploration and exploitation of oil and gas in the Greenland offshore areas of the Davis Strait. The presented information is also available for the companies operating in Greenland, for example for the preparation of Environmental Impact Assessments of their activities.

The SEIA is part of a series of five SEIAs covering the waters off entire West Greenland and Northeast Greenland, and the SEIA covering the adjacent waters to the north – the Disko West area – is also being updated.

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 are assessed. Finally, the report identifies 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 petroleum activities in the Barents Sea (Anon 2003) and the Oil and Gas Assessment by Arctic Council (AMAP 2010b). Note that the assessment does not assess the global climate impact of gasses released when potential oil and gas from Greenland fields is burned by consumers.

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 pelagic environment**

The physical conditions of the study area are briefly described with focus on oceanography and ice conditions. The southern part of the assessment area generally has open water all year around, except for the most western part. In the north-western part sea ice is usually present from about February to May. During cold winters, 'fastice' is formed in the innermost parts of the fjords. Icebergs are occasionally present in late winter and early spring, but rarely encountered north of Fyllas Banke. This is explained by the pattern of currents, the bathymetry and the distant iceberg sources.

Among the most important features of the environment are the shallow-water banks along the west coast of Greenland. High water velocity at these banks creates strong upwelling, which in turn provides nutrients for sustained high primary productivity in these relatively shallow areas. Open drift ice can occur on the banks, but they are normally ice-free year-round, except for the Store Hellefiskebanke on the northern edge of the assessment area. The banks can sustain high productivity several months longer than the deep waters offshore. Another important feature of the area is the relationship between frontal hydrography, the marginal ice zone and plankton communities at the transition between the waters of Arctic and temperate origin. Moreover, there are physical and chemical differences between (the shallow and freshwater influenced) inshore and the offshore area. Therefore, physical processes in the frontal zones affect planktonic organisms in a number of ways, including nutrient entrainment, elevated primary and secondary production and plankton aggregation.

In general, the pelagic environment of the assessment area is characterised by low biodiversity (except for the benthos community) with often numerous and dense animal populations; a relatively simple food web from primary producers to top predators; and a few species playing a key role in the ecology of the region. The most significant ecological event in the marine environment is the spring bloom of phytoplankton (peaking in April/May), the primary producers in the food web. The phytoplankton bloom is trailing the receding ice edge and occurs all over the area. The phytoplankton are grazed upon by zooplankton, including the important copepods *Calanus* (mainly *C. finmarchicus*), which represent one of the key species groups in the marine ecosystem. Not only do the zooplankton transfer energy to consumers at higher trophic levels, such as fish, baleen whales and seabirds, but they also play a key ecological role in supplying the benthic communities with high quality food by means of their large and fast-sinking fecal pellet.

As the assessment area is situated within the sub-Arctic region, the marine environment is dominated by Atlantic species, such as the *C. finmarchicus* copepod. However, a recently discovered southward current along the Southwest Greenland continental shelf, could imply that Arctic zooplankton will be more important in the offshore areas than at the more studied coastal sites. In addition, the biomass is expected to differ between offshore and inshore areas, with lower densities in the offshore areas.

**Benthic flora and fauna**

The macroalgae are found along shorelines attached to hard and stable substrate, and may occur at a depth of more than 50m. Biomass and production of littoral and sub-littoral macroalgae can be significant and are important for higher trophic levels of the food web as they provide substrate for sessile animals, shelter from predation, protection against wave action as well as currents and desiccation or are utilised directly as a food source. During the dark winter period when phytoplankton is absent, the kelp carbon becomes increasingly important as a food source for the macrofauna. In general, the production of kelp is high in the assessment area due to the year-round open water period in most of the area. Unique for the assessment area is the presence of seagrass, *Zostera marina* (a red listed species), which forms dense meadows on soft and sandy seabeds in fjord arms around Nuuk. Also, the coralline red algae *Corallina officinalis* is only found in the Nuuk area in Greenland. Further, loose-lying branched species of coralline red algae, rhodoliths, are present in the Nuuk area.

The seabed macrofauna (benthos) consume a significant proportion of the available production and, in turn, are an important food source for fish, seabirds and mammals. The assessment area has the largest number of historical sampling stations and holds more than 1000 registered species of benthic invertebrates. Recent studies have revealed a highly heterogenous substrate composition as well as local species richness of soft bottom infauna as high as >80 species/taxa per 0.1$m^2$ grab sample. Species characterizing benthic VME's (Vulnerable Marine Ecosystems, according to FAO criteria for vulnerability to bottom trawling) have been found several times, and recently Greenland's first soft coral garden habitat was described within the assessment area and found to represent a true benthic VME-candidate, covering a 486 $km^2$ area spanning ~60 km of continental slope.

**Sea ice ecology**

Sea ice is a highly dynamic and extreme environment with large vertical variations in the ice in light conditions, temperature, salinity and nutrient availability. Organisms living inside the brine channels and at the bottom of the sea ice include viruses, bacteria, algae, ciliates, heterotrophic flagellates, amphipods and copepods. Studies conducted outside the assessment area show that the sea ice primary productivity is 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. Studies conducted within the assessment area are largely missing, including studies of the 'west-ice' in the north-western part of the assessment area.

**Fish**

Fish fauna in the offshore areas, including the marine shelf, is dominated by demersal (bottom living) species such as Greenland halibut, Atlantic halibut, redfish, wolffish and several less commercially interesting species. For the Greenland halibut, which is highly important for the commercial fishery (see below), the main spawning ground is presumed to be located within the assessment area and is important for stock recruitment both within and outside the assessment area (Northwest Greenland and Canada). Sandeel occur in dense schools on the banks and are important prey for some species of fish, seabirds and baleen whales. In the coastal zone, three important species spawn: Atlantic cod, capelin and lumpsucker. The capelin is important prey for larger fish, marine mammals, seabirds and for human use. Both the Atlantic cod and lumpsucker (the eggs) are utilised on a commercial basis. Arctic char is also an important species of the coastal waters and is the target of much recreational fishing. Other species utilised in small-scale commercial or subsistence fisheries include Atlantic salmon, Atlantic halibut and wolffish.

**Seabirds**

Seabird colonies are numerous in the assessment area, but typically smaller in size compared with more northern breeding areas in West Greenland. In total, 20 species are known as regular breeders in the assessment area and the highest density of colonies is found in the extensive archipelago between 63° and 66°, despite the fact that not all areas have been thoroughly surveyed for breeding birds. Two species are rare breeders to Greenland, the Atlantic puffin and the common murre, which are listed as vulnerable and endangered, respectively, on the Greenland Red list.

For 13 bird species the importance of the assessment area is classified as 'high' on a national or international scale due to the number of breeding, moulting or wintering birds (Tab. 3.7.1). The assessment area is especially important as a wintering area. It makes up a large proportion of the open water region in Southwest Greenland, where large numbers of seabirds from Russia, Iceland, Svalbard and Canada assemble from October to May. More than 3.5 million birds are estimated to winter in the coastal areas alone. The most abundant species are thick-billed murre, common eider, king eider and little auks. A large, but unknown number of seabirds also migrate through or winter in the offshore areas.

**Marine mammals**

Marine mammals are significant components of the marine ecosystem. Five species of seal occur in the assessment area, of which harp seals are numerous throughout the area during most of the year. Another species, the harbour seal, is listed as critically endangered in Greenland. The northernmost part of the assessment area overlaps with the southern edge of a key wintering habitat for walruses. Among the whales, several baleen whales, such as minke whales, fin whales, humpback whales and sei whales, are seasonal inhabitants of the assessment area and relatively abundant. The area is part of their foraging area during summer and the distribution of the whales often correlates with their main prey: capelin, krill and sandeel. However, recent surveys from 2015 indicate a shift, or fluctuation, in the main distribution of minke, fin and humpback whales from West to East Greenland. The bowhead whale migrates through the assessment area in the period January-February towards feeding and possibly mating grounds just north of the assessment area. Several toothed whales are common in the assessment area: harbour porpoise, long-finned pilot whale, northern bottlenose whale and white-beaked dolphin. The southern wintering grounds of beluga whales and narwhals extend into the northern part of the assessment area. Polar bears occur during winter and spring, depending on and in association with the very variable sea ice cover.

## Nature protection and threatened species

**International designations**

The fjord Ikkattok and adjacent archipelagos near Paamiut are designated as wetlands of international importance under the intergovernmental environmental treaty, the Convention on Wetlands (the Ramsar Convention), also known as Ramsar sites.

**National legislation**

Three areas within the assessment area are protected according to the Nature Protection Act. However, two of these are inland sites and will not be affected by offshore oil activities. The third site is the island of Akilia near Nuuk, which is close to the outer coast and protected due to geological interest (Fig. 4.1.1). Seven sites are protected as seabird breeding sanctuaries under the Bird Protection Executive Order and all seabird breeding colonies are protected from disturbing activities according to the same Order.

With reference to the Mineral Extraction Law, several areas are designated as 'areas important to wildlife' and here mineral (and hydrocarbon) exploration activities are regulated in order to protect wildlife. This include, for example, the most important seabird breeding colonies

**Threatened species**
Greenland issued in 2018 a new updated and enlarged list of threatened species – a red list. According to this, ten species of mammals, twelve birds and one fish species occurring in the assessment area are evaluated as threatened or near threatened (Tab. 4.3.1). The international red list from IUCN classify ten marine mammals and five birds from the assessment area as threatened or near threatened (Tab. 4.3.3)

## Human impacts in the assessment area

The assessment area is 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.

**Contaminants**
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 is 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.

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

**Human use – hunting and fishery**
Human use of natural resources occurs throughout the assessment area; subsistence and small-scale use is extensive in the coastal areas, while there are substantial commercial fisheries in the offshore parts. Due to open water being present all year round in most coastal areas, commercial, subsistence and recreational hunting is possible throughout the year, except in legally closed seasons. Seabirds are among the most popular hunted resources and are bagged in large numbers, although gradually declining over the past two or three decades. The most important species are thick-billed murre and common eider. Seals are also harvested in large numbers in the assessment area. The skins are purchased and prepared for the international market by a tannery in South Greenland and the meat is consumed locally. The most important species is the harp seal. Walruses, belugas and narwhals are caught during winter and spring in the northern part of the assessment area and regulated by quotas.

Also harbour porpoises, minke whales, fin whales and humpback whales are caught in the assessment area, with harbour porpoise and minke whale as far the most numerous species. Minkes and humpback and fin whales are subject to annual quotas set by the IWC. Quotas also regulate polar bear catches, but only a few animals are shot every year in the assessment area.

Commercial fisheries represent the most important export industry in Greenland, accounting for 90% of the total Greenlandic export revenue (4.1 billion DKK in 2018). Greenland halibut, deep-sea shrimp and snow crab are the main commercially exploited species within the assessment area and annual catches make up a large proportion of total landings in Greenland, although the proportion of shrimps taken in the assessment area has decreased considerably in the last five years. More shrimps are now caught north of the assessment area. The Atlantic cod fishery has increased over the past decade, but recruitment appears to fluctuate quite a bit. Compared with historical levels (1960s) catches are still small. In the coastal area, various species are exploited on a small-scale commercial, subsistence or recreational basis, such as lumpsucker, wolffish, redfish, Atlantic cod, Greenland cod, capelin and Atlantic salmon.

**Tourism**

Tourism is a growing industry in Greenland and now counts as the third largest economic activity in the country. The total number of guests in Greenland in 2019 was 105,000 or 266,000 'bed nights', of which more than half went to the assessment area, especially Nuuk. In addition, cruise ships bring in tourists in ever increasing numbers. The coastal marine area is very important for tourist activity.

**Climate change**

Climate scenarios for the Baffin Bay - Davis Strait 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 year. In the northern region less sea ice will lead to a longer phytoplankton growing season, but, on the other hand, more precipitation and more freshwater from the melting Ice Sheet may lead to a stronger stratification of the water column, which could result in reduced nutrient supply from the deeper layers to the photic zone. The assessment area is, to some extent, already ice-free year-round, so future changes of the ecosystem is mainly expected to be caused by warming and possible changes in upwelling, stratification and mixing forces.

Implications for fisheries and hunting are likely to occur within the assessment area and future sustainability of human use will likely depend on flexible management plans, which will facilitate the use of new or alternative living resource. For some populations, climate change may act as an additional stressor in relation to existing impacting factors such as fishery or hunting, leading to higher sensitivity to oil spill incidents. Other populations may become more abundant and robust as a consequence of climate change. Species composition may also change, with some species disappearing or moving north, as currently observed for the northern shrimp, and other species moving in from the south, taking advantages of increasing water temperatures, like the Atlantic cod or the Atlantic mackerel.

To follow such 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 with other human activities and climate change.

## Assessment of oil and gas activities in the Davis Strait assessment area

The assessments presented here are based on our present knowledge concerning the distribution of species and their tolerance and threshold levels toward human activities in relation to oil exploration and production. However, the Arctic is changing due to climate change and this process seems to be accelerating. This means that conclusions and assessments may need to be adjusted in the future. Furthermore, a large part of the assessment area is poorly studied and increased knowledge may lead to additional adjustments.

## Assessment: exploration

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

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

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

The fishery at risk of impact from noise from seismic surveys in the assessment area is the Greenland halibut fishery. The risk is temporary (days or weeks) displacement of fish and consequently reduced catches from the trawling grounds. Although the precise location of the Greenland halibut spawning grounds is not known, planning of seismic surveys in the area where spawning is expected to take place should consider avoiding overlap with the spawning period (early winter). The fishery for northern shrimp and snow crab will probably not be affected.

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

Drilling mud and cuttings that are released to the seabed. Due to environmental concerns oil-based mud is brought to land to be treated, while water-based mud is acceptable to release as long as the added chemicals are not hazardous. Within the assessment area local effects on the benthos are expected from discharging the water-based muds. Any drilling should be avoided in the most vulnerable areas. Baseline studies at drill sites must be conducted prior to drilling to document whether unique communities or species such as cold-water coral and sponge gardens are at risk of being harmed by increased sedimentation. Post-drilling studies should be carried out to document whether activities caused any specific effects. The most efficient way to reduce impacts on the seabed is a no release solution, where all the drilling waste is brought to land or re-injected into the well.

Exploration drilling is an energy-intensive process emitting large amounts of greenhouse gases. Even a single drilling will increase the Greenland contribution to global emissions significantly.

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

## Assessment: development and production

Activities during development, production and transport are long-lasting and several activities have the potential to cause severe impacts on the environment. The impacts will depend on the number of activities, how far they are dispersed in the areas in question, and also on their duration. 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.

**Emissions and discharges**

Drilling will continue during development and production phases and drilling mud and cuttings will be produced in much larger quantities than during exploration. Discharges should be limited as much as possible by recycling and reinjection and only environmentally safe substances (such as the 'green' and 'yellow' substances classified by OSPAR) tested for toxicity and degradability under Arctic conditions should be permitted to be discharged. In Greenland the use of 'black' chemicals is not permitted and use of 'red' chemicals requires specific permission. Even the non-toxic discharges alter the sediment substrate and if these substances are released to the seabed impacts must be expected on the benthic communities near the release sites.

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, produced water in ice covered areas may 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.

Discharge of ballast water is also of concern as this carries the risk of introducing non-native and invasive species. Ballast water must therefore be handled and discharged subject to specific rules. The IMO ballast water management convention was adopted in 2017, and guidelines has been issued (IMO Link). All vessels and drilling units involved in hydrocarbon activities in Greenland should follow the IMO guidelines or the relevant Canadian regulations (Link). The problem with invasive species is currently not severe in the Arctic, but the risk will increase with climate change and the intensive tanker traffic associated with a producing oil field.

Development of an oil field and production of oil are energy-consuming activities that would contribute significantly to the Greenland emission of greenhouse gases. A single large Norwegian production field for example, release almost three times as much as the total Greenland $CO_2$ emission of today.

**Noise**

Noise from drilling and the positioning of machinery, which will continue during the development and production phase, may potentially lead to permanent loss or displacement of important summer habitats for cetaceans, especially if several production fields are active at the same time. Noise from ships (incl. ice-breaking) and helicopters, which becomes more persistent than in the exploratory phase, can both affect marine mammals and seabirds. The most sensitive species within the assessment area are the colonial seabirds, bowhead whales, narwhals, beluga whales, minke whales, fin whales, harbour porpoises and walruses – species that may associate noise with negative events (hunting). Traditional hunting grounds may also be affected. Applying fixed flying lanes and altitudes will reduce impacts from helicopter noise.

**Placement of structures**

Placement of offshore structures and infrastructure may locally impact seabed communities and there is a risk of spoiling important feeding grounds – walrus is highly sensitive, but occurs mainly north of the assessment area. However, feeding areas for king eiders wintering at the shallow-water shelf banks (especially Fyllas Banke) may also be at risk. Inland structures may locally impact breeding birds; obstruct rivers, with implications for anadromous Arctic char; damage coastal flora and fauna; and have an aesthetic impact on the pristine landscape, which in turn may impact the local tourism industry.

A specific impact on fisheries is the exclusion/safety zones (typically 500 m) that will be established both around temporary and permanent offshore installations. These may affect some of the important fishing areas for Greenland halibut and northern shrimp.

Illuminated structures and flares may attract seabirds in the hours of darkness, and there is a risk of mass mortality especially for eiders and possibly little auks.

**Cumulative impacts**

There will be a risk of cumulative impacts when several activities take place either simultaneously or consecutive. For example, seismic surveys have a high potential for cumulative impacts. Cumulative impacts may also occur in combination with other human activities, such as hunting, or in combination with climate change.

The best way of mitigating impacts from development and production activities is to combine a detailed background study of the environment (in order to locate sensitive ecosystem components) with careful planning of structure placement and transport corridors. Subsequent application of BEP, BAT and compliance with international standards such as OSPAR and HOCNF can do much to reduce emissions to air and sea.

## Assessment: Oil spill

The most environmentally severe accident from the activities described above would be a large oil spill. Accidental oil spills may occur either during drilling (blowouts) or from accidents when storing or transporting oil. Large oil spills are relatively rare events today 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.

Oil spill simulations (examples of potential trajectories of oil spills) were carried out for six locations within the assessment area – three sites in the shelf-region and three sites further offshore (Fig. 8.3.1). In general, for the offshore simulations, the oil spill trajectory was towards the southwestern part of the assessment area, potentially affecting an offshore area between Greenland and Canada with a rough estimation of 70,000 $km^2$. Oil spilled in the shelf-region had a somewhat similar behavior, however, one simulation had a north-going path before bending off towards southwest. In two of the shelf-region spill sites, the oil also affected the coast. In all simulations, small proportions of the oil (< 5%) could potentially reach the seabed.

Large oil spills have the potential to impact all levels in the marine ecosystem, from primary production to the top predators. A large oil spill represents a threat at population and maybe even species level and the impacts may last for decades, as documented for Prince William Sound in Alaska. For some populations oil spill mortality can to an extent be compensatory (be partly compensated by reduced natural mortality due to less competition), while for others it will largely be additive to natural mortality. Some populations may recover quickly while others will recover to pre-spill conditions very slowly, depending on their life strategies and population status. For species which are vulnerable to oil spills and are also harvested, oil spill impacts could be mitigated by managing the harvest wisely and sustainably. The lack of efficient response methods in partly ice-covered waters and remoteness will add to the severity of an oil spill.

For this impact assessment the offshore areas are divided into eight sub-areas and classified according to their sensitivity to oil spill, taking into account the relative abundance of species/species groups; species or population specific oil sensitivity values; oil residency; human use; and a few other parameters. During all seasons the offshore areas closest to the coastal zone covering the shelf bank areas are among the most sensitive areas. These areas are especially important for migrating/wintering seabirds, human use of northern shrimp and snow crab, and as foraging areas for baleen whales. During spring and winter the southwest corner of the assessment area is also classified as highly sensitive to oil spill due to extensive Greenland halibut fishery and whelping areas for hooded seals in the western pack ice in March and April.

A comparison of seasons, based on absolute sensitivity values and averaged across all offshore areas, shows that winter is most sensitive to oil spill, closely followed by spring and autumn, while summer is least sensitive to oil spill. The main reason for this difference is the large number of wintering/migrating seabirds during winter, spring and autumn, which are all very sensitive to oil (especially auks and seaducks).

The coastal zone of the assessment area is even more sensitive to oil spill due to a higher biodiversity and due to the fact that oil may be trapped in bays and fjords where high and toxic concentrations can build up in the water. There is the potential for a number of negative impacts – on spawning concentrations of fish, such as capelin and lumpsucker, in spring; Arctic char assembling outside their spawning rivers; and on many seabird populations in summer, during migration periods and especially in winter when seabirds from a variety of breeding locations in the North Atlantic gather in Southwest Greenland. Long-term impacts may occur in the coastal zone if oil is buried in sediments or among boulders, in mussel beds or is imbedded in crevices in rocks. Oil seeps from these sites and causes chronic pollution which may persist for decades. In Prince William Sound in Alaska such preserved oil has caused negative long-term effects on e.g. birds utilising the polluted coasts and some populations have not recovered. The coastal zone is also of crucial importance for local hunters and fishermen, and in the case of an oil spill, these activities may be adversely affected by closure zones and/or by changed distribution patterns of the targeted species. The tourist industry in the assessment area will probably also be impacted negatively by oil exposure in the coastal area.

Another vulnerable feature is the winter/spring period with ice- covered waters in the northern and western part of the assessment area. Spilled oil would be contained between the ice floes and on the rough underside of the ice. However, oil in ice may be transported in an almost un-weathered state over long distances and when the ice melts may impact the environment, e.g. fish larvae, seabirds and marine mammals, far from the spill site. Oil may also be caught along ice edges and in marginal ice zones with sensitive aggregations such as primary producers, seabirds and marine mammals.

In general, accidents are best mitigated by careful planning, strict Health, Safety and Environment (HSE) procedures and application of the Precautionary Principle in combination with BEP, BAT and international standards (OSPAR). However, knowledge of the behaviour of spilled oil in ice environments is very limited and the technology for cleaning up oil spills in ice-covered waters is inadequate and in need of further development.

**Primary production and zooplankton**

It is assessed that the impact of a surface oil spill in the assessment area on primary production and zooplankton in open waters will be low due to the large temporal and spatial variation in these events and occurrences. There is, however, a risk of impacts (reduced production) in localised primary production areas and the spring bloom will be the most sensitive period. However, if a large subsea plume of dispersed oil in toxic concentrations occurs, stronger impacts than from a surface spill must be expected, especially on primary producers, zooplankton and fish/shrimp larvae.

**Fish and crustacean larvae**

In general, eggs and larvae of fish and crustacean are more sensitive to oil than adults and may theoretically be impacted by reduced annual recruitment with some effect on subsequent populations and fisheries for a number of years. Atlantic cod is especially sensitive as their eggs and larvae can be concentrated in the upper 10m of the water column, whereas larvae of shrimp and Greenland halibut, for instance, are found deeper and would therefore be less exposed to harmful oil concentrations from an oil spill at the surface. However, a subsea blowout with the properties and quantities of the Deepwater Horizon spill (more than 800,000 tonnes, the largest peace-time marine oil spill ever) may expose eggs and larvae over much larger areas and depth ranges and may potentially also impact the recruitment and stock size of other species, such as shrimp, Greenland halibut, snow crab and sandeel.

**Benthos**

Bottom-living organisms such as bivalves and crustaceans are vulnerable to oil spills; however, no effects are expected in the open water unless oil sinks to the seabed. In shallow waters (< 10-15m), highly toxic concentrations of hydrocarbons can reach the seafloor with possible severe consequences for local benthos and thereby also for species utilising the benthos – especially common eider, king eider, long-tailed duck, bearded seal and walrus. A subsea spill with the size and properties of the spill from the Deepwater Horizon in the Mexican Gulf has the potential to impact the seabed communities in deep waters too.

**Adult fish**

Impacts from a surface spill on adult fish stocks in the open sea are not expected. The situation is different however in coastal areas, where high and toxic oil concentrations can build up in sheltered bays and fjords resulting in high fish mortality (see above). Once more, a large subsea blowout could represent an exception as far as low impact is concerned. Considerable plumes of dispersed oil can occur in the water column from a subsea blowout and may impact the fish both directly or through the food chain. Greenland halibut would be exposed in both ways, because they move up from the seabed to the pelagic waters to feed.

**Fisheries**

An oil spill in the open sea will affect fisheries mainly by means of temporary closure in order to avoid contaminated catch. Closure time would depend on the duration of the oil spill, weather, etc. The offshore fishery for Greenland halibut within the assessment area is large and a closure zone would probably extend further west and cover Canadian fishing grounds too. The reason is that Greenland halibut moves considerable distances over a very short time and contaminated (tainted) fish may move out of the assessment area and be caught far from a spill site.

The assessment area is also among the most important fishing grounds in Greenland for northern shrimp and snow crab, and closure zones may also have significant economic consequences for this section of the fishing industry.

Oiled coastal areas would also be closed for fisheries for a period – the duration of the closure would depend on the behaviour of the oil. There are examples of closure for many months due to oil spills, particularly if oil is caught in sediments or on beaches. The commercial inshore fishery targets primarily lumpsucker and local populations of Atlantic cod, while capelin form part of the subsistence and recreational fishery.

**Seabirds**

Seabirds are extremely vulnerable to oil spills in the marine environment as they usually spend much time at the surface where most oil spills occur. Their plumage is highly sensitive to oil, as only small amounts can destroy its insulation and buoyancy properties. Exposed birds usually die from hypothermia, starvation, drowning or intoxication. In the assessment area the coastal zone is particularly sensitive as high concentrations of seabirds are found all year around. A substantial number of these birds, including breeding birds, moulting birds as well as wintering birds, are associated with habitats along the highly exposed outer coastline. In these areas, oil spill response is hampered by remoteness, the complex coastal morphology and the often harsh weather conditions. The seabird species most vulnerable to oil spills are those with low reproductive capacity (low population turnover), a trait especially found among auks, fulmars and many seaducks. These species, e.g. thick-billed murres, little auks, eiders and long-tailed ducks, winter in the assessment area in large numbers as Southwest Greenland constitutes an international wintering area for seabirds from a range of breeding locations in the North Atlantic.

During autumn and winter, a number of species are also at risk further offshore in the assessment area, including the shelf areas; although birds tend to be more dispersed in the open water compared to coastal habitats. Some of the important species include northern fulmar, black-legged kittiwake, puffin, little auk, thick-billed murre, black guillemot and king eider. Especially the king eider is vulnerable in the offshore area as the birds assemble in large dense flocks on the shallow-water shelf banks during winter (Fyllas Banke and Store Hellefiske-banke). A major oil spill in these areas could seriously affect this population.

**Marine mammals**

Polar bears and seal pups are highly vulnerable to direct oiling and even short exposures can be lethal, as the oil affects the insulation properties of the fur. There are seal whelping areas in the assessment area (see below), while polar bears are associated with the Davis Strait pack ice, of which the extent lying within the assessment area varies.

Whales, seals and walruses are vulnerable to surface oil spills. The baleens of the baleen whales may become smothered with oil. This may lead to toxic effects and injuries in the gastrointestinal tract if oil is ingested. There is also the potential for inhalation of oil vapours and direct contact of the oil with eye tissues. The extent to which marine mammals actively avoid an oil slick and also how harmful the oil would be to fouled individuals is uncertain. However, observations indicate that at least some species do not perceive oil as a danger and have repeatedly been reported to swim directly into oil slicks.

Marine mammal species affected by an oil spill during winter in the assessment area could include bearded seal, hooded seal, ringed seal, harbour seal, bowhead whale, narwhal, white whale, polar bear, harbour porpoise, walrus, bottlenose whale and sperm whale. Harbour seals are especially vulnerable as they are endangered in Greenland, and hooded seals too, because whelping patches are located in the eastern Davis Strait pack ice. Marine mammals that use the area as a feeding ground during summer include harp seal, hooded seal, ringed seal, harbour seal, fin whale, humpback whale, minke whale, sei whale, harbour porpoise, white beaked dolphin, bottlenose whale, sperm whale, and pilot whale. Blue whale occurs only rarely in the assessment area but is vulnerable due to its very small population.

## Mitigation and oil spill response

It is recommended that environmental impacts from oil and gas activities are mitigated by including detailed background knowledge on the environment in the planning of the activities. It is further recommended to combine this information 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. If the regulation of activities is based on detailed background knowledge, it allows for exchanging the precautionary principle with empirical knowledge to the benefit of both operators and the environment.

## Oil spill contingency and response

The environmental risk of large oil spills can be minimized 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. Cold conditions can extend the operational window for dispersion. Dispersion transfer the oil from the sea surface to the water column, where it can affect organisms, which would not be affected from surface oil. The method requires a comparative analysis of environmental pros and cons, a SIMA (Spill Impact Mitigation Assessment) before it can be applied. Dispersion will also facilitate natural degradation of the oil, which in Greenland waters, however, seems often to be of limited use, 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 have 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.

## Recommendations from DCE and GINR on area restrictions

The DCE and GINR recommendations on area restrictions for oil exploration (hydrocarbon licence) in this strategy period 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 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.

None of the especially valuable areas (criteria 1) previously identified on a national scale is located within the Davis Strait assessment area. Among the important areas identified or confirmed within the assessment area (and not covered by criteria 2 and 3), is an offshore area consisting of a soft coral garden. This area is also recommended as a candidate for area restriction. With respect to criteria 2, DCE /GINR recommend to consider a coastal protection zones corresponding to zones used in northern Norway, and DCE/GINR propose a 65 km coastal protection zone in three areas with high biological value and high sensitivity, namely the fjords and surroundings of Nuuk, the fjords and surroundings of Maniitsoq and an area south of Sisimiut. For the remaining coastline DCE/GINR recommend a 35 km protection zone. Concerning ice cover (criteria 3), DCE and GINR recommend to consider allowing oil activity only if the ice cover is below a certain value, which we recommend to be somewhere in between the one defined by the Norwegian criteria of 15% ice frequency and the 30% mean sea ice cover in March (see Chapter 9).

**Knowledge gaps**

There is a general lack of knowledge on many of the ecological components and processes in the Davis Strait area. Identification of knowledge gaps for environmental management and regulation of future oil activities in the Davis Strait is presented in Chapter 9. To manage future oil activities, more information is required in order to: a) assess, plan and regulate activities to minimise the risk of impacts; b) identify the most sensitive areas and update the Oil Spill Sensitivity Atlas; c) establish a baseline to use in 'before and after' studies for impacts from any large oil spills.

**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.

# Dansk resumé

Denne rapport er en opdateret, strategisk miljøvurdering (SMV) af aktiviteter forbundet med olieefterforskning og -udvinding i den grønlandske del af Davisstrædet (Merkel et al. 2012). Der refereres til det aktuelle område som *vurderingsområdet* for Davisstrædet, hvilket er beliggende mellem 62° og 67° N og strækker sig mod vest ud til grænsen for den grønlandske *Exclusive Economical Zone* (EEZ) (Fig. 1.1.1). Opdateringer sker med baggrund i, at området planlægges åbnet for *open door*-ansøgninger[2] i november 2020.

Miljøvurderingen er udarbejdet af DCE - Nationalt Centre for Miljø og Energi (DCE) og Grønlands Naturinstitut og er 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. Opdateringen er baseret på publiceret og upubliceret viden, som er blevet tilgængelig siden den første strategiske miljøvurdering i 2012.

Miljøvurderingen skal indgå i beslutningsprocessen om den fremtidige olieefterforskning og -udvinding i den grønlandske del af Davisstrædet. Desuden står den beskrevne viden til rådighed for de selskaber, der skal udføre miljøvurdering (VVM) af deres aktiviteter i Grønland.

Den aktuelle rapport udgør én ud af fem strategiske miljøvurderinger, som dækker alle havområder i Vestgrønland samt Nordøstgrønland. Rapporten som dækker det tilstødende havområder mod nord, Disko Vest området, er også under opdatering.

Rapporten giver en kortfattet beskrivelse af det fysiske miljø, efterfulgt af en mere detaljeret gennemgang af de biologiske forhold. Dernæst følger en gennemgang af de beskyttede områder, de truede arter, forureningskilder samt den menneskelige udnyttelse af de biologiske resurser. Baseret på denne beskrivelse af den nuværende situation, vurderes de potentielle konsekvenser af olieaktiviteter, herunder oliespild, derefter diskuteres hvilke områder, det kan være relevant at friholde for olieefterforskning for at beskytte miljøet i den kommende strategiperiode, bl.a. baseret på de norske kriterier anvendt i Barentshavet. Endelig vurderes det hvilken ny viden, som er mest aktuel at tilvejebringe, såfremt det skal være muligt at reducere usikkerheden på vurderinger af de potentielle konsekvenser. Det skal bemærkes, at miljøvurderingen ikke belyser det klimaaftryk som forbrugerne efterlader, når de afbrænder olie/gas fra de potentielle grønlandske oliefelter.

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, er vurderinger af aktiviteter i denne forbindelse ikke konkrete, men bygger på erfaringer fra andre områder med så vidt muligt sammenlignelige forhold. Der er især trukket på den omfangsrige litteratur om de to store oliespild i USA (Exxon Valdez and Deepwater Horizon), den norske miljøvurdering af olieaktiviteter i Barentshavet (Anon 2003), samt på Arktisk Råds "Arctic Oil and Gas Assessment" (AMAP 2010b).

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.

På grund af barske vejrforhold og udbredt havis i de nordlige og vestlige dele af vurderingsområdet, forventes olieefterforskningsaktiviteterne at være begrænset til sommer og efterår (ca. juni – november). Såfremt en egentlig olieproduktion påbegyndes, forventes der dog at pågå aktiviteter året rundt.

## Miljøet

**Det pelagiske miljø**

De fysiske forhold i vurderingsområdet er kort beskrevet med fokus på oceanografi og isforhold. Den sydlige del af området er normalt isfrit året rundt, med udtagelse af de mest vestlige dele. Den nordvestlige del af vurderingsområdet er sædvanligvis isdækket fra omkring februar til maj. I kolde vintre dannes der desunden fastis i de inderste dele af fjordene. Af og til forekommer der isbjerge i området, hyppigst senvinter og forår. Isfjelde ses dog sjældent nord for Fyllas Banke. Dette skyldes strømforhold, bathymetri og den lange afstand til produktive isbræer.

Offshore-bankerne i Sydvestgrønland hører til blandt de vigtigste karakteristika for havmiljøet i vurderingsområdet. En høj vandgennem-strømning over disse forholdsvis lavvandede områder forårsager en kraftig opstigning af næringsrigt vand, som skaber basis for en langvarig høj primærproduktion. Bankerne er sædvanligvis helt eller delvis isfrie (løst drivis kan forekomme) året rundt, med undtagelse af Store Hellefiskebanke i den nordlige del af vurderingsområdet. Den høje primærproduktivitet på bankerne opretholdes i op til flere måneder længere end på dybere offshore lokaliteter. En anden vigtig egenskab for området er overgangszonen, hvor arktiske og tempererede havstrømme mødes. De fysiske processer der er forbundet med frontzonerne påvirker planktonorganismerne på forskellig vis, herunder næringstilgangen og dermed niveauet for primær- og sekundærproduktion samt planktonfordelingen. Desuden adskiller havvand fra de mere kystnære områder sig fysisk og kemisk fra det mere oceaniske vand, idet det opblandes med ferskvand fra oplandet.

Det pelagiske miljø i offshore områderne er karakteriseret ved lav biodiversitet (undtaget bundfaunaen) - men ofte talrige og tætte koncentrationer af de tilstedeværende populationer, en relativ simpel fødekæde fra primærproducenter til topprædatorer og nogle få arter der spiller en nøglerolle i det økologiske system. Den mest markante økologiske begivenhed i det marine miljø er forårsopblomstringen (april/maj) af fytoplankton, som udgør primærproducenterne i fødekæden. Forårsopblomstringen sker i hele vurderingsområdet, og hvor der er is, sker den i takt med isens tilbagetrækning. Fytoplankton græsses af zooplankton, inklusiv de vigtige Calanus vandlopper (primært *C. finmarchicus*), som udgør nøglearter i det marine økosystem. Udover at zooplankton udgør føde for de højere trofiske niveauer i fødekæden, så som fisk, bardehvaler og havfugle, så spiller det også en økologisk nøglerolle for bundfaunaen, som forsynes med værdifuld føde i form af nedsynkende fækalier fra zooplankton organismerne.

Da vurderingsområdet ligger indenfor det sub-arktiske område, er det marine miljø domineret af atlantiske arter, så som *C. finmarchicus* vandlopperne. For nylig er der imidlertid identificeret en hidtil ubeskrevet sydgående strøm langs kontinentalsoklen i Sydvestgrønland, som kan betyde, at zooplankton fra det arktiske område er vigtigere for offshore områderne, end tilfældet er i de bedre undersøgte kystnære områder. Samtidig forventes det, at densiteten er lavere i offshore områderne, sammenlignet med de kystnære områder.

**Bentisk flora og fauna**

Makroalgerne findes langs kystlinjen, er tilknyttet hård bund, og kan forekomme på mere end 50 m dybde. Biomassen og produktionen af litorale og sublitorale makroalger kan være betydelig og dermed vigtig for de højere trofiske niveauer i fødekæden. De kan fungere som substrat for fastsiddende organismer, yde beskyttelse mod prædation, udtørring, strøm og bølgeslag eller som direkte fødeemne. I de mørke vintermåneder når fytoplankton er fraværende, udgør det partikulære organiske stof fra makroalgerne en meget væsentlig fødekilde for bundfaunaen. Generelt er produktionen af makroalger høj i vurderingsområdet, grundet de overvejende isfrie forhold året rundt. Unikt for vurderingsområdet er forekomsten af ålegræs *Zostera marina* (en rødlistet art), som danner tætte ´enge´ på blød sandbund i fjordene omkring Nuuk. I samme område forekommer koralrødalgen *Corallina officinalis*, som det eneste sted i Grønland. Derudover er der forekomst af løstliggende kalkrødalger.

Havbundens makrofauna konsumerer en betydelig del af den tilgængelige primærproduktion og udgør til gengæld vigtige fødeemner for fisk, havfugle og havpattedyr. Vurderingsområdet har et stort antal historiske indsamlingsstationer, hvorfra mere end 1000 forskellige arter af bunddyr er registreret. Nye studier har afsløret en meget heterogen sammensætning af bundtyper, såvel som en meget høj artsrigdom på blødbundslokaliteter med op til 80 arter/artsgrupper per $0.1m^2$ prøveflade. Arter, som karakteriserer de såkaldte VME'er (Sårbare marine økosystemer – *Vulnerable Marine Ecosystems,* ifølge FAOs kriterier for sårbarhed overfor bundtrawl) er fundet flere steder i vurderingsområdet. For nylig blev Grønlands første koralhave med bløde koldtvandskoraller beskrevet indenfor vurderingsområdet og vurderet som en egnet kandidat til et VME for bunddyr med et areal på 486 $km^2$ og en udstrækning på 60 km langs kontinentalsoklen.

**Havisens økologi**

Havis er yderst dynamisk og samtidig et ekstremt miljø med store vertikale variationer i lysforhold, temperatur, saltholdighed og tilgængelige næringsstoffer. Organismer, som lever inde i de små saltholdige hulrum i isen samt på undersiden af isen, inkluderer vira, bakterier, alger, ciliater (infusionsdyr), flagellater, tanglopper og vandlopper. Undersøgelser fortaget udenfor vurderingsområdet viser, at primærproduktionen i havis er af stor betydning for de højere trofiske niveauer i den arktiske fødekæde på tidspunkter af året, hvor den pelagiske og bentiske produktion er lav. Forholdene i vurderingsområdet er dog dårlig undersøgt, inklusiv Vestisen i den nordvestlige del af området.

**Fisk**

Fiskefaunaen i offshore områderne, inklusiv fiskebankerne, er domineret af bundlevende arter, såsom hellefisk, helleflynder, rødfisk, havkat samt andre ikke-kommercielle arter. For hellefisk, der udgør en meget vigtig kommerciel fiskeriresurse, antages det, at det primære gydeområde ligger indenfor vurderingsområdet og er væsentlig for bestands-rekrutteringen også udenfor området (Nordvestgrønland og Canada). Tobis forekommer i tætte stimer på fiskebankerne og udgør vigtigt bytte for visse fisk, havfugle og bardehvaler. I det kystnære område gyder tre vigtige arter: torsk, lodde og stenbider. Lodde er vigtig som bytte for større fisk, havfugle, havpattedyr samt for mennesker. Både torsk og stenbider (rogn) udnyttes på kommerciel basis. Fjeldørred er også en vigtig art i det kystnære område og er genstand for meget lystfiskeri. Andre arter, som udnyttes i mindre skala, kommercielt eller ikke-kommercielt, er havørred, helleflynder og havkat.

### Havfugle

Havfugle kolonier er talrige i vurderingsområdet, om end de typisk er mindre i størrelse sammenlignet med nordligere kolonier i Vestgrønland. I alt er 20 arter kendt som almindelige ynglefugle fra området og den højeste tæthed af kolonier findes i skærgårdsområdet mellem 63° and 66°N på trods af, at ikke alle områder er systematisk gennemsøgt for ynglefugle. To arter hører til blandt de mere sjældne ynglefugle i Grønland, nemlig lunde og atlantisk lomvie, og disse er listet som henholdsvis ”sårbare” og ”udryddelsestruet” på den grønlandske rødliste.

For 13 arter er deres vigtighed for vurderingsområdet klassificeret som ”høj” på en national eller international skala, grundet antallet af ynglefugle, fældefugle eller overvintrende fugle (Tab. 3.7.1). Vurderingsområdet er særlig vigtigt som overvintringsområde for havfugle. Området udgør en stor andel af åbentvandsområdet i Sydvestgrønland, som huser et stort antal overvintrende havfugle fra Rusland, Island, Svalbard og Canada i perioden oktober - maj. Det er estimeret at mere end 3,5 millioner fugle overvintrer alene i det kystnære område. De mest talrige arter er polarlomvie, almindelig ederfugl, kongeederfugl og søkonge. Et ukendt, men stort, antal havfugle migrerer desuden gennem eller overvintrer i offshore-områderne.

### Havpattedyr

Havpattedyr udgør en signifikant komponent af det marine økosystem. Fem arter af sæler forekommer i vurderingsområdet, blandt hvilke grønlandssæl er talrig i hele området gennem det meste af året, mens spættet sæl er opført som ”kritisk udryddelsestruet” på den grønlandske rødliste. Den nordlige del af vurderingsområdet overlapper med den sydlige del af et vigtigt overvintringsområde for hvalros. Blandt hvalerne, er der flere bardehvaler som periodevist forekommer relativt hyppigt i vurderingsområdet, herunder vågehval, finhval, pukkelhval og sejhval. Området er en del af deres fourageringsområde om sommeren og fordelingen af hvalerne er ofte korreleret med de primære fødeemner: lodde, krill og tobis. Nye fly-surveys (2015) indikerer dog et skift eller en variation i den primære udbredelse af vågehval, finhval og pukkelhval, fra Vestgrønland til Østgrønland. Grønlandshval migrerer gennem vurderingsområdet i januar - februar måned, på vej mod fourageringsområder og muligvis yngleområder umiddelbart nord for vurderingsområdet. Flere tandhvaler er også almindelige i området, herunder marsvin, grindehval, døgling og hvidnæse. De sydlige overvintringsområder for hvidhvaler og narhvaler strækker sig desuden ind i den nordlige del af vurderingsområdet. Isbjørn forekommer i den vestlige del af området vinter og forår, afhængig af og knyttet til Vestisens udbredelse i Davisstrædet.

## Naturbeskyttelse og truede arter

### Internationale udpegninger

Fjorden Ikkattok og de omkringliggende øgrupper nær Paamiut er udpeget som vådområder af international betydning jf. Konventionen om vådområder af international betydning (”Ramsar-konventionen”).

### National lovgivning

Tre områder er fredet i henhold til Naturfredningsloven. To af disse er dog terrestriske områder og vil ikke være påvirket af olieaktiviteter. Det tredje område er øen Akilia ved Nuuk, som er beliggende i den yderste skærgård og fredet på grund af geologiske forekomster (Fig. 4.1.1). Syv lokaliteter er beskyttet som havfugle reservater ifølge fuglebekendtgørelsen, som også beskytter andre havfugle kolonier mod forstyrrelser i form af et færdselsforbud, i den tid fuglene er tilstede.

Ifølge Råstofloven er flere områder udpeget som "vigtige områder for dyrelivet", hvor råstofaktiviteter er reguleret med henblik på ikke at påvirke fugle og pattedyr. Det omfatter f.eks. de vigtigste havfugle kolonier.

**Truede arter**
Grønland fik en ny national rødliste i 2018, og jf. denne kategoriseres ti arter af pattedyr, tolv fuglearter og én art af fisk fra vurderingsområdet som næsten truet (NT) eller truet (VU, EN, CR) (Tab. 4.3.1). Den internationale rødliste udpeger ti havpattedyr og fem fugle fra vurderingsområdet som næsten truede eller truede (Tab. 4.3.3).

## Menneskelige påvirkninger (presfaktorer)

Vurderingsområdet er påvirket af flere forskellige menneskelige aktiviteter og rapporten gennemgår et udvalg af disse, idet disse kan interagere med påvirkninger fra olieefterforskning og -udvinding.

**Langtransporteret forurening**
Indholdet af tungmetaller (primært kviksølv) og POP'er, hvis overvågning koordineres af AMAP, bioakkumuleres i fødekædernes toprovdyr og i mennesker, der lever af fangst og fiskeri. Især kviksølv giver anledning til bekymring og niveauet er måske stigende i vurderingsområdet. Bly har været faldende, mens der ikke synes at være tidstrend for cadmium. 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 i vurderingsområdet er generelt lavt, men forhøjet i havneområder.

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

**Fangst og udnyttelse**
Mennesker udnytter de naturlige resurser i hele området; fritidsfangst og erhvervsfangst i mindre skala er udbredt i det kystnære område, mens et betydeligt kommercielt fiskeri foregår udenskærs. Da det meste af det kystnære område ofte er næsten isfrit året rundt, er fangstmulighederne også gode det meste af året, om end der er fangstforbud i visse perioder. Havfugle er blandt de vigtigste resurser og bliver skudt i et betydeligt antal, om end antallet har været nedadgående gennem de sidste to til tre årtier. Sæler bliver også skudt/fanget i stort antal. Skindene bliver solgt og klargjort til det internationale marked på et garveri i Sydgrønland, mens kødet konsumeres lokalt. Den vigtigste art er grønlandssæl. Hvalros, hvidhval og narhval nedlægges vinter og forår i den nordlige det af området og er reguleret af kvoter. Desuden nedlægges marsvin, vågehval, finhval og pukkelhval i området, hvoraf fangsten af

de to førstnævnte udgør langt den største andel. Vågehval, finhval og pukkelhval er underkastet fangstkvoter, bestemt af IWC. Isbjørn skydes fåtalligt i den nordlige del af vurderingsområdet og reguleres ligeledes af kvoter.

Det kommercielle fiskeri repræsenterer det vigtigste eksporterhverv i Grønland og i 2018 udgjorde det 90 % af Grønlands eksportindtægt (4.1 milliard DKK). Hellefisk, rejer og krabber er de primære arter, der udnyttes kommercielt i vurderingsområdet og de årlige fangster udgør en stor andel af de totale fangster i Grønland. Andelen af den grønlandske rejefangst, der fanges i vurderingsområdet, er dog faldet betydeligt de sidste fem år, mens fangsten er steget nord for vurderingsområdet. Torskefiskeriet er vokset indenfor det seneste årti, men rekrutteringen til bestanden varierer betydeligt. Sammenlignet med tidligere historiske store forekomster (1960'erne), er de nuværende fangster af torsk dog stadig små. I det kystnære område pågår et mindre fiskeri, som fritidsfangst eller kommerciel fangst, af arter som stenbider, havkat, rødfisk, torsk, fjordtorsk (uvak), lodde, fjeldørred og laks.

**Turisme**

Turisme er et voksende erhverv i Grønland og er nu den tredjestørste økonomiske sektor på landsplan. I 2019 var det totale antal gæster i Grønland 105.000 og antallet af overnatninger var 266.000. Mere end halvdelen af disse gæster rejste til vurderingsområdet og især til Nuuk. Antallet af besøgende krydstogtskibe er også stigende. Seværdigheder i de kystnære områder er yderst vigtigt for turisterne.

**Klimaændringer**

Klimascenarier for Baffin Bugt - Davisstrædet regionen forudsiger en lokal temperaturstigning på 1 til 4 °C ved udgangen af 2030 og 1.5 til 10 °C i 2080 (sammenlignet med gennemsnittet 1986–2005), svarende til en opvarmning på 0,2 °C per årti over de næste 50 år. I de nordlige områder vil mindre havis betyde en længere vækstsæson for primærproducenterne, men til gengæld kan mere nedbør og mere smeltevand fra Indlandsisen betyde en kraftigere lagdeling af vandsøjlen, hvilket kan medføre en mindre tilførsel af næringsstoffer fra de dybere vandlag til de øverste vandlag, hvor fotosyntesen foregår. Vurderingsområdet er dog allerede isfrit det meste af året og derfor forventes det, at de fremtidige ændringer af økosystemet primært påvirkes af de stigende temperaturer samt ændringer af strømforhold, lagdeling og opblanding af vandmasserne.

Fangst og fiskeri i vurderingsområdet vil højst sandsynligt blive påvirket af klimaændringerne, så en bæredygtig fangst vil i fremtiden være afhængig af en fleksibel forvaltning af resurserne, samt en omstillingsparathed overfor nye eller alternative resurser. For nogle bestande vil klimaændringer virke som en ekstra stressfaktor, på linje med f.eks. fiskeri og jagt, og medføre en højere følsomhed overfor oliespild. Andre bestande kan blive større og mere robuste som en konsekvens af klimaændringer. Det er ligeledes sandsynligt, at artssammensætningen vil ændre sig. Nogle arter kan forsvinde eller deres udbredelse forskydes nordover, som det fx synes at være tilfældet med rejen i øjeblikket. Andre kan komme ind fra syd og drage fordel af de stigende temperaturer og ændrede fødeforhold, som fx atlantisk torsk og makrel.

Fremtidig overvågning og udforskning af økosystemet i vurderingsområdet er essentielt for at kunne følge disse ændringer og for at kunne bidrage med viden til en fremtidig økosystem-baseret forvaltning af de menneskelige aktiviteter, der effektivt kan tilpasse sig hurtige ændringer i økosystemet.

**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. Flere seismiske undersøgelser samtidigt eller efter hinanden eller udledning af produktionsvand fra mange produktionsbrønde bør således vurderes samlet og ikke kun enkeltvis. De samlede påvirkninger kan betyde, at man kommer over tålegrænsen for en bestand. Olieaktiviteter vil også kunne give anledning til kumulative effekter fra forstyrrelser eller oliespild sammen med for eksempel påvirkninger fra fangst, der kan have gjort dyr mere agtpågivende overfor forstyrrelser. Nogle gange kan effekter af forskellige aktiviteter forstærke hinanden så den samlede effekt bliver kraftigere end man ville forvente ud fra summen af de enkelte påvirkninger (synergi).

## Vurdering af olieaktiviteter i Davisstrædet

Nærværende vurderinger bygger på viden om arternes nuværende fordeling, deres tolerance og tærskelværdier overfor olierelaterede aktiviteter, samt på de eksisterende klimatiske forhold. Klimaændringer forventes imidlertid at ændre meget på miljøet i vurderingsområdet i de kommende årtier og det er derfor ikke givet, at konklusionerne er gældende for fremtidige forhold. Samtidig er en stor del af vurderingsområdet dårligt undersøgt og ny viden kan derfor også ændre på konklusionerne.

## Vurdering af efterforskningsaktiviteter

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

De væsentligste påvirkninger fra efterforskningsaktiviteter kan være forstyrrelser fra støjende aktiviteter (f.eks. seismiske undersøgelser, boring i havbunden og helikopterflyvninger) fra selve boreprocessen og udledninger. Alvorlige påvirkninger kan undgås med forebyggende tiltag, som f.eks. ved at undgå aktiviteter i særligt følsomme områder eller perioder.

De arter i området som er mest sensitive overfor støj fra seismiske undersøgelser er bardehvalerne (vågehval, finhval, sejhval og pukkelhval) og tandhvaler som kaskelot og døgling. Disse risikerer at blive bortskræmt fra vigtige opholdsområder om sommeren. En fordrivelse eller forskydning i udbredelse af hvalerne vil påvirke tilgængeligheden for fangerne, såfremt de oprindelige opholdsområder var vigtige fangstområder. Narhval, hvidhval, grønlandshval og hvalros er også sårbare overfor seismisk støj, men deres forekomst i området overlapper kun i mindre grad med de forventede seismiske undersøgelser.

Da seismiske undersøgelser kun er midlertidige, er risikoen for langtidspåvirkninger på populationer, forårsaget af enkelte surveys, ret lav. Risikoen er dog tilstede, såfremt der udføres flere undersøgelser samtidig, eller hvis undersøgelserne foregår i det samme kritiske område i lange perioder eller i adskillelige år i træk (kumulative effekter). Særlige 3D-seismiske undersøgelser, der typisk foregår i begrænsede områder, kan give anledning til mere markante midlertidige påvirkninger.

Indenfor fiskeriet, er risikoen for påvirkninger af seismisk støj størst for hellefisk. Disse risikerer midlertidigt (dage eller uger) at blive kortskræmt og kan resultere i mindre fangst på fiskepladserne. Selvom det præcise gydeområde for hellefisk er usikkert, må det anbefales at undgå seismiske undersøgelser i deres gydeperiode (tidlig vinter). Fiskeriet af rejer og krabber vil sandsynligvis ikke påvirkes.

Støj fra boreplatforme er også midlertidige, men mere permanente end seismiske undersøgelser. De mest sårbare arter i vurderingsområdet er hvaler og hvalros. Såfremt alternative habitater er tilgængelige for hvalerne, forventes der ikke nogen negativ effekt af aktiviteten, men hvis flere platforme opererer samtidig i et område, er der større risiko for bortskræmning fra de mulige alternative habitater.

Boremudder og –spåner forventes normalt udledt på havbunden. Af miljøhensyn bliver olieholdig boremudder transporteret til land, mens vandbaseret boremudder normalt udledes så længe de tilsatte kemikalier ikke er sundhedsfarlige. Der er dog lokale effekter på havbunden også ved udledning af vandbaseret boremudder pga. sedimentationen. Prøveboringer i de mest sårbare områder bør derfor helt undgås. Der bør foretages basisundersøgelser på borestederne før boringerne, med henblik på at dokumentere og vurdere om unikke bunddyrssamfund eller arter, så som koldtvandskoraller eller svampehaver, vil være i risiko for at blive påvirket af en øget sedimentation. Undersøgelser efter boringer skal dokumentere, at der ikke er større effekter end forventet. Miljøpåvirkningerne fra boremudder og -spåner kan forebygges ved at deponere begge dele på land eller i gamle borehuller.

Efterforskningsboringer er energikrævende processer og vil medføre store udledninger af drivhusgasser. Blot en enkelt boring vil forøge det grønlandske bidrag betydeligt.

Endelig vil der være risiko for oliespild (‘blow-out’) i forbindelse med en efterforskningsboring (se nedenstående).

## Vurdering af udviklings- og produktionsaktiviteter

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.

**Udledninger**

Boringerne vil fortsætte under udvikling og produktionsfasen og boremudder og spåner vil blive produceret i meget større mængder end i efterforskningsfasen. Udledninger bør minimeres mest muligt, ved at genbruge og tilbageføre materialerne og kun udledning af miljøvenlige kemikalier (f.eks. dem som ifølge OSPAR er klassificeret som ’grønne’ og ’gule’), der er blevet testet for giftighed og nedbrydning under arktiske forhold, bør tillades. Brugen af ”sorte” kemikalier er forbudt i Grønland og de ”røde” kemikalier kan kun benyttes hvis der tildeles dispensation. Selv ved ikke-giftige udledninger kan sedimentationen ændre fordelingen af kornstørrelser på havbunden og påvirke bundfaunaen i nærheden af udledningsstederne.

Produktionsvand (der pumpes op sammen med olien) udgør langt den største udledning til havmiljøet ved olieproduktion. Et oliefelt kan udlede op til 30.000 $m^3$ om dagen, og på årsbasis udledes der på den norske sokkel 148 millioner $m^3$. På grund af de store mængder er der i de senere år udtrykt bekymring for udledning af produktionsvand, for på trods af, at det er behandlet og overholder internationale miljøstandarder indeholder det stadig en del forurenede stoffer. 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 begrænses ved skærpede krav til indholdsstoffer eller undgås ved at pumpe vandet tilbage i oliebrønden (*re-injection*).

Udledninger af ballastvand medfører en risiko for at introducere ikke-hjemmehørende eller invasive arter. Derfor skal ballastvand behandles og udledes efter særlige regler. IMO konventionen om ballastvand trådte i kraft i 2017 og en række guidelines er udarbejdet (IMO Link). Alle skibe og boreenheder som tager del i olie og gas aktiviteter i Grønland skal følge guidelines fra IMO eller de tilsvarende canadiske regler (Link). Invasive arter er endnu ikke et stort problem i Arktis, men risikoen vil stige i takt med klimaændringer og den mere intensive trafik af tankskibe som opstår ved et producerende oliefelt.

Udvikling af et oliefelt og produktionen af olie er meget energikrævende og aktiviteten vil bidrage markant til Grønlands udledning af drivhusgasser. Et af de store norske oliefelter udleder i dag således næsten tre gange så meget $CO_2$ som hele Grønland tilsammen.

**Støj**

Støj fra boringer og positionering af skibe mv., vil fortsætte i en udviklings- og produktionsfase. Det kan potentielt føre til permanente tab eller forskydninger af vigtige sommerhabitater for hvalerne, særligt hvis flere produktionsfelter er aktive samtidig. Støj fra skibe (inkl. isbrydere) og helikoptere, bliver mere permanente i udviklings- og produktionsfasen i forhold til efterforskningsfasen, kan påvirke både havpattedyr og havfugle. De mest sårbare arter i vurderingsområdet er de kolonirugende havfugle, grønlandshval, narhval, hvidhval, vågehval, finhval, marsvin og hvalros – arter som muligvis forbinder støj med negative begivenheder, så som jagt. Traditionelle fangstområder kan også blive påvirket. Brug af faste flyveruter og –højder vil kunne minimere påvirkningerne fra helikopterstøj.

**Placering af installationer**

Placering af offshore installationer og etablering af infrastruktur kan lokalt påvirke artssamfund på havbunden og der er en risiko for at ødelægge vigtige fourageringsområder - hvalros er sårbar, om end de hovedsageligt forekommer i den nordlige del af vurderingsområdet. Fourageringsområder for overvintrende kongeederfugle på fiskebankerne (særligt Fyllas Banke) er også følsomme. Installationer på land kan lokalt påvirke ynglende fugle, hindre fjeldørreder vejen til visse elve, ødelægge den kystnære flora og fauna, samt påvirke det æstetiske indtryk af det uberørte landskab. Sidstnævnte kan få betydning for turismen.

En særlig påvirkning af fiskeriet er de sikkerheds/afspærringszoner (typisk 500 m), som etableres rundt om midlertidige eller permanente offshore installationer. Disse vil få en betydning, i de områder hvor der fiskes intensivt efter hellefisk og rejer.

Oplyste installationer og flares (gasflammer) kan tiltrække havfugle når det er mørkt og der er en risiko for, at specielt ederfugle og måske søkonger kolliderer med installationerne.

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

Påvirkninger fra udviklings- og produktionsfasen kan begrænses mest muligt ved at kombinere detaljerede miljøundersøgelser (for at lokalisere sårbare økosystemkomponenter) med nøje planlægning af placeringen af installationer og transportruter. Ligeledes skal BEP, BAT og internationale standarder (f.eks. OSPAR og HOCNF) implementeres for at reducere udledninger i havet og til atmosfæren.

## Oliespild

Det miljømæssige mest kritiske uheld, der kan ske ved de ovennævnte aktiviteter, er et stort oliespild. Et oliespild kan ske under selve boringen ('blowout') eller ved uheld i forbindelse med opbevaring eller transport af olien. Store oliespild er forholdsvis sjældne og den globale tendens i mængden af spildt olie er nedafgående. Risikoen er imidlertid altid tilstede.

Simuleringer af oliespild (potentielle drivbaner for et oliespild) er foretaget på seks lokaliteter i vurderingsområdet – tre steder på de relativt kystnære fiskebanker og tre steder længere til havs (Fig. 8.3.1). For de sidstnævnte gik den generelle drivbane for olien mod sydvest, med en potentiel påvirkning på et 70.000 km$^2$ stort havområde mellem Canada og Grønland. Olien fra de mere kystnære simuleringerne havde en lignede drivbane, men i et tilfælde fulgte olien en nordgående drivbane inden den bøjede af mod sydvest. I to af de kystnære simuleringer blev kysten også påvirket af olien. I alle seks simuleringer var der risiko for, at noget af olien nåede havbunden, om end i små mængder (< 5%).

Store oliespild kan potentielt påvirke alle niveauer af det marine økosystem, fra primær-producenter til topprædatorer. Det kan udgøre en trussel på populations- og måske endda artsniveau og påvirkningerne kan vare i adskillelige årtier, som det er dokumenteret for Prince William Sundet i Alaska. For nogle populationer kan dødeligheden i nogen udstrækning være kompensatorisk, idet den delvist erstatter naturlig dødelighed, mens den for andre populationer hovedsageligt vil være additiv i forhold til den naturlige dødelighed. Nogle populationer kommer hurtigt på fode igen, mens det for andre kan gå meget langsomt, afhængig af deres livsstrategi og populationsstatus. For arter, der er sårbare overfor olie og som samtidig udsættes for fangst, kan påvirkninger fra et oliespild reduceres ved at forvalte fangsten på en mere restriktiv og bæredygtig måde. Mangel på effektive afværgeforanstaltninger i isdækkede farvande og den ofte afsides beliggenhed, vil forværre den kritiske situation ved et oliespild.

For dette vurderingsområde er offshore områderne opdelt i otte områder, som hver især er klassificeret i forhold til deres sårbarhed overfor oliespild. Analysen er baseret på arternes eller artsgruppernes hyppighed, arts- eller bestandsspecifikke sårbarhedsværdier overfor olie, estimerede opholdstider for olien (oil residency), resurse udnyttelse og enkelte andre parametre. Gennem alle årstider er de mest kystnære offshore områder, cirka svarende til kontinentalsoklen, blandt de mest sårbare-områder. Disse er meget vigtige for migrerende og overvintrende havfugle, som fiskeområder for rejer og krabber og som fourageringsområde for bardehvaler. Om foråret og om vinteren klassificeres desuden det sydvestlige hjørne af vurderingsområdet som meget sårbart overfor oliespild. Det skyldes primært et intensivt hellefiskfiskeri og at der i marts og april måned findes yngleområder for klapmyds langs kanten af vestisen.

En sammenligning af årstider, baseret på absolutte sensitivitetsværdier og gennemsnitsværdier for alle offshore-områder viser, at vinteren er den mest sårbare periode, tæt efterfulgt af forår og efterår, mens sommeren er mindst sårbar overfor oliespild. Den primære grund til denne forskel er de store forekomster af migrerende/overvintrende havfugle gennem forår, vinter og efterår. Havfugle er generelt meget sårbare overfor olie, særligt alkefugle og havænder.

Det kystnære område i vurderingsområdet er særlig sårbart, fordi olien her kan påvirke områder med høj biodiversitet. Sårbarheden skyldes også, at olien kan blive fanget i bugter og fjorde, hvor høje og giftige koncentrationer af olie kan opstå. Der vil være risiko for negativ påvirkning af gydende fisk som lodde og stenbider om foråret, fjeldørred som samles foran elvene og mange havfuglepopulationer - både om sommeren, i trækperioder og særligt om vinteren, hvor havfugle fra mange steder i Nordatlanten samles i Sydvestgrønland. Langtidspåvirkninger kan forekomme i det kystnære område, såfremt olien indlejres i sedimentet, mellem sten, i muslingebanker eller i klippesprækker. Fra sådanne olieaflejringer kan olien langsomt sive og forårsage en kronisk forurening, der kan vare ved i årtier. I Prince William Sund i Alaska har sådanne olieaflejringer haft negative langtidseffekter for de fugle, der udnytter de forurenede kyster og nogle arter er endnu ikke kommet på fode igen. Det kystnære område er også meget vigtigt for de lokale fiskere og fangere og i tilfælde af et oliespild, kan deres aktiviteter blive markant påvirket af forbudszoner og ændrede fordelingsmønstre blandt fangstdyrene. Turistindustrien vil også blive negativ påvirket af et oliespild i det kystnære område.

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

Generelt forebygges oliespild bedst ved nøje planlægning og brug af standardiserede sikkerhedsprocedurer (HSE), forsigtighedsprincipper (BEP, BAT) og internationale standarder (OSPAR). Den foreliggende viden om oliespilds bevægelighed i isdækkede farvande er dog begrænset og den tilgængelige teknologi til bekæmpelse af olie i isdækket farvand er endnu utilstrækkelig.

**Primærproduktion og zooplankton**

Det vurderes, at påvirkningerne på primærproduktion og zooplankton fra et overfladespild i det åbne hav vil være lav i vurderingsområdet på grund af den store udbredelse i tid og rum af disse forekomster. Der er imidlertid en risiko for en negativ påvirkning (nedsat produktion) på primærproduktionen lokalt og forårsperioden med algeopblomstring vil være den mest sårbare periode. Det er dog givet, at et stort undersøisk olieudslip på størrelse med det i den Mexicanske Golf, må forventes at have større påvirkninger end et overfladesplid, for primærproduktionen, zooplankton og fiske/reje-larver.

**Fisk og krebsdyr larver**
Generelt er æg og larver fra fisk og krebsdyr mere sårbare overfor olie end de voksne individer og bestandene kan potentielt blive påvirket med reduceret rekruttering og efterfølgende konsekvenser for bestandsstørrelser og fiskeriudbytte i en årrække. Atlantisk torsk er særlig sårbar, fordi dens æg og larver kan være koncentreret i de øverste 10 m af vandsøjlen, hvorimod f.eks. larver af rejer og hellefisk normalt går dybere og derfor er mindre udsat overfor skadelige koncentrationer af olie på havoverfladen. Et undersøisk udslip på størrelse med det i den Mexicanske Golf 2010 (mere end 800.000 tons olie – det største oliespild i efterkrigstiden), med store lommer af olie fordelt i vandsøjlen, kan dog eksponere æg og larver overfor olie i store områder og dybdeintervaller og kan potentielt påvirke rekrutteringen og bestandsstørrelsen af arter som rejer, hellefisk, krabber og tobis.

**Bundfauna**
Bundlevende organismer som muslinger og krebsdyr er sårbare overfor oliespild, om end der ikke forventes nogen effekter på det åbne hav, med mindre olien synker til bunden. På lavt vand (< 10-15 m) kan høje toksiske koncentrationer af olie nå havbunden, med mulige konsekvenser for den lokale bundfauna og de arter, der udnytter disse, særligt almindelig ederfugl, kongeederfugl, havlit, remmesæl og hvalros. Et stort undersøisk olieudslip vil også kunne påvirke bunddyrene på dybt vand.

**Voksne fisk**
Der forventes ikke påvirkninger fra et overfladespild på voksne fisk i det åbne hav. Et stort undersøisk 'blow-out' vil derimod godt kunne ramme pelagiske og bundlevende fisk langt til havs, enten direkte eller indirekte gennem fødekæden. Hellefisk vil være udsat på begge måder, idet de bevæger sig op fra havbunden for at søge føde i de pelagiske vandmasser. Situationen er mest kritisk for det kystnære område, hvor store og toksiske koncentrationer af olie kan opbygges i beskyttede bugter og fjorde og resultere i høj dødelighed blandt fiskene (se ovenstående).

**Fiskeriet**
Et oliespild på det åbne hav vil primært påvirke fiskeriet gennem midlertidige forbudszoner, som skal forhindre fangst af kontaminerede fisk. Varigheden af sådanne forbudszoner vil afhænge af varigheden af olieudslippet, vejret og andet. Udenskærsfiskeriet efter hellefisk er stort i vurderingsområdet og eventuelle forbudszoner vil sandsynligvis også omfatte canadiske fiskeområder vest for vurderingsområdet. Dette skyldes, at hellefisk kan bevæge sig over store afstande på forholdsvis kort tid og der er således risiko for, at kontaminerede fisk (med afsmag – "tainted") fanges langt fra det oprindelige olieudslip.

Vurderingsområdet er også et af de vigtigste fiskeområder i Grønland for rejer og krabber. Forbudszoner kan ligeledes medføre betydelige økonomiske tab for dette fiskeri.

Oliekontaminerede kyster vil også medføre nedlukning af fiskeriet i kortere eller længere periode. Der er eksempler på mange måneders fiskeforbud som konsekvens af oliespild, særligt hvis olien er indlejret i sedimentet eller strandkanten. Det kommercielle kystnære fiskeri går primært efter stenbider og lokale bestande af torsk, mens lodde primært fanges til privat forbrug.

**Havfugle**

Havfugle er meget sårbare overfor olie i det marine miljø, idet de normalt tilbringer meget tid på havoverfladen, hvor de fleste oliespild sker og hvor olien typisk spredes. Sårbarheden er knyttet til deres fjerdragt, som blot ved meget små mængder olie mister deres isolations- og opdriftsevne. Kontaminerede fugle dør som oftest af underafkøling, sult, drukning eller pga. forgiftning. I vurderingsområdet er det kystnære område særligt sårbart, fordi der forekommer store koncentrationer af fugle det meste af året. En betydelig del af disse fugle, inklusiv ynglefugle, fældefugle og overvintrende fugle, er knyttet til habitater i den yderste skærgård. Et olieberedskab er vanskeliggjort i sådanne områder pga. den afsides beliggenhed, en kompleks kystmorfologi og ofte barske vejrbetingelser. De mest sårbare arter er havfugle med en langsom reproduktionsevne, et karaktertræk for mange alkefugle, mallemukker og havænder. Arter som polarlomvie, søkonge, ederfugle og havlit overvintrer i vurderingsområdet i stort tal, idet området er en del af et internationalt vigtigt overvintringsområde (åbentvandsområdet i Sydvestgrønland) for havfugle fra hele Nordatlanten.

Om efteråret og om vinteren er nogle arter af havfugle fra vurderingsområdet også i risiko for olieforurening længere til havs, inklusiv fiskebankerne, omend fuglene på det åbne hav sædvanligvis er mere spredte end i det kystnære område. Nogle af de vigtige arter er mallemuk, ride, lunde, søkonge, polarlomvie, tejst og kongeederfugl. Blandt disse er kongeederfugl den mest sårbare art, idet den samles i store tætte flokke på fiskebankerne om vinteren (Fyllas Banke og Store Hellefiskebanke). Et stort oliespild i disse områder kan decimere population.

**Havpattedyr**

Isbjørne og sælunger er blandt de mest sårbare havpattedyr overfor den direkte kontakt med olie og kun en begrænset eksponering kan være dødelig, idet olien påvirker pelsens isolationsevne. Der er vigtige forekomster af sælunger i vurderingsområdet (se nedenstående), mens isbjørne forekommer i varierende grad, afhængig af pakisens udbredelse i Davisstrædet.

Hvaler, sæler og hvalrosser kan påvirkes af oliespild på havoverfladen. Bardehvalerne kan få barderne indsmurt i olie og derved indtage olien med deres føde. Det kan føre til forgiftning og skader i maveregionen. De risikerer også at indånde oliedampe og at få olie i øjnene. I hvilken grad havpattedyr aktivt kan undgå at komme i kontakt med en oliepøl og samtidig hvor skadelig olien er for de ramte individer, er usikkert. Observationer indikerer imidlertid, at i det mindste nogle arter ikke opfatter olie som en trussel og de er gentagne gange set svømme direkte ind i en oliepøl.

Arter af havpattedyr, som kunne blive ramt af et oliespild i vurderingsområdet, kunne være remmesæl, klapmyds, ringsæl, spættet sæl, grønlandshval, narhval, hvidhval, isbjørn, marsvin, hvalros, døgling og kaskelothval. Spættet sæl er særlig sårbar fordi den er truet i Grønland, samt klapmyds fordi yngleområderne findes i den østlige pakis i Davisstrædet. Havpattedyr, som fouragerer i området om sommeren, inkluderer grønlandssæl, klapmyds, ringsæl, spættet sæl, finhval, pukkelhval, vågehval, sejhval, marsvin, hvidnæse, døgling, kaskelothval og grindehval. Blåhval forekommer sjældent i vurderingsområdet, men er sårbar pga. den meget lille population.

### 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 OSPAR fastsætter, og internationale vejledninger (fra fx Arktisk Råd) sikre, at forurening fra udledninger til luft og hav bringes ned til acceptable niveauer og at risikoen for uheld minimeres.

Myndighedernes miljøregulering 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 standarter.

### 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 effektivt 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. Biologisk nedbrydning har i flere undersøgelser vist sig at være meget langsom i grønlandske farvande, bl.a. fordi indholdet af næringsstoffer i vandet 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 når beredskabet planlægges, dels på et strategisk niveau (*Environment & Oil Spill Response tool*, EOS), dels i en operativ situation ved en SIMA (*Spill Impact Mitigation Assessment).*

## Anbefalinger fra DCE og GN vedr. områdebegrænsninger

DCE og GNs anbefalinger vedrørende områdebegrænsninger for olieaktiviteter (olie licencer) er baseret på anvendelse af tre kriterier for friholdelse af områder i den kommende strategiperiode: 1) Områder, der allerede er udpeget som de mest værdifulde på nationalt niveau, dvs. områder med særlig økologisk og biologisk værdi og høj følsomhed overfor oliespild, eller områder vurderet som meget værdifulde og sårbare i forbindelse med udarbejdelsen af denne rapport, 2) afstand til kystlinjen og dennes følsomhed overfor oliespild, da det er meget svært at beskytte kysten, hvis der sker et kystnært oliespild, samt 3) sandsynligheden for forekomst af is, da der ikke findes effektive metoder til bekæmpelse af oliespild i drivis.

Ingen af de særlige sårbare områder som tidligere er udpeget på nationalt niveau, ligger indenfor vurderingsområdet i Davisstrædet. Blandt vigtige områder indenfor vurderingsområdet, som ikke også er omfattet af kriterie 2 eller 3, foreslås det at overveje områdebegrænsninger i en nylig identificeret udenskærs koralhave. Vedrørende kriterie 2, anbefaler DCE /GN at benytte norske afstandskriterier og etablere en 65 km beskyttelseszone i tre specifikke særligt sårbare kystområder, nemlig fjordområdet og skærgården ved Nuuk, fjordområdet og skærgården ved Maniitsoq samt et kystområde syd for Sisimiut. For den resterende kystlinje anbefales en 35 km beskyttelseszone. Angående isdække (kriterie 3), anbefaler DCE/GN at overveje, kun at tillade olieaktiviteter i områder med minimalt isdække. Den præcise grænse for et acceptabelt isdække anbefales at ligge et sted mellem de norske anbefalinger, som kun tillader aktiviteter hvis is-frekvensen er mindre end 15%, og en grænse som er defineret ved det gennemsnitlige 30% isdække i marts måned (se kapitel 9).

## Manglende viden

Der er generelt mangel på information om økologiske komponenter og processer i Davisstrædet. En identifikation af videnshuller i forhold til en miljømæssig forvaltning og regulering af kommende olieaktiviteter i Davisstrædet er præsenteret i kapitel 9. For at forvalte kommende olieaktiviteter behøves der mere viden for at kunne a) vurdere, planlægge og regulere aktiviteterne således, at påvirkninger minimeres mest muligt; b) identificere de mest sårbare områder og herunder, at opdatere de eksisterende sensitivitetsatlas for oliespild; c) etablere baseline viden til brug i studier før og efter et eventuelt stort oliespild.

### Forklaring af ofte benyttede termer

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.

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.

Konsekvens af (*impact*) bruges, som effekt, men i lidt bredere betydning, som f.eks. konsekvensen på miljøet ved brug af giftige borekemikalier.

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*) er et begreb, der inkluderer 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.

# Imaqarniliaq

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Avatangiisinik naliliineq Davisstrædip Kalaallit Nunaannut qaninnerusortaani siunissami uuliaqarneranik misissueqqissaarnerit piiaanerillu pillugit aalajangiiniarnermi tunngavinnut ilaassaaq. Kiisalu ilisimasat allaaserineqartut ingerlatseqatigiiffiit Kalaallit Nunaanni suliaminnut atatillugu avatangiisinut sunniutinik naliliineranni atugassanngortinneqassallutik.

Nalunaarusiaq manna periusissiorfiusunik avatangiisinik naliliinerit tallimaasut Kitaata Tunullu imartaannut tunngasut ilagaat. Nalunaarusiat imartanut avannarliusunut, Qeqertarsuup Kitaanut tunngasut aammattaaq suliarineqarput.

Nalunaarusiami avatangiisit ersittut naatsumik oqaluttuarineqarput, kingornalu uumassuseqassusermut tunngasutsukumiinerusumik nassuiarneqarlutik. Tamatuma kingorna allaaserineqarput sumiiffiit illersugaasut, uumasut navianartorsiortut, mingutsitsinerup aallaavii kiisalu uumassusilinnik inuit iluaquteqarnerat. Massakkut pissusiusunik nassuiaatit taakku tunngavigalugit uuliasiornerit sunniutigeratarsinnaasaat nalilersorneqarput, soorlu uuliaarluernerup kinguneri, tamtuma kingorna piffissami naliliiffiusumi tulliuttumi avatangiisit illersorumallugit uuliaqarneranik misissueqqissaarfiusariaqanngitsut eqqartorneqarput ilaatigut Barentshavimi norgemiut najoqqutarisartagaannik tunngaveqarluni. Kiisalu sunniutaasinnaasut nalilerneqarneri qularnaannerulersinniarlugit ilisimasat nutaat massakkut pisariaqarnerpaat suussanersut nalilersorneqarput. Oqaatigineqassaaq avatangiisinik naliliinermi atuisut Kalaallit Nunaanni uuliaqarfinnit / gasseqarfinnit qaqitanik ikuallaassagaluarunik silap pissussaanut sunniutaat ilannngunneqarneq ajormata.

Uuliasiorfiup ingerlanerani tamarmi suliaasartut naatsumik oqaluttuarineqarput taavalu suliat pisartullu misilittakkat naapertorlugit avatangiisinut annerpaamik sunniuteqartartut ajornanngiinnera naapertorlugu nalilersorneqarlutik. Kisianni li Kalaallit Nunaanni uuliamik qalluineq misilittagaqarfigineqanngimmat sulianik taakkuninnga naliliinerit sulianut taakkununnga tunngasorpiaviunatik sumiiffinni allani sapinngisamik sanilliunneqarsinnaasuni misilittakkanik tunngaveqarlutik. 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.

Sumiiffiup naliliiviusup avannarpasinnerusortaani kippasinnerusortaanilu silap ilungersunartuunera immallu sikuusarnera pissutigalugu uuliaqarneranik misissueqqissaarnerit taamaallaat aasaanerani ukiaaneranilu (juni – november missaanni) ingerlanneqartassasut naatsorsuutigineqarpoq. Uuliasiornivilli aallartissagaluarpat suliat ukioq naallugu ingerlanneqartassasut naatsorsuutigineqarpoq.

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

## Avatangiisit

**Immap ikerani avatangiisit**

Sumiiffimmi naliliiviusumi avatangiisit tigussaasut immap sikullu pissusii aallaaviginerullugit naatsumik oqaluttuarineqarput. Sumiiffiup kujasinnerusortaa nalinginnaasumik ukioq kaajallallugu imaasarpoq taamaallaat kippasinnersaa minillugu. Sumiiffiup naliliiviusup avannamut kitaa februaarimiit maajimut sikuukkajuttarpoq. Aamma ukioq issikkaangat kangerluit qinngui aalaakaasumik sikuusarput. Tamaani ilulissat takkuttaannarput, annerpaamik ukiorissinerani upernaakkullu. Ilulissalli Fyllas Bankep avannaani qaqutigoorput. Tamatumunnga pissutaapput sarfaq, immap naqqata pissusaa kiisalu iigartartunut ungasinerujussua.

Kalaallit Nunaata kitaata kujasinnerusortaata avataani ikkannersuit sumiiffiup naliliiviusup imartaani avatangiisini ilisarnaqutaanerpaajupput. Imartat taakku itisoorsuunngitsut sarfarnerujussuat pissutigalugu imaq inuussutissaqarluartoq nillikaasarpoq taavalu naasuaraasat uumasuaqqallu sivisuumik pinngorarnissaannut tunngavissiisarluni. Ikkannersuit ukioq tamaat tamakkiisumik imaasarput imaluunniit ilaatigut sikusimasinnaasarlutik (saatsersunik sikoqarsinnaasarpoq), sumiiffiulli naliliiviusup avannarpasinnerusortaa Store Hellefiskebanke taamaangilaq. Ikkannersuarni uumasuaqqat naasuaqqallu pintngorarnerujussuat sumiiffinnut itinersunut saniliullugu qaammatinik qassiinik sivisunerusarpoq. Sumiiffiuttaaq pissusia pingaarutilik alla tassaavoq sumiiffiup ikaarsaarfiunera, tassa issittup kiannerumaallu imartaasa naapiffiat. Naapiffiup pissusii uumasuaqqanut assigiinngitsumik sunniuttarpoq, soorlu inuussutissat nalliussuuttarnerat taamalu uumasuaqqat uumasuarartortullu amerlassusii kiisalu uumasuaqqat agguataarneri. Tamatuma saniatigut sinerissamut qaninnerusortaani imaq imavimmiit pissutsimigut akumigullu allaasarpoq nunamiit imiinnarmik akuugaanerusarami.

Avataani immap ikerani uumassusillit assigiinngissitaartut amerlanngitsuinnaasarput (natermiulli taamaanngillat) – qasseerpassuartigulli amerlasoorsuusarput eqimasaqalutillu, uumasuaqqaniit kiisortunut qullerpaanut nerisareqatigiit qanittuinnaasarlutik uumasullu amerlanngitsut uumassusileqarfinni pingaaruteqartaqalutik. Imaani avatangiisini uumassusileqarnikkut pisartoq malunnaateqarnerpaaq tassaasarpoq upernaakkut (april/maj) naasuaraasat fyplankonit, nerisareqatigiinni aallaaviusartut pinngorartorujussuanngortarnerat. Upernaakkut naasuaraasat pinngorartarnerat sumiiffimmi naliliiviusumi tamarmi pisarpoq, sikoqartillugulu sikup tunuariartornera ilaarlugu pisarluni. Naasuaraasat taakku uumasuaqqanit, aamma pingaarutilinnit illeqqanit Calanusinit (annermik tassaasut *C. finmarchicus),* nerineqartarput, taakkulu imminni imaani uumassusileqarfinni qitiusaqalutik. Uumasuaqqat nerisareqatigiinnermi qulliusunit, soorlu aalisakkanit, arfernit soqqalinnit timmisanillu imarmiunit nerisarineqarnermit saniatigut aamma uumasunut natermiunut uumassusileqarnikkut pingaaruteqarput, taakkumi uumasuaqqat anaannik nerisaqarluartuugamik.

Sumiiffik naliliiffiusoq issittup kujatinnguaniimmat imaani avatangiisit atlantikup uumasuinik peqarluarput, soorlu illeqqanik *C. finmarchicusinik.* Qanittukkulli Kalaallit Nunaata kitaata kujasinnerusortaani nunaviup avammut atanera atuarlugu sarfamik kujammukaartoqarnera paasineqarpoq, taamaammallu sinerissami sumiiffinnut mississorluagaanerusunut sanilliullugu uumasuaqqat issittumeersut avataani pingaarnerusinnaapput. Aammattaaq naatsorsuutigineqarpoq sinerissamut sanilliullugu avataani uumasuaqqat akuttunerussasut.

**Immap naqqata naasui uumasuilu**

Immap naasuit (qeqquakkut) sineriammi manngertumik natilimmi naammattuugassaasarput, 50 meterinillu itissusilik tikillugu takussaasarlutik. Qeqqussakkut amerlasinnaaqaat naajorartaqalutillu, sorpassuartigullu nerisareqatigiinni qaffasinnerusuniittunut pingaaruteqartarlutik. Qeqqussat uumasunut nikiuitsunut uumaffiupput, aammalu qeqquaqarfissuit aalisakkat piaraannut pingaaruteqarput kiisortunut, parnunnermut, sarfamut malinnullu illersorfigisaramikkit, kiisalu qeqqussat nerisarineqartarput. Aammattaaq qeqquakkut kaperlannerani uumasuaraasat fyplanktonit peqartinnagit imaani sorujuarannguanik uumassusilinneersunik pilersueqataasuupput immap naqqani uumasunut amerlaqisunut nerisaalluartuullutik. Ataatsimut isigalugu sumiiffimmi naliliiffiusumi immap naaneri amerlaqasaqaat ukioq kaajallallugu annermik sikuusannginnera pissutigalugu. Sumiiffiup naliliiffiusup immikkoorutigaa immap ivigaasaanik aappaluartunik *Zostera marina*nik peqarluarami, taakku Kalaallit Nunaanni kisiartaallutik Nuup eqqaani kangerluit natiini sioraasuni aqitsuni amerlasoorsuakkuutaarlutik naasarput. Tamaanissaaaq Kalaallit Nunaanni kisiartaalluni aappalaartunik koraleqarpoq, latiinerisut *Corallina officinalisinik* atilinnik. Tamatuma saniatigut aappalaartunik kalkiusunik algeqarpoq atavissuunngitsunik.

Immap naqqata uumasui angisuut naasuaraasat pinngorartut ilarpassuinik nerisaqartuupput taamalu aalisakkanut, timmissanut imarmiunut miluumasunullu imarmiunut nerisaalluarlutik. Sumiiffimmi naliliiffiusumi qangaaniiilli katersisarfeqarpoq, taakkunanilu immap natermiui assigiinngitsut 1000 sinnillit nalunaarsorneqarsimapput. Misissuinerit nutaat takutippaat immap natermiui assorsuaq assigiinngissitaartuusut, allaammi misissuiffimmi 0.1m$^2$ angitigisumi assigiinngitsut 80 tikillugit amerlassuseqartarlutik. Uumassusillit uumassusileqarfinnut misikkarissunut (FAO-p natersiutinik kilisannermut misikkarinneragaanut VME *Vulnerable Marine Ecosystems)* ilisarnaataasartut sumiiffimmi naliliiffiusumi piffinni qassiini nassaarineqarsimapput, qanittukkullu Kalaallit Nunaanni koraleqarfissuaq siulleq, qituttunik nillertup koraaleqarfiusoq sumiiffiup naliliiffiusup iluaniittoq allaaserineqarpoq aammalu immap natermiuinut uumassusileqarfittut misikkarissutut nalilerneqarluni, taannalu 486 km$^2$ -inik angissuseqarpoq nunaviullu avammut atanera atuarlugu 60 km-inik takissuseqarluni.

**Immap sikuani uumassusileqarfik**
Immap sikua allanngorartorujussuuvoq aammalu avatangiisit sakkortuullutik taavalu qaamaneq, kissassuseq, tarajoqassuseq aammalu inuussutissat eqqarsaatigalugit itissutsini assigiinngitsuni allanngorarfiusorujussuulluni. Uumassusileqarpoq, sikut taserartaanni tarajuusuni sikulluni ataani uumasuusuni, soorlu virusit, bakteriat, algit, ciliatit uumasuaraarannguit, flagellatit, kingukkut illeqqallu. Sumiiffiup naliliiffiusup avataani misissuinerit takutippaat immap sikuani uumassusileeqqat pinngorarnerat issittumi nerisareqatigiinni qutsinnerusunut immap ikerani naqqanilu uumassusillit pinngorarpiannginnerisa nalaani assut pingaaruteqartartoq. Taamaattorli sumiiffimmi naliliiffiusumi pissutsit qanoq issusii misissorluarneqarsimanngeqaat, pingaartumik avannamut kitaani sikuusartumi.

**Aalisakkat**
Avataani aalisakkat, aamma ikkannersuarni, tassaanerupput natermiut, soorlu qalerallit, nataarnat, suluppaakkat, qeeqqat kiisalu aalisakkat iluanaarniutigineqanngitsut allat. Qalerallit, inuussutissarsiutigalugu aalisarneqartuni pingaaruteqaqisut, suffiffigisartagaat pingaarnerpaaq sumiiffiup naliliiffiusup iluaniittutut naatsorsuutigineqarpoq aammalu sumiiffiup avataani qalerallit pinngorarfiattut isigineqarluni (Kalaallit Kitaata avannaa kiisalu Canada). Putooruttut ikkannersuaqarfinni amerlasoorsuakkuutaartarput taavalu aalisakkat, timmissat arferillu soqqallit ilaannut nerisaalluartuullutik. Sinerissamut qanittumi aalisakkat pingaarutillit pingasut suffisarput: saarulliit, ammassat nipisaallu. Ammassat aalisakkanit annerusunit, timmisanit miluumasunillu imarmiunit kiisalu inunnit nerisaalluartuupput. Saarulliit nipisaallu suaat, inuussutissarsiutaapput. Eqallut aamma sinerissamut qanittumiittartut pingaaruteqarput aliikkutaralugu aalisarluarneqartarlutik. Uumasut allat annikinnerusumik piniarneqartartut, iluanarniutigalugu imaluunniit iluanaarniutiginagu, tassaapput eqaluit, nataarnat kiisalu qeeqqat.

**Timmissat imarmiut**
Timmisat ineqarfii sumiiffimmi naliliiffiusumi amerlapput naak Kitaata avannaani timmissat ineqarfiinit avannarpasinnerusumiittunit minnerusaraluarlutik. Katillugit timmissat 20-it tamaani nalinginnaasumik erniorfeqartutut ilisimaneqarput timmiaqarfiillu akulikinnerpaaffigaat qeqertaqarfik avannarpasissutsit 63° aamma 66°N akornanniittoq naak sumiiffiit tamakkerlutik timmissanut piaqqiorfiunersut misissorneqarsimanngikkaluartut. Timmissat assigiinngitsut marluk Kalaallit Nunaanni erniortunit qaqutigoornernut ilaapput, tassa qilanngat kiisalu atlantikup apppai, taakkulu Kalaallit Nunaata uumasunik navianartorsiortunik nalunaarsuiffiani ”mianernartutut” ”nungutaanissamullu navianartorsiortutut” nalunaarsorneqarsimapput.

Timmissat assigiinngitsut 13-it sumiiffimi naliliiffiusumi nuna tamakkerlugu imaluunniit nunat tamalaat akornanni pingaassusiat eqqarsaatigalugu ”qaffasissutut” nalunaarneqarsimapput erniortut, isasut imaluunniit ukiisartut amerlassusii eqqarsaatigalugit (Tab. 3.7.1). Sumiiffik naliliiffiusoq timmissanut imarmiunut ukiivittut pingaaruteqaqaaq. Sumiiffik Kitaata kujasinnerusortaani sikuuneq ajortup ilarujussuaraa, taamaaniittarpullu timmiarpassuit oktober – maajimi ukiiartortut Ruslandimeersut, Islandimeersut, Svalbardimeersut Canadameersullu. Naatsorsuutigineqarpoq sinerissap qanittuinnaani timmissat 3,5 millionit ukiisartuusut. Amerlanerpaasartut tassaapput appat, mitit, mitit siorakitsut kiisalu appaliarsuit. Aammattaaq sumiiffiit avasissut akunnerini timmissat amerlassusii ilisimaneqanngitsut ingerlaartarput ukiisarlutilluunniit.

**Miluumasut imarmiut**
Miluumasut imarmiut imaani uumassusileqarfinni annertuumik inissisimapput. Puisikkut assigiinngitsut tallimat sumiiffimmi naliliiffiusumi naammattuugassaasarput, taakkunanga aataat sumiiffimmi tamarmi ukiup annersaani amerlasarput, qasigissalli Kalaallit Nunaanni uumasunik navianartorsiortunik nalunaarsuiffimmi ”nungutaaqqajaalluinnartutut” nalunaarsimallutik. Sumiiffiup naliliiffiusup avannarpasinnerusortaa aarrit ukiivisartagaata kujasinnerusortaanut atavoq. Arferni arferit soqqallit sumiiffimmi naliliiviusumi takussaalluartarput, soorlu tikaagulliit, tikaagulliusaat, qipoqqaat aammalu tikaagulliusarnat. Sumiiffik tamanna aasaanerani neriniarfigisartagaannut ilaavoq arferillu nerisarnerusatik naapertorlugit agguataarsimasarput: ammassaat, krill kiisalu putooruttut. Taamaattorli timmisartumiit misissuinerit nutaat (2015) naapertorlugit malunnarpoq tikaagulliit, tikaagulliusaat kiisalu qipoqqaat siammarsimaffiat Kitaaniit Tunumut nuulersimasut imaluunniit allanngorartoqalersimasoq. Arfiviit sumiiffimmi naliliiffiusumi januaarip februaarillu qaammataani neriniarfimminnukarlutik aqqusaartarput immaqalu sumiiffiup naliliiviusup avannaani piaqqivigisartakkaminnut ingerlaarlutik. Aammattaaq sumiiffimmi arferit kigutillit nalinginnaapput, soorlu niisat, niisarnat, anarnat aammalu aarluarsuit qaqortunik siunillit. Qilalukkat qaqortat qernertallu ukiivigisartagaasa kujasinnerusortaat aamma sumiiffiup naliliiviusup avannaanut atapput. Sumiiffiup kitaata tungaanit ukiukkut upernaakkullu nanoqartarpoq, Kitaani Davidsstrædimi qanoq sikuutiginera apeqqutaalluni.

## Pinngortitamik illersuineq uumasullu navianartorsiortut

**Nunat tamalaat akornanni toqqakkat**
Paamiut eqqaanni Kangerluk Ikkattoq kiisalu taassuma eqqaani qeqertat masarsoqarfittut nunat tamalaat akornanni pingaarutilittut toqqarneqarsimapput, tak. Masarsoqarfiit nunat tamalaat akornanni pingaarutillit pillugit Naalagaaffiit Isumaqatigiissutaat (”Ramsarimi isumaqatigiissut).

**Nunami namminermi inatsisit**
Pinngortitamik eqqissisimatitsineq pillugu inatsit naapertorlugu sumiiffiit pingasut eqqissisimatinneqarput. Taakkunanngali marluk nunamiikkamik uuliasiornermit sunnerneqarnavianngillat. Pingajuat tassaavoq Nuup eqqaani qeqertaq Akilia, qeqertat avallersaaniittoq nunallu sananeqaataa pillugu eqqissisitaasoq (Assiliartaliussaq 4.1.1). Sumiiffiit arfineq-marluk timmissat pillugit nalunaarut naapertorlugu timmissanik imarmiunik eqqissisimatitsivittut illersugaapput, taakkunanissaaq timmissat imarmiut najugaqarfii allat timmissat tamaaniinnerisa nalaanni angallannikkut akornusersugaanermut illersugaapput.

Aatsitassanut inatsit naapertorlugu sumiiffiit qassiit ”sumiiffittut uumasunut pingaarutilittut” toqqagaapput, tamaani pisuussutinut uumaatsunut tunngasunik suliat timmissanik miluumasunillu sunniinissaq pinaveersaarniarlugu aqutaapput. Soorlu tamakku tassaapput timmissat imarmiut najugaat pingaarutillit.

**Uumasut navianartorsiortut**
Kalaallit Nunaanni uumasut navianartorsiortut pillugit nalunaarsuiffik nutaaq 2018-imi atuutilerpoq, taannalu naapertorlugu miluumasut imarmiut assigiinngitsut qulit, timmissat assigiinngitsut aqqaneq marluk kiisalu aalisakkat ataatsit sumiiffimmi naliliiviusumiittut navianartorsiunngersaasutut imaluunniit navianartorsiortutut (VU, EN, CR) nalilerneqarput (Tab. 4.3.1). Nunat tamalaat akornanni navianartorsiortunik nalunaarsuiffimmi miluumasut imarmiut assigiinngitsut qulit kiisalu timmissat assigiinngitsut qulit naliliiviusumi ittut navianartorsiunngersaasutut imaluunniit navianartorsiortutut nalilerneqarput (Tab. 4.3.3).

## Inuit sunniineri

Sumiiffik naliliiffiusoq inuit piliaannit assigiinngitsorpassuarnit sunnerneqartarpoq nalunaarusiamilu tamakku ilaat nassuiarneqarput uuliaqarneranik misissueqqissaarnerit qalluinerillu sunniutaanut taputartuussinnaanerat pillugu

**Ungasissumiit mingutsitsineq**
Sumiiffimmi naliliiffiusumi uumassusillit saffiugassamik oqimaatsumik (annermik kviksølvimik) kiisalu mingunnik arrortikkuminaatsunik (Persistent Organic Pollutants) akoqariartuinnarput, AMAP-imit ataqatigiissaagaasumik malinnaavigineqartumik, taakkulu nerisareqatigiinni kiisortut qullerpaat timaanni inunnilu piniarnermik aalisarnermillu inuussuteqartuni eqiteruttarput. Pingaartumik kviksølv

aarleqqutaavoq, sumiiffimmilu naliliiffiusumi qaffakkiartorsimassagunarluni. Aqerloq annikilliartorsimavoq, cadmiummili piffissap ingerlanerani taamaagunarani. 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.

**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. Sumiiffimmi naliliiffiusumi plasticimik mingutsitsinerup ilarujussua najukkameersuuvoq, plasticili aamma avataaniit sarfamit tikiunneqartarpoq.

**Piniarneq iluaquteqarnerlu**
Sumiiffimmi tamarmiusumi inuit pisuussutinik iluaquteqarput; sunngiffimmi piniarneq inuussutissarsiutigalugu piniarneq annertunngitsumik sinerissami ingerlanneqarput, aningaasarsiutigaluguli aalisarneq avataani annertuumik ingerlanneqarluni. Sinerissap qanittua ukiup annersaani imaasarmat ukiup annersaani piniarfigittarpoq naak piffissat ilaanni piniarneq inerteqqutaasaraluartoq. Timmissat imarmiut piniakkani pingaarnernut ilaapput amerlasuullu pisarineqartarlutik naak ukiuni qulikkaani marlunni pingasuni kingullerni pisat ikiliartorsimagaluartut. Aamma puiserpassuit pisarineqartarput. Amii Kujataani ammerivimmut tunineqartarput avammullu nioqqutissiassanngorlugit piareersarneqartarlutik, neqaallu tamaani najugalinnit nerineqartarlutik. Aataaq puisini pingaarnerpaavoq. Aarrit, qilalukkat qaqortat qernertallu sumiiffiup avannarpasinnerusortaani ukiukkut upernaakkullu pisarineqartarput pisassiisarnikkullu aqunneqarlutik. Aamma niisat, tikaagulliit, tikaagulliusaat qipoqqaallu tamaani pisarineqartarput, taakkunanngalu taaneqartut siulliit marluk pisarineqartuni amerlanerpaajusarlutik. Tikaagulliit, tikaagulliusaat qipoqqaallu pisassiissutaasarput IWC-imit aalajangersagaasunik. Nannut sumiiffiup naliliiffiusup avannarpasinnerusortaani amerlangitsut pisarineqartarput pisassiinikkuttaarlu aqutaallutik.

Inuussutissarsiutigalugu aalisarneq Kalaallit Nunaanni inuussutissarsiutini avammut tunioraaviusuni pingaarnerpaajuvoq 2018-imilu Kalaallit Nunaata avammut niuernermit isertitaanit 90 %-inik isertitsiviusimalluni (4.1 milliard DKK). Qalerallit, raajat assagiarsuillu tassaapput sumiiffimmi naliliiffiusumi aningaasarsiutigineqarnerpaajusut ukiumullu pisaasartut Kalaallit Nunaanni pisarineqartartut tamarmiusut ilarpassuarisarpaat. Taamaattorli sumiiffimmi naliliiviusumi kalaallit raajartarisartagaat ukiuni kingullerni tallimani malunnaatilimmik ikileriarsimapput, sumiiffiulli naliliiffiusup avannaani pisat qaffariarsimallutik. Saarullinniarneq ukiuni qulikkaani kingullerni qaffassimavoq, saarulliilli amerliartortarnerat allanngoraqaaq. Qangaanerusorli takkussimaarsimanerujussuannut (1960-ikkunni) sanilliullugu ullumikkut pisaasartut suli ikittuinnaapput. Sinerissamut qanittumi aalisarneq annikinneruvoq, tassa sunngiffimmi aalisarnertut imaluunniit inuussutissarsiutigalugu aalisarnertut ingerlanneqartarpoq, soorlu nipisaat, qeeqqat, suluppaakkat, saarulliit, uukkat, ammassaat, eqaluit kiisalu kapisillit aalisarneqartarlutik.

**Takornariartitsineq**
Takornariartitsineq Kalaallit Nunaanni inuussutissarsiutaavoq siuariartortoq massakkullu nuna nuna tamakkerlugu aningaasarsiorfiit annerit pingajorilersimallugu. 2019-imi Kalaallit Nunaanni tikeraat katillutik 105.000-iusimapput unnuinerillu 266.000-iusimallutik. Taakku affaat sinneqartut sumiiffimmut naliliiffiusumut pingaartumillu Nuummut ingerlasarput. Aamma umiarsuarnik takornariutinik tikiuttartut amerliartorput. Sinerissami takusassaqqissut takornarianut assorujussuaq pingaaruteqarput.

**Silap pissusiata allanngoriartornera**
Baffinip Kangerliumarngani Davisstrædemilu silap pissusiata qanoq issusissaanik eqqoriaanerit naapertorlugit 2030-ip naanerani sila 1–4 °C-inik kiannerulersimassangatinneqrapoq taavalu 2080-imi 1.5-iniit 10 °C-inut kiannerulersimassangatinneqarluni (1986-2005-imi agguaqatigiisitsinermut sanilliullugu), tassa ukiuni tulliuttuni 50-ini agguaqatigiissillugu ukiuni qulikkaani ataatsinik 0,2 °C-inik

qaffattarluni. Avannarpasinnerusumi imaq sikuunikinnerusalerpat uumasuaraasat naajorartarfiat sivitsussaaq, kisiannili siallersarnera Sermersuullu aakkiartornera annerulerpata immap qaleriissiternera agguataarluarsimanerulissaaq, tamatumalu kingunerisaanik immap itineraniit qaavanut naasuaraasat pinngorarfiannut inuussutissat ingerlaarnerat annikinnerulissaaq. Kisiannili sumiiffik naliliiffiusoq ukiup annersaani sikuusanngereermat naatsorsuutigineqarpoq uumassusileqarfiup siunissami allannguutai annermik kiannerulerneranit kiisalu sarfap allanngorneranit, immap qaleriissiterneranit aammalu erngit akuleriiaannerannit sunnigaanerulerumaartut.

Sumiiffimi naliliiffiusumi piniarneq aalisarnerlu silap allanngorneranit sunnigaanissaat ilimanaqaaq, taamaammat siunissami piujuaannartitsinermik tunngaveqarluni piniartoqarsinnaassappat pisuussutinik eqaatsunik aqutsineq apeqqutaassaaq, kiisalu pisuussutinut nutaanut allanulluunniit piareersimaneq apeqqutaassalluni. Uumasoqatigiikkuutaat ilaannut silap allanngornera ilungersornertitsisuussaaq, soorlu aalisarneq piniarnerlu taamaattoq, taavalu uuliaarluernermut misikkarinnerulersitsinermik nassataqassalluni. Uumasoqatigiikkuutaat ilaat silap allanngornera pissutigalugu amerlanerulerlutillu isumannaanerulersinnaapput. Aamma uumasoqatigiikkuutaat assigiinngitsut katitigaanerat allanngussasoq ilimanaateqarpoq. Uumasut ilaat tammarsinaapput imaluunniit siammarsimaffiat avannarparsinnaavoq, soorlu massakkut raajat taama pisut. Allat kujasinnerusumiit nalliullutik kiannerulernera nerisassaqassusiatalu allanngornera iluaqutigisinnaavaat soorlu atlantikup saarullii kiisalu avaleraasartuut.

Allannguutit tamakku malinnaavigisinnaajumallugit aammalu inuit suliaannik uumassusileqarfimmi allanngulertortunut naleqqussapallannerusinnaasunik uumassusileqarfinnik tunngaveqartunik aqutsisinnaanissamut ilisimasanik pissarsisinnaajumalluni siunissami uumassusileqarfinnik malinnaaviginninnerit misissuisarnerillu pingaaruteqarput.

**Sunniutit kattunneri**
Uuliasiornerup avatangiisinut sunniutaanik naliliinermut atatillugu sunniutit kattunneri puigorneqassanngillat. Taakku tassaapput inuit suliaasa tamarmiusut piffissami sumiiffimmilu kattunneri. Sajuppillatsitsisarnerit qassiit ataatsikkut tulleriissarlutilluunniit ingerlanneqartut imaluunniit qillerivinnit amerlasuunit qilleriviit imertaannik aniatitsineq sunniutinik kattutsitsisinnaapput. Sunniutit kattunneri pissutigalugit uumasoqatigiit attassinnaasaat sinnerneqarsinnaavoq. Uuliasiornikkuttaaq akornusersuinerit uuliaarluernerilluunniit assersuutigalugu piniarnerup sunniutaanit qallerneqarsinnaapput, taamalu piniakkat akornusersorneqarnermut sillimanerulersinnaallutik. Ilaanni suliat assigiinngitsut ataatsimut sunniutaat imminnut sakkortusaqatigiissinnaasarput taamalu ataasiakkaaginnarnerminniit kattunnermikkut annerusumik sunniuteqarsinnaallutik (sunniutit kattunneri).

## Davisstrimi uuliasiornernik naliliinerit

Matumani naliliinerit uumasut massakkut agguataarsimanerinik, taakku uuliasiornermit artukkerneqaratik tatineqarsinnaassusiannik, kiisalu silap pissusiinik atuuttunik tunngaveqarput. Silalli pissusai ukiuni qulikkaani tulliuttuni sumiiffimmi naliliiffiusumi avatangiisinik allannguerujussuarnissaat naatsorsuutigineqarmat inerniliinerit siunissamissaaq atuutissanersut qularnaatsumik oqaatigineqarsinnaanngilaq. Aamma sumiiffiup naliliiffiusup ilarujussua misissorluarneqarsimanngeqaaq taamaammallu ilisimasaat nutaat inerniliinernik allanngortitsisinnaapput.

## Misissueqqissaarnernik naliliinerit

Misissueqqissaarnerit ingerlaavartuuneq ajorput, amerlanertigut ukiualunni ingerlasarput amerlanertigullu sumiiffimmi akuersissuteqarfiusumi tamarmi siammarsimasarlutik. Uuliamik nassaartoqanngippat suliat unitsivinneqassapput. Uuliaqarpat qilleriviliornermut ikaarsaartinneqassapput qalluisoqalissallunilu (matuma kingulia takuuk).

Misissueqqissaarnertigut akornusersuinerit annersaat qillerinermi namminermi qalluinermilu sulianit nipiliorfiusunit pisarpoq (soorlu sajuppillatsitsisarluni misissuinernit, qillerinernit kiisalu qulimiguullit angalasarnerinit). Pinaveersaartitsiniutaasuik iliuuseqarnikkut sunniutit ilungersunartut pinngitsoortinneqarsinnaapput, soorlu sumiiffit misikkarivissut piffissalluunniit misikkariffiusut suliaqarfiginaveersaarnerisigut.

Uumasut sumiiffimmiittut sajuppillatsitsisarluni nipiliornernut misikkarinnerpaajusut tassaapput arferit soqqallit (tikaagulliit, tikaagulliusaat, tikaagulliusaarnat qipoqqaallu) kiisalu arferit kigullit soorlu kigutilissuit anarnallu. Taakku aasisarfimminnit pingaarutilinnit nujoqqatsinneqarsinnaapput. Arferit qimaatinneqarnerat siammarsimaffiisaluunniit allanngortinneqarnerat piniarneqarsinnaanerannut sunniuteqassaaq najortagarisimasaat piniarfiusarsimappata. Qilalukkat qernertat qaqortallu, arfiviit aarrillu aammattaaq sajuppillatsitsisarluni nipiliornermut misikkarissuupput, taamaattorli tamaani najortagaat sajuppillatsitsisarluni nipiliorfiusussanut annikitsunnarmik attuumassuteqarput.

Sajuppillatsitsisarluni misissuinerit piffissami killilimmi pisarnerat pissutigalugu uuttortaanernit ataasiartanit uumasoqatigiit sivisuumik atuuttussamik sunniuteqarsinnaanerat ilimanaatikeqaaq. Taamaattorli misissuinerit qassiit ataatsikkut ingerlanneqarpata, imaluunniit piffissami pingaarutimmi ataatsimit misissuinerit sivisuumik imaluunniit ukiuni qassiini tulleriisartumik ingerlanneqarpata sivisuumik atuuttumik sunnerneqaratarsinnaapput (sunniutit kattunneri). Pingaartumik sajuppillatsitsisarluni misissuinerit 3D-it piffimmi killimmi ingerlanneqakkajuttarput piffissami killilimmi malunnaateqarnerusunik sunniuteqarsinnaapput.

Aalisarneq eqqarsaatigalugu sajuppillatsitsisarluni misissuinernit sunnigaasinnaanerpaasut tassaapput qalerallit. Taakku sivikitsuinnarmik (ulluni sapaatilluunniit akunnerini) nujoqqatsinneqarsinnaapput aalisarfinnilu pisat ikilinerannik nassataqarsinnaallutik. Qalerallit suffiffigisartagarpiaat nalornissutigineqaraluartut suffinerisa nalaanni (ukioqqaakkut) sajuppillatsitsisarluni misissuinerit pinngitsoorneqarnissaat kaammattuutigineqassaaq. Raajarniarneq assagiarsunniarnerlu sunnerneqassagunanngillat.

Qillerivinniit nipiliorneq aamma ataavartuusanngilaq, kisiannili sajuppillatsitsisarluni misissuinerniit ataavarnerusarluni. Sumiiffimmi naliliiviusumi uumasut sunnertianerpaat tassaapput arferit aarrillu. Arferit allanik najugassaqarpata suliat ajortumik kinguneqassangatinneqanngillat, sumiiffimmili ataatsimi qilleriviit qassiit ataatsikkut ingerlappata najugaqarfigisinnaasaannit allanit nujoqqatsinneqaratarsinnaanerat ilimanaateqarnerussaaq.

Qillerinermi marraq perrassaat kiisalu qillernerlukut immap naqqanut nalinginnaasumik aniatinneqartarnissaat naatsorsuutigineqarpoq. Avatangiisit pillugit marraq qillerinermi perrassaat uuliartalik nunaliaaneqartarpoq, imertalilli nalinginnaasumik aniatinneqartarluni akuutissat akuliunneqartut peqqissusermut ulorianaateqanngippata. Marraalli katersuunneratigut marraap qillerinermi perrassaataasup imertallup aniatinneqarnera immap naqqanut sunniuteqarsinnaavoq. Taamaammat sumiiffinni misikkarinnerpaani misiligummik qillerinerit pinngitsoorneqavittariaqarput. Qillerisoqartinnagu avatangiisit qanoq issusii misissuiffigineqartariaqarput immap natermiui imaluunniit uumassusillit soorlu nillertup koraalii svampeqarfiilluunniit marraap kiviorarneranit sunnerneqassanersut nalilerniarlugu. Qillerinerit kingornagut misissuinertigut uppernarsarneqassaaq ilimagisamit annerusumik sunniisoqarsimannginnersoq. Marraap qillerinermi perrassaatip qillernerlukullu avatangiisinut sunniinissaat pinaveersaartinneqarsinnaavoq taakku tamaasa nunaliaattarnersigut imaluunniit qilligatoqqanut maqittarnerisigut.

Misissueqqissaarluni qillerinerit nukimmik atuiffiusaqigamik gassinillu kiatsinnartunik annertoorujussuarmik aniatitsiviusarput. Qillerineq ataasiinaannguarluunniit Kalaallit Nunaanni aniatinneqartunut ilasaataassaqaaq.

Aammattaaq misissueqqissaarluni qillerinermi tissaluttoornissaq ('blow-out') ilimanaateqaratarsinnaavoq. (matuma kingulianiittoq takuuk).

## Ineriartortitsinermi tunisassiornermilu sulianik naliliineq

Misissueqqissaarnerup nalaani pisartut paarlattuannik uuliasiorfimmik ineriartortitsineq uuliamillu tunisassiorneq sivisoorsuarmik ingerlasarput, suliallu qassiit avatangiisinut assorujussuaq sunniuteqarsinnaasarlutik. Avatangiisit allanngortinneqannginneranni qanoq issusiinik ilisimasaqarneq tunngavigalugu pilersaarusioqqissaarnikkut, peqqissusiseq, 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.

**Aniatitsinerit**
Uuliasiorfinnik ineriartortitsinerup tunisassiornerullu nalaanni qillerinerit ingerlaannartussaapput taavalu misissueqqissaarluni qillerinermit annerujussuarmik qillerinermi perrassaat qillernerlukullu pilersiortorneqassallutik. Atortunik sananeqaatinillu atoqqiisarnikkut utertitsisarnikkullu kiisalu akuutissanik avatangiisinut uloriananngitsunik (soorlu OSPAR-ip immikkoortiterisarnera naapertorlugu ´qorsunnik´kiisalu ´sungaartunik´) atuinikkut, taakku toqunassusermut misilinneqarsimassapput taavalu issittumi nungujartorsinnaasut akuerineqarsinnaasariaqarlutik. Akuutissanik "qernertunik" atuineq Kalaallit Nunaanni inerteqqutaavoq taavalu akuutissat "aappalaartut" taamaallaat atorneqarsinnaapput immikkut akuersissuteqartoqarneratigut. Aniatitat toqunartoqanngikkaluarunilluunniit kiviortartut pissutigalugit immap naqqaniittut angissusii allanngortinneqarsinnaapput aniaffiullu eqqaani immap natermiuisa uumasuinut sunniuteqarsinnaallutik.

Imeq uuliamik qalluinermi atorneqartoq imaanut aniatitsinermi annerpaajusarpoq. Uuliasiorfik ullormut 30.000 m3 tikillugit annertutigisumik aniatitsisinnaasarpoq, ukiumullu Norgep nunavittaata avammut atanerani 160 millioner m3 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).

Imermik pertujaallisaammik aniatitsinerit sumiiffiup uumasutoqarinngisaannik ingiaasartunilluunniit eqqussivioratarsinnaapput. Taamaammat malittarisassat immikkut ittut naapertorlugit imeq pertujaallisaat suliarineqartassaaq aniatinneqarlunilu. Imeq pertujaallisaat pillugu IMO-kkut isumaqatigiissut 2017-imi atuutilerpoq najoqqutassallu qassiit suliarineqarlutik (IMO Link). Umiarsuit qilleriviillu tamarmik Kalaallit Nunaanni uuliasiornermik gassisiornermillu suliaqartussat IMO-p najoqqutassiaanik imaluunniit taakku assipaluinik canadamiut najoqqutassiaannik malinnissapput. (Link). Uumasut ingiaasartut Issittumi maannamut annerusumik ajornartorsiutaasimanngillat, silalli pissusiata allanngoriartornera ilaarlugu kiisalu uuliasiorfeqalerneratigut uuliamik assartuutit angallannerulerneratigut tamakku tikiunneqarnissaat ilimanaateqarnerujartussaaq.

Uuliasiorfimmik sanaartorneq uuliamillu tunisassiorneq nukerujussuarmik pisariaqartitsiviusarput sulialu tamakku Kalaallit Nunaata gassinik kiatsinnartunik aniatitsineranut assut alliallaataassallutik. Norgemi uuliasiorfiit annerit ilaat Kalaallit Nunaanni $CO_2$-mik aniatitamit tamarmiusumit pingasoriaatingajammik aniatitsisarpoq.

**Nipiliorneq**
Qillerinernit aammalu umiarsuit sumiiffissaminnut inissinniarnerini allanilu nipiliornerit qilleriviit suliarineqarnerisa tunisassiornerullu nalaani ingerlaanartussaassapput. Tamatumuunakkut arferit aasisarfii pingaarutillit qaqugumut annaaneqarsinnaapput pingaartumik qalluiviit ataatsikkut qassiit ingerlanneqarpata. Umiarsuit (aamma sikusiutit) kiisalu qulimiguullit nipiliornerat misissueqqissaarnerup nalaanut sanilliullugu qilleriviliornerup qalluinerullu nalaanni ataavarnerulissaaq taavalu miluumasunut timmissanullu imarmiunut sunniuteqarsinnaalluni. Sumiiffimmi naliliiffiusumi uumasut sunnertianerpaat tassaapput timmissat imarmiut attarmoorlutik manniliortartut, arfiviit, qilalukkat qernertat qaqortallu, tikaaguliit, tikaagulliusaat, niisat kiisalu aarrit, - tassa uumasut nipiliornermut misillersimasut, soorlu piniarnermut eqqaanaralugu. Piniartarfitoqqat aamma sunnigaasinnaapput. Qulimiguullit aalajangersimasumik aqquteqarneratigut portussutsimillu aalajangersimasumik atuineratigut nipiliornerisa sunniutaat minnerpaatinniarneqarsinnaapput.

**Atortulersuutit inissinneqarnerat**
Atortulersuutinik pilersuivinnillu avataani inissiineq immap naqqata uumasuinut sunniuteqarsinnaavoq kiisalu neriniarfiit pingaarutillit aserorneqaratarsinnaallutik – aarrit sumiiffiup naliliiviusup

avannarpasinnerusortaaniinnerugaluarlutik sunnertiasuupput. Mitit siorakitsut ikkannersuarni ukiisut (pingaartumik Fyllas Bankemi) aamma misikkarissuupput. Nunami atortulersuutit tamaani timmissanut piaqqiortunut sunniisinnaapput, eqalunnut majunngitsoortitsisinnaallutik, sinerissami naasunut uumasunullu aseruisinnaallutik, kiisalu nunamik attorneqanngitsutut ittumik takussunarsaasinnaallutik. Kingulliullugu taaneqartoq takornariartitsinermut sunniuteqarsinnaavoq.

Aalisarnermut sunniutaasut immikkut ittut tassaapput avataani atortulersuutit ataavartuunngitsut ataavartulluunniit eqqaanni isumannaallisaanermut killiliiviit (500 meteriukkajuttut). Tamakku annertuumik qaleralinniarfimmi raajarniarfimmilu sunniuteqassapput.

Sanaartukkat qaammarsarsimasut kiisalu gassimik ikumatitsinerit taarnerani timmissanik kajungilersitsisinnaapput taavalu pingaartumik mitit immaqalu aamma appaliarsuit apornissaat ilimanaateqarsinnaalluni.

**Sunniutit kattunneri**
Suliat ataatsikkut tulleriiginnarlutilluunniit ingerlanneqarneranni sunniutit kattullutik sakkortuneruleratarsinnaapput. Assersuutigalugit sajuppillatsitsisarluni misissuinerit sunniutinik kattunnerinik kinguneqarsinnaaqaat. Aammattaaq inuit suliaannik allanik ilaqarnermikkut sunniutit kattussinnaapput, soorlu piniarnermut taputartuullutik imaluunniit silap pissusaata allanngorneranut taputartuullutik.

Qilleriviliornermit qalluinermiillu avatangiisinut sunniutit pitsaanerpaamik pinaveersaartinneqarsinnaapput avatangiisit suliffiussat sunnigaannginnerini avatangiisit pillugit ilisimasanik sukumiisunik pigisaqarnikkut kiisalu atortulersuutit angalanermilu aqqutissat inissisimaffiit pilersaarusioqqissaarnerisigut. Tamatuma saniatigut periaatsinikkiisaluavatangiisitigutperiaatsinikpitsaanerpaanikatuinikkut,kiisalununattamalaatpiumasaqaataanik, (soorlu OSPAR, HOCNF) malinninnikkut silaannarmut imaanullu aniatitsinerit akuerineqarsinnaasumut killilerneqarsinnaaput ajutoortoqarsinnaaneralu ilimanannginnerulersinneqarsinnaalluni.

## Uuliaarluerneq

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 qaqutiguukannilersimaqaat kiisalu nunarsuarmi tamarmi uuliaarluersarnerit ikiliartorlutik. Ajutoorsinnaanerli ilimanaateqartuaannarpoq.

Uuliaarluernermik pisuusaartitsinerit (uuliaarluernerup saatserfigisinnaasaanik) sumiiffimmi naliliiviusumi piffinni arfinilinni ingerlanneqarpoq – piffinni pingasuni sinerissamut qanikannersumi aalisagaqarfinni kiisalu avasinnerusumi piffiit pingasut (Assiliartaliussaq 8.3.1). Kingullerni taaneqartuni uulia kujammut kimmut saatserpoq, imartarlu Canadap Kalaallillu Nunaata akornanni ittoq 70.000 km$^2$-inik angissusilik sunnersinnaallugu. Uulia sinerissamut qaninnerusuni pisuusaartinneqartoq assingusumik saatserpoq, ataatsimili kujammut kimmut aallartinnani avannamut uulia saatseqqaarpoq. Sineriammut qanittoq pillugu pisuusaartitsinermi sineriak aamma uuliamit sunnigaavoq. Pisuusaartitsinerni arfinilinni tamani uuliap ilaata annikitsup immap naqqanut pinissaa ilimanaateqarpoq (< 5%).

Uuliaarluernerit annertuut imaani uumassusileqarfinnut sutigut tamatigut sunniuteqarsinnaapput, uumasuaqqanit pinngoqqaataasuniit kiisortunut qullerpaanut. Ataatsimoortukkuutaanut ilami allaat immaqa uumasoqatigiinnut navianartorsiortitsisinnaapput sunniutaallu ukiuni qulikkaani qassiini atuussinnaalluti, soorlu tamanna Alaskami Prince William Soundimi uppernarsarneqartoq. Ataatsimoortukkuutaat ilaanni toqusut taarserneqartarsinnaaput, tassami isumaminnik toqusussanut taartaaginnassammata, ataatsimoortukkuutaanili allani isumaminnik toqusunut ilasaataassalluni. Ataatsimoortukkuutaat ilaat amerleqqipallattarput, allalli kigaatsuararsuusinnaasarput uumanerminni periaasii ataatsimoortukkuutaallu qanoq issusiat apeqqutaalluni. Uumasut uuliamut misikkarissut saniatigullu piniagaasut uuliaarluernermit sunnigaanerat killilersimaarneqarsinnaavoq piniarnerup annerusumik killilersimaarneratigut piujuaannartitsinermillu tunngaveqartinneratigut. Immami sikuusumi pinaveersaartitsiniutinik iliuusissaqarluannginnera kiisalu avinngarusimasumiinnera uuliaarluernermik suli ulorianarnerulersitsissaaq.

Sumiiffimmi naliliiviusumi tassani avasissoq sumiiffinnut arfineq-pingasunut agguataarneqarpoq, taakkulu tamarmik immikkut uuliaarluernermut misikkarissusertik naapertorlugu immikkoortiterneqarput. Misissueqqissaarnermi tunngavigineqarput uumasut uumasoqatigiikkuutaalluunniit qassiit akulikissusii, uumasut ataatsimoortukkuutaalluunniit uuliamut misikkarissusiat, qanoq sivisutigisumik uuliamiinnerannik missingiineq (oil resisdency), uumasut atugaanerat kiisalu uuttuutit ataasiakkaat allat. Ukiup qanoq ilinerini tamani sinerissap avataa, nunaviup avammut atanerata nalikannia, tamani misikkarnerinnerpaajusarpoq. Imartat tamakku timmissanut imarmiunut ingerlaartunut ukiisunullu, raajarniarnermi assagiarsunniarnermilu, kiisalu arfernut soqqalinnut neriniarfittut pingaaruteqartorujussuusarput. Upernaakkut ukiullullu sumiiffiup naliliiffiusup kujammut kippasinnerusortaa uuliaarluernermut misikkarissorujussuartut aamma nalilerneqarpoq. Annermik pissutaavoq assut qaleralinniarfiunera kiisalu marts apriilimilu kitaata sikuata sinaavani natsersuarnit erniorfiusarnera.

Ukiup qanoq ilinerinik sanilliussinikkut, malussarissusiviit kiisalu imartani avasissuni agguaqatigiissitat tunngavigalugit takuneqarsinnaavoq ukiumi pinngortitaq sunnertianerpaajusartoq, upernaaq ukiarlu qanillutik tulliupput, aasarlu uuliaarluernermut annikinnerpaamik sunnertiaffiulluni. Taama assigiinngissusiannut pissutaanerpaaq tassaavoq upernaakkut, ukiukkut aasakkullu timmissat imarmiut ingerlaartut / ukiisut amerlasoorsuusarnerat. Timmissat imarmiut ataatsimut isigalugu uuliamut misikkarissorujussuupput, pingaartumik appakkut qeerlutuukkullu.

Sumiiffimmi naliliiffiusumi sineriak misikkarilluinnartuuvoq sumiiffiit assigiinngitsorpassuarnik uumasullit uuliamit sunnerneqarsinnaammata. Sunnertiassusiat aamma pissuteqarpoq uuliap kangerliumanerni kangerlunnilu unissinnaassusianik, taakkunanimi uulia assut kimittorsinnaavoq toqunarsisinnaallunilu. Aalisakkat suffisut soorlu ammassaat nipisaallu upernaakkut innarlerneqarsinnaapput, eqaluit kuuit akuini katersuuttut aammalu timmissat imarmiorpassuit innarlerneqarsinnaapput – tassa aasakkut ingerlaarneranni pingaartumillu ukiukkut timmissat imarmiut Atlantikup Avannaaniitut amerlaqisut Kitaata Kujataani eqiterunnerisa nalaanni. Uulia marrarmi, ujaqqat akornanni, uiloqarfinni qaarsulluunniit quppaanni unerarpat sinerissami sunniutit sivisorsuusinnaapput. Uuliap unerarfimminit taama ittunit seererusaarsinnaavoq mingutsitsinermillu ataavartunngortitsinnaalluni ukiuni qulikkaani ingerlasumik. Alaskami Prince William Soundimi uuliap unerarfii taama ittut timmissanut sinerissanik mingutsitanik atuisunut sivisuumik atuuttumik innarliipput timmissallu ilaat suli naqqissimanngillat. Sinerissattaaq aamma aalisartunut piniartunullu pingaaruteqaqaat uuliamillu mingutsitsisoqarpat suliat tamakku inerteqquteqarfinnit piniakkallu siammarsimaffiisa allanngornerinit assut sunnigaasinnaallutik. Aammattaaq sinerissamut qanittumi uuliaarluerneq takornariartitsinermut innarliisinnaavoq.

Sumiiffiup naliliiviusup avannaata kitaalu ukiukkut upernaakkullu aarlerinaateqarnerusarpoq Kitaata sikuata siammarsimanera pissutigalugu. Sikulimmi uuliaarluertoqassagaluarpat uulia aallaqqaammut sikut akornanniissarpoq kiisalu siku ataanni qangattannguaniissalluni. Sikut aallaqqaammut uuliaarluernermik siammatsaaliuissapput, sikulli uulia najummisutut ittarmagu aamma ungasissorsuarmut ingerlassinnaavaa (annerusumik nungujartortinnagu) taamalu maqisoorfioqqaartumiit ungaseqisumi avatangiisit, soorlu timmissat imarmiut kiisalu miluumasut imarmiut sunnersinnaallugit. Aamma uulia sikup sinaavani unissinnaavoq, tamaani sunnertiasunik naasuaraasarpassuit pinngorarfeqartarput, kiisalu timmissallu miluumasulluunniit imarmiut amerlallutik tamakkunaniittarlutik.

Uuliaarluernermit sunniutit pitsaanerpaamik pinaveersaartinneqarsinnaapput isumannaallisaanermi assigiissaakkanik periusissiornikkut, sillimanissamik periaasissiornikkut (periaatsinik kiisalu avatangiisitigut periaatsinik pitsaanerpaanik atuinikkut BEP aamam BAT), kiisalu nunat tamalaat piumasaqaataanik (OSPAR) atuinikkut. Taamaattorli immami sikuusumi uuliaarluernerup ingerlaartarneranik ilisimasat killeqarput aammalu immami sikuusumi uuliamik akiuiniarnermi atortorissaarutit pissarsiarineqarsinnaasut suli maannamut amigarput.

**Naasuaqqat uumasuaqqallu pinngorarnerat (planktonit)**
Avataani immami sikuunngitsumi immap qaani uuliaarluertoqarpat naasuaqqat uumasuaqqallu pinngorarnerat annikitsuinnarmik sunnerneqassanngatinneqarpoq tamakku sivisuumik sumiiffimmilu annertoorujussuarmi pinngorartarnerat pissutigalugit. Taamaattorli najukkami sumiiffimmi aalajangersimanerusumi pinngorarnerat annikinnerulersinnaavoq upernaakkullu naasuaqqat pinngorarnerat misikkarinnerpaajussaaq. Qularnanngilarli Mexicop Kangerliumanersuani pisutut angitigisumik immap

iluani uuliamik maqisoortoqalissappat naasuaqqat, uumasuaqqat, kiisalu aalisakkat/raajat qullugiaasa pinngorarnerat immap qaani maqisoornermiit annerusumik sunnigaassasoq.

**Aalisakkat peqquillu qullugiaat**
Aalisakkat peqquillu qullugiaat inersimasunit uuliamut misikkarinneruppput ataatsimoortukkuutaallu sunnigaasinnaallutik pinngortut ikilinerisigut tamannalu amerlassusiinut aalisarnermillu pissarsianut ukiuni qassiini sunniuteqarsinnaavoq. Avataata saarullii pingaartumik sunnertiasuupput taakku suaat qullugiaallu immap qatsinnersaani 10 meteriusuni katersuuttaramik, taavali soorlu raajat qalerallillu qullugiaat nalinginnaasumik itinerusumiittaramik immap qaani uuliap ulorianartumik kimitussuseqarfianit ingalassimasarlutik. Taamaattorli immap iluani maqisoorneq Mexicop Kangerlimanersuani 2010-i pisutut angitigisoq (uulia 800.000 tonsinit anneq– sorsuunnersuit kingorna uuliamik maqisoornerit annersaat), immap ikerani annertoorujussuarnik uuliaarluerfiusoq suannik qullugissanillu piffimmi annertuumi immallu ikerani annertuumi uuliaarluertitsisinnaaavoq taavalu raajat, qalerallit, assagiarsuit putooruttullu pinngorarnerannut amerlassusiannullu sunniuteqarsinnaalluni.

**Immap natermiui**
Immap natermiui soorlu uillut peqquillu uuliaarluernermit sunnertiasuupput naak uulia immap naqqanut kivinngippat sunnigaanissaat naatsorsuutigineqanngikkaluartoq. Ikkattumi (<10-15 m) uulia assut toqunartulik immap naqqanut pisinnaavoq, immap naqqata uumasuinut uumasunullu taakkuninnga nerisaqartunut, pingaartumik miternut, miternut siorakitsunut, allernut, ussunnut aavernullu kinguneqarsinnaasumik. Immap naqqani uuliaarluerneq annertooq aamma immap itisuup natermiuinut sunniuteqarsinnaavoq.

**Aalisakkat inerisimasut**
Immap qaani maqisoornerup immami sikuunngitsumi aalisakkanut inerisimasunut sunniuteqarnissaa naatsorsuutigineqanngilaq. Immalli iluani aniasoornersuaq aalisakkanut ikerinnarmiunut toqqaannartumik imaluunniit nerisareqatigiinneq aqqutigalugu eqquisinnaavoq. Qalerallit taakku tamaasa aqqutigalugit eqqugaasinnaapput tassami immap naqqaniit qullartertaramik nerisassarsiorlutik. Sinerissami kangerliumanerni kangerlunnilu uuliap toqunaqaluni annertuumik eqiteruffigisinnaasaani ajornerpaajusinnaavoq aalisakkallu toqorarnerujussuannik nassataqarsinnaalluni (siuliani takuuk).

**Aalisarneq**
Imaani sikuunngitsumi uuliaarluerneq aalisakkanik mingutsitanik pisaqarnissaat pinngitsoortinniarlugu imartat aalisarfigeqqusaajunnaarallarnerisigut aalisarnermut annermik sunniuteqarsinnaavoq. Uuliamik maqisoornerup sivisussusia, sila allalu inerteqqutit sivisussusiannut apeqqutaassapput. Sumiiffimmi naliliiffiusumi avataani qaleralinniarneq annertoqaaq aalisaqqusiunnaartoqassagaluarpallu sumiiffiup naliliiffiusup kitaani canadamiut aalisarfiat ilanngunneqassasoq ilimanarpoq. Tamatumunnga pissutaasoq tassaavoq piffissap sivisugisassaanngitsup ingerlanerani qalerallit sumorsuaq ingerlasinnaasarnerat taamalu aalisakkat uuliasunnilersimasut uuliaarluerfioqqaartumiit ungaseqisumi pisarineqariataarsinnaanerat.

Sumiiffik naliliiffiusortaaq Kalaallit Nunaanni raajarniarfiit assagiarsunniarfiillu pingaarnersaannut ilaavoq. Aamma inerteqquteqarfiit aalisarnerni taakkunani annertuumik annaasaqartitsisinnaapput.

Sineriak uuliamik mingutsitaappat aamma aalisarneq sivikitsumik sivisunerusumilluunniit matuneqassaaq. Uuliaarluernerup kingunerisaanik aalisarnerup qaammaterpassuarni inerteqqutigineqarneranut assersuutissaqarpoq, pingaartumik uulia marrarmi sissamiluunniit unerarsimatillugu. Sinerissami inuussutissarsiutigalugu aalisarneqartut tassaanerupput nipisaat kiisalu saarulliit tamaani ittut, taavalu ammassat annermik nammineq atugassatut piniarneqartarlutik.

**Timmissat imarmiut**
Timmissat imaani avatangiisini uuliaarluertoqartillugu assorsuaq misikkarittarput tassami immap qaaniikkajuttarput, immallu qaava amerlanerpassuartigut uuliaarluerfiusarpoq siammarfiusarlunilu. Misikkarissusiat meqquisa pissusiannik aallaaveqarpoq, tassami uuliamit annikitsunnguamilluunniit pineqaraangamik oqorunnaartarput puttaqutaajunnaartarlutillu. Timmissat uuliaarluersimasut amerlanertigut qiullutik, perlerlutik, ipillutik toqunartoqalerlutilluunniit toqusarput. Sumiiffimmi naliliiviusumi sineriak annermik mianernaateqarpoq ukiup annersaani timmiarpassuaqartarami. Timmissat taakku ilarpaalussui, aamma piaqqiortut, isasut kiisalu ukiisut qeqertat avalliit eqqaanni timmiaqarfinnut atasuupput. Sumiiffinni

taama ittuni uuliamut upalungaarsimaniarneq ajornakusoortuuvoq avinngarusimanerat pissutigalugu, sinerissap allanngorartorsuunera kiisalu silap ilungersunartarnera pissutigalugu. Timmissat eqqortianerpaat tassaapput timmissat imarmiut kigaatsumik amerliartorsinnaassusillit, taamaappullu appakkut, qaqulluit kiisalu qeerlutuukkut amerlaqisut. Timmissat soorlu appat, appaliarsuit, mitit kiisalu allerit sumiiffimmi naliliiffiusumi amerlasoorsuullutik ukiisarput, tamannalu Atlantikup avannaani tamarmi timmissat imarmiut nunanit tamalaaneersut ukiisarfigaat pingaarutilik (Kujataata kitaani imaq sikuunnigtsoq)

Ukiakkut ukiukullu timmissat imarmiut ilaat sumiiffimmi naliliiviusumiittut avasinnerusumiittut, aamma ikkannersuarni aalisagaqarfinni ittut, uuliamik mingutsitsinermut navianartorsiorsinnaapput naak timmissat imaannarmiittut sineriammiittunut sanilliullutik siammasinnerusaraluartut. Timmissat pingaarutillit ilaat tassaapput qaqulluit, taateraat, qilanngat, appaliarsuit, appat, serfat kiisalu mitit siorakitsut. Taakkunannga mitit siorakitsut sunnertianerpaajupput ukiuunerani ikkannersuarni amerlasoorsuullutik eqiteruttaramik (Fyllas Banke aamma Store Hellefiskebanke). Imartani taakkunani uuliaarluertoqassagaluarpat timmissat ikilisinneqarujussuarsinnaapput.

**Miluumasut imarmiut**
Nannut puisaaqqallu toqqaannartumik uuliaarluinermut misikkarinnerpaajupput annikitsuinnarmilluuniillu pineqarunik toqqutigisinnaasarpaat meqquisa oqorsaasinnaassusiat uuliamit sunnerneqartarmat. Sumiiffimmi naliliiviusumi pingaarutilinnik puiasaaraqarfeqarpoq (kingulianiittoq takuuk), nannulli takkusimasarnerat allanngorarnerusarpoq Davisstrædimi sikut siammarsimassusiat apeqqutaasarmat.

Arferit, pusit aarrillu immap qaani uuliaarluernermit sunnigaasinnaapput. Arferit soqqallit soqqaat uuliaarluersinnaapput taavalu nerisaminnut ilanngullugu uuliamik iisisinnaallutik. Tamanna toqunartoqalissutigisinnaaavaat aqajaqqumikkulu ajoquserneqaatigisinnaallugu. Aamma uuliap aalaanik najuussuisinnaapput isimikkullu uuliatersinnaallutik. Miluumasut imarmiut uuliamik qanoq ingalassimannitsigisinnaanerat ataasiakkaanullu uuliap qanoq ajoqusiitigisarnera ilisimaqqissaarneqanngilaq. Taamaattorli uumasut ilaasa uulia navianartutut isigineq ajoraat ataasiaratillu takuneqartarlutik uuliaarluineq toqqaannarlugu ornikkaat.

Miluumasut imarmiut sumiiffimmi naliliiffiusumi uuliaarluernermit eqqugaasinnaasut tassaapput ussuit, natsersuit, natsiit, qasigissat, arfiviit, qilalukkat qernertat qaqortallu, nannut, niisat, aarrit, anarnat kigutilissuillu. Qasigissat Kalaallit Nunanani navianartorsioramik assorsuaq inniminarput, kiisalu natsrsuit Davisstrædip sikuata kangisissuani erniorfeqaramik inniminartuullutittaaq. Milumasut imarmiut tamaani aasaanerani neriniartartut ilaatigut tassaapput aataat, natsersuit, natsiit, qasigissat, tikaagulliusaat, qipoqqaat, tikaagulliit, tikaagulliusaarnat, niisat, aarluarsuit qaqortunik siunillit, anarnat, kigutilissuit kiisalu niisarnat. Tunnullit sumiiffimmi naliliiffiusumi qaqutigoortuupput, ikittuinnaanertilli pillugu sunnertiasuullutik.

## Sunniutinik pinaveersaartitsineq

Uuliaqarneranik misissueqqissaarnermit qalluinermiillu avatangiisinut sunniutit pitsaanerpaamik pinaveersaartinneqarsinnaapput avatangiisit suliffiussat sunnigaanginnerini 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.

## Upalungaarsimaneq akiuiniarnerlu

Uuliaarluerneq siullermik periaatsinik pitsaanerpaanik aammalu avatangiisitigut periaatsinik 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, ( SIMA, Spill Impact Mitigation Assessment)

## Sumiiffinnik killiliineq pillugu Danmarkimi Avatangiisinik Nukissiutinillu Misissuisoqarfimmit Pinngortitaleriffimmiillu kaammattuutit

Uuliasiornermut atatillugu sumiiffinnik killiliineq pillugu Danmarkimi Avatangiisinik Nukissiutinillu Misissuisoqarfimmit Pinngortitaleriffimmiillu kaammattuutit piffissami periusissiorfiusumi aggersumi uuliasiortoqannginissaanut tunngaviit pingasut atorneqartut aallaavigalugit suliaapput: 1) Sumiiffiit nuna tamakkerlugu sumiiffittut nalilerujussuartut toqqarneqareersimasut, tassa sumiiffiit uumassusileqarfittut uumassusillillu eqqarsaatigalugit immikkut nalilittut aammalu uuliaarluernermut misikkarissorujussuartut isigineqartut, imaluunniit nalunaarusiap matuma suliarineqarnerani nalitoorujussuartut nalilerneqartut, 2) sinerissamut ungasissusia sinerissallu uuliaarluarnermut misikkarissusia, tassami sinerissamut qanittumi uuliaarluertoqarpat sineriak illersoruminaatsorujussuussaaq, kiisalu 3) sikoqarnissaanik ilimanassusia, tassami sikuni saatsersuni uuliaarluernerup akiornissaanut periaatsinik pisaasunik soqanngilaq.

Nuna tamakkerlugu sumiiffiit misikkarilluinnartut arlaannaalluunniit siusinnerusukkulli tikkuarneqareersutut Davisstrædimi sumiiffimmi naliliiviusumi inngilaq. Sumiiffimmi naliliiviusumi sumiiffiit pingaarutillit ilaat, uuttuummi 2 aamma 3-miinngitsut, eqqarsaatigalugit avataani koraleqarfimmi nassaarineqaqqammersumi sumiiffimmik killiliisoqarnissaa siunnersuutigineqarpoq. Uuttuut 2 eqqarsaatigalugu Danmarkimi Avatangiisinik Nukissiutinillu Misissuisoqarfiup / Pinngortitaleriffiup kaammattuutigaat norgemiut ungasissutsimut uuttuutaat atorneqassasut kiisalu sinerissami sumiiffinni misikkarilluinnartuni pingasuni illersuiffissanik 65 km-inik killeqarfiliisoqassasoq, tassa Nuup eqqaani kangerlunni qeqertarfimmilu, Maniitsup eqqaani kangerlunni qeqertanilu kiisalu Sisimiut kujataanni sinerissami. Sinerissap sinnera eqqarsaatigalugu 35 km-inik illersuiffissaliinissaq kaammattuutigineqarpoq. Sikuusarnera eqqarsaatigalugu (uuttuut 3), Danmarkimi Avatangiisinik Nukissiutinillu Misissuisoqarfiup / Pinngortitaleriffiup kaammattuutigaat annikinnerpaamik sikuusartumi taamaallaat uuliasiortoqarsinnaanissaa isumaliutigineqassasoq. Akuerineqarsinnaasumik sikuusarnerata killeqarfippiaa pillugu kaammattuutigineqarpoq norgemiut killigititaata, tassa sikut takussaanerisa 15%-imit annikinnerup aatsaat uuliasiortoqarsinnaanerata kiisalu marsip qaammataani agguaqatigiissillugu 30%-imik sikuunerata akornannut inissinneqassasoq (takuuk kapitali 9).

## Ilisimasat amigartut

Davisstrædimi uumassusileqarfiit immikkoortortaat suullu piartuaarneri pillugit paasissutissat amigaatigineqarput. Avatangiisinik aqutsineq kiisalu Davisstrædimi uuliasiornissanik malittarisassaqartitsineq eqqarsaatigalugit ilisimasatigut amigaataasut kapitali 9-imi saqqummiunneqarput. Uuliasiornissat aqussinnaajumallugit ilisimasat amigaatigineqarput imaaliorsinnaajumalluni a) sunniutit minnerpaasussanngorlugit suliat nalilersorsinnaanngorlugit, pilersaarusiorsinnaanngorlugit malittarisassiorsinnaanngorlugillu; b) sumiiffiit sunnertianerpaat suussusersissallugit, tassungalu ilanngullugu uuliaarluernermut misikkarissutsimik nalunaarsuiffiit pioreersut nutartissallugit; c) pinngortitap allanngortinneqartigani qanoq issusianik ilisimasat pissarsiarissallugit annertuumik uuliaarluertoqaratarsinnaanera sioqqullugu kingoqqullugulu misissuisarnerni atugassanik.

## Taaguutit tulliuttuni atorneqartut pillugit nassuiaatit

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.

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.

Kinguneri (*impact*). Sunniutinut siammasinnerusunngorlugu taaguutigineqartoq, soorlu qillerinermi akuutissat toqunartut atorneqarnerisa avatangiisinut kingunerinut.

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.

Avatangiisitigut ajutoorfiusinnaasut (*Environmental risk*) tassani nassuiarneqarput inuit suliaat pissutigalugit avatangiisinut sunniutaasinnaasut, soorlu misissueqqissaarluni qillerinerit qanoq ilimanartigineri taakkulu qanoq kinguneqarneri.

# 1 Introduction

In the period 1976 – 2011, a total of seven exploratory wells were drilled within the Davis Strait assessment area between 62° and 67° N (Fig. 1.1.1), but only minor quantities of oil and gas was encountered and not enough for commercial exploitation (Boertmann 2018, Wegeberg et al. 2018b). Related to this activity, site-specific Environmental Impact Assessments (EIAs) were made prior to drilling in the Fylla Licensing Area, the Lady Franklin area and the Kangaamiut area (Mosbech et al. 1996, Anon 2004a, b). As part of a new licensing round, a more comprehensive Strategic Environmental Impact Assessment (SEIA) was prepared by Merkel et al. (2012), covering the entire assessment area as shown in Fig. 1.1.1. When opening the Davis Strait area for 'open door' applications in September 2020, the 2012-assessment was more than 5 years old and an updated SEIA was needed (Mosbech et al. 2019).

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).

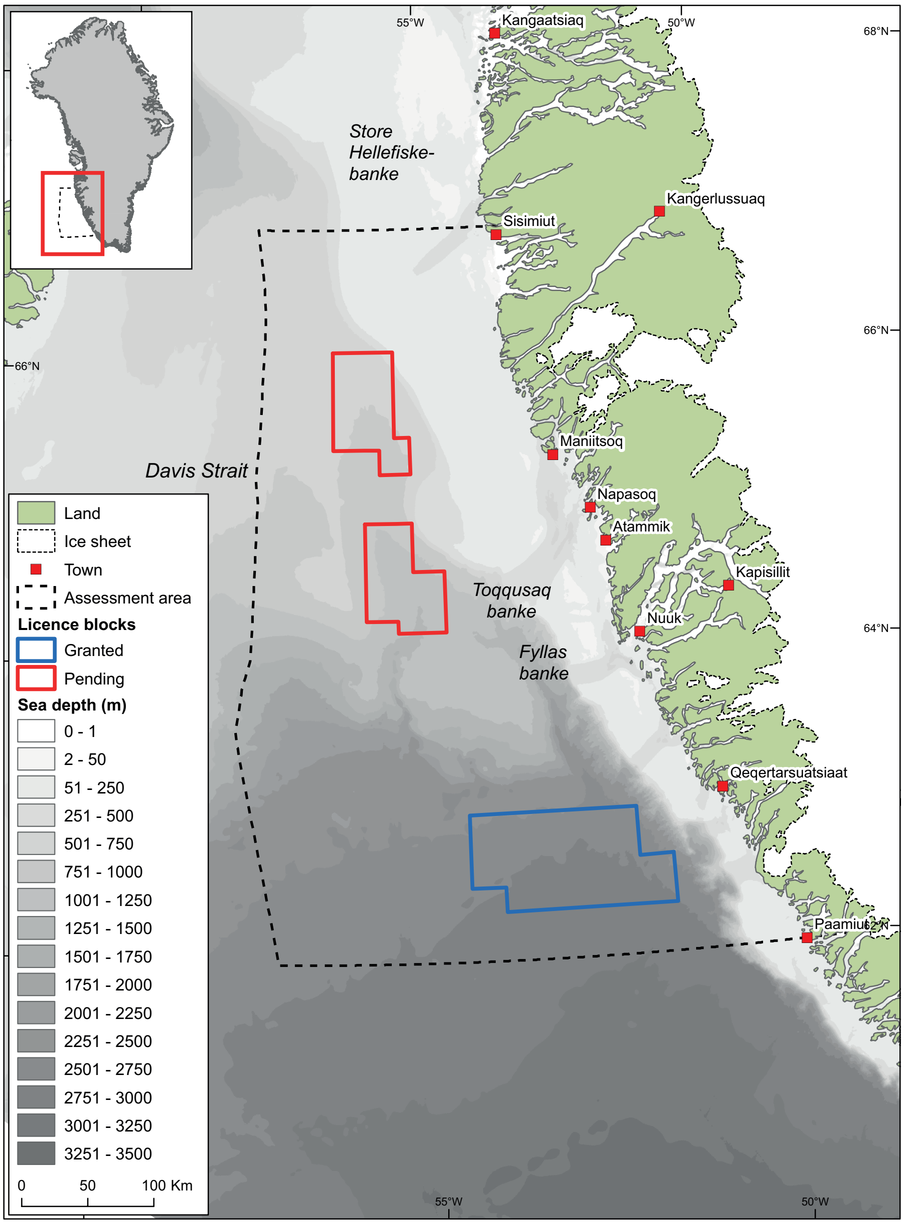



**Figure 1.1.1.** The assessment area, existing licence blocks and the surrounding areas in Southwest Greenland, including main cities and important shallow-water shelf banks

The current 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 the Greenland Institute of Natural Resources (GINR) and DCE - the Danish Centre for Environment and Energy at Aarhus University. Normally, a dedicated research programme is carried out either before or after the SEIA, but this has not been the case for the Davis Strait area. Both this update and the 2012 assessment are based purely on existing published and unpublished sources (for additional information see Merkel et al. 2012).

It is important to stress that a SEIA does not replace the need for site-specific Environmental Impact Assessments (EIAs). The SEIA provides an overview of the environment in the 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. The 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 EIAs.

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 now, 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 62° to 67° N in eastern Davis Strait (approximately from Paamiut to Sisimiut, Fig. 1.1.1) are in focus, as this is the region which potentially can be most affected by oil activities, particularly from accidental oil spills. This focus area will be referred to as the 'assessment area'. An SEIA has been produced for the area north of 67° N (Boertmann et al. 2013, currently being updated) and another one south of 62° N (South Greenland, Frederiksen et al. 2012a). The land areas are not included in the assessments.

The present assessment area extends over waters of two municipalities: Sermersooq and Qeqqata. Four main cities are located within the area, Sisimiut, Maanitsoq, Nuuk and Paamiut, counting roughly 6,236, 3,187, 17,591 and 1,527 people in 2019, respectively. Except for Paamiut, the number of residents is increasing in these cities. In addition, seven settlements are found between 62° to 67° N (from north to south: Sarfanngiut, Kangerlussuag, Kangaamiut, Napasoq, Atammik, Kapisillit and Qeqertarsuatsiaat), with altogether approx. 1,500 inhabitants in 2019 (Greenland Statistics 2020, Link).

## 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 Chapter 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.

The potential impact on VECs of activities during the various phases of the life cycle of a hydrocarbon licence area are summarised in a series of tables in Chapter 7 (Tab. 7.1.1, 7.1.2 and 7.1.3). 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 impossible. 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 2010b), the extensive literature from the Exxon Valdez oil spill in Alaska in 1989 (e.g. Shigenaka 2014, Esler et al. 2017), the increasing literature from the Deepwater Horizon spill in 2010 (e.g. Beyer et al. 2016) as well as from the Norwegian SEIAs of hydrocarbon activities, for example in Lofoten-Barents Sea (Anon 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 (Merkel et al. 2012), the assessment area has been included in the AMAP (2018a) report on 'Adaptation Actions for a Changing Arctic - Perspectives from the Baffin Bay/Davis Strait Region' with many different and highly relevant topics. The information has also been included in reports about 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, Christensen et al. 2016, Wegeberg et al. 2016a, Wegeberg et al. 2016b).

Many uncertainties remain and expert judgement or general conclusions from research and EIAs carried out in other Arctic areas have been applied in order to evaluate risks and to assess the impacts. 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 B.

Please consult Annex C for a comprehensive list of abbreviations and acronyms used in this report. See also the Summary for a glossary to some of the terms frequently used in the SEIA.

# 2 Physical environment

*David Boertmann & Christian Mohn (AU)*

The assessment area covers the Greenland part of the Davis Strait. In a climatic context it is within the low-Arctic zone characterized by an average air temperature above 5 °C in July (Brown et al. 2018a). In a marine context it is characterized as sub-Arctic, because the upper water layers are of mixed polar and non-polar origin (Dunbar 1954).

The Davis Strait is the narrowing that separates western Greenland and Baffin Island, the largest island in the Canadian Arctic Archipelago. In the north, it is connected to Baffin Bay, which again is connected to the Polar Basin through Nares Strait. In the south it is connected to the Labrador Sea. Sea ice forms in winter and has its largest extension on the Canadian side.

The shelf comprises the rather shallow waters inside the shelf break. It is up to 130 km wide in the southern part of the assessment area and 200 km wide in the northern part. Outside the shelf break the depths reach more than 2000 m in both the northern and southern part of the assessment area.

The shelf includes several large shoals or banks e.g., Fyllas Banke, Sukkertop Banke and Lille Hellefiskebanke, typically ranging between 20 and 100 m in depth. Deep troughs traverse the shelf, separating the fishing banks.

Supplementary information on the physical conditions in the assessment area can be found in following sources, of which some probably have been outdated by the ongoing climate changes: Nazareth and Steensboe (1998), Buch (2000), Karlsen et al. (2001), Buch (2002), Buch et al. (2004), Hansen et al. (2004), Myers et al. (2009) and Ribergaard (2010). Information can also be found in the oil spill sensitivity atlas covering the assessment area (Mosbech et al. 2004a, b). An updated view on water masses on the pan-West Greenland continental shelf and their link to proglacial fjords have recently been given by Rysgaard et al. (2020).

## 2.1 Weather and Climate

The weather in the assessment area is determined by the North American continent, the North Atlantic Ocean and particularly the sea currents. However, the Greenland Ice Sheet and the coasts of Greenland also have a fundamental impact on the local weather. Many Atlantic depressions develop and pass near the southern tip of Greenland and frequently cause very strong winds off West Greenland. Also, more local phenomena such as fog or polar lows are common features near the West Greenland shores. The probability of strong winds increases close to the Greenland coast and towards the Atlantic Ocean. Detailed descriptions of local wind patterns can be found in the oil spill sensitivity atlas covering the assessment area (Mosbech et al. 2004b).

## 2.2 Oceanography

### 2.2.1 Currents

The Davis Strait is a major gateway for the export of cold and low salinity waters from the narrow channels of the Canadian Arctic Archipelago (CAA) to the Northwestern Subpolar North Atlantic (Fig. 2.2.1). Davis Strait covers the area extending from West Greenland to Baffin Island south of Baffin Bay and

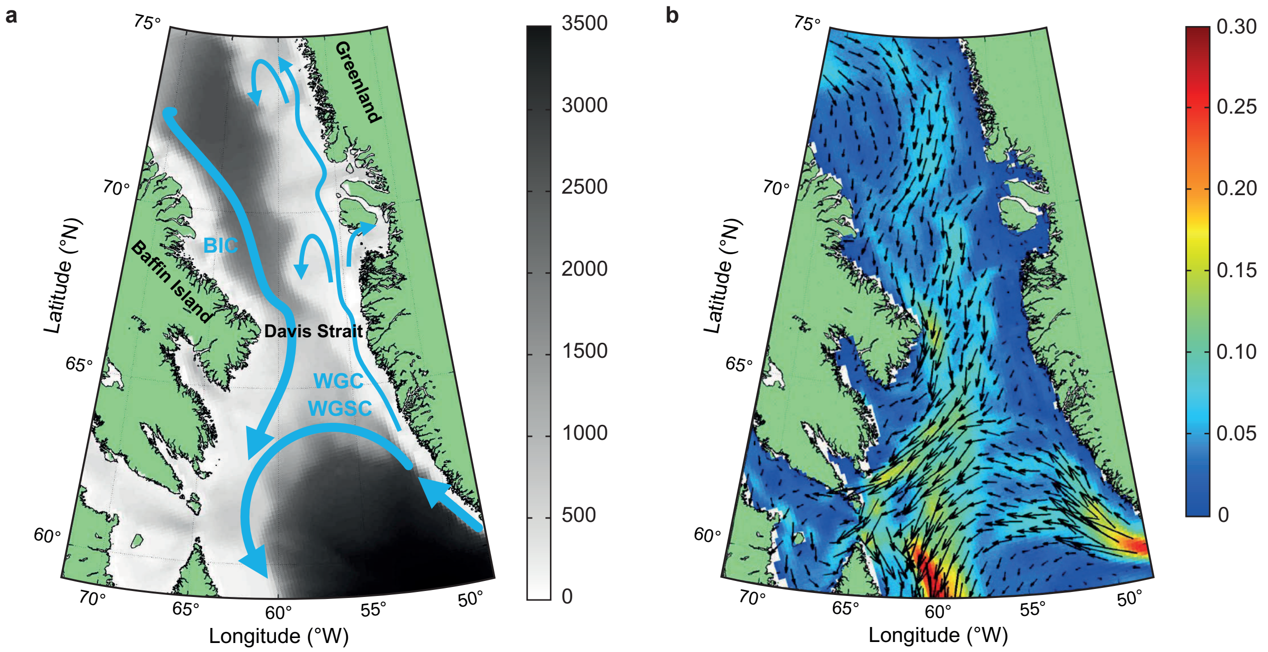



**Figure 2.2.1.** Major sea surface currents in the northern Atlantic. (a) General circulation through Davis Strait along West Greenland, Baffin Bay and in the northwestern North Atlantic (Fig. 1 in Curry et al. 2014). Cold Artic Water (AW) leaves Davis Strait as the broad, surface-intensified Baffin 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 (WGSC) of North Atlantic origin largely follows the continental slope in the depth range 150 – 800 m. The bulk of the warm Atlantic inflow around Southern Greenland is deflected westward at approximately 64° N latitude. (b) Upper ocean circulation (0-200 m) in the wider assessment area (Baffin Bay, Davis Strait, Labrador Sea) averaged over a period of 5 years (2013 -2017). Currents were obtained from the TOPAZ4-Hycom coupled hydrodynamics sea-ice model (marine.copernicus.eu). Coloured contours indicate current velocities in m/s.

between 60° and 70° N. Davis Strait and Fram Strait between Svalbard and Northeast Greenland account for 84% of the total freshwater export from the Arctic, with over half the freshwater export propagating through Davis Strait (Beszczynska-Möller et al. 2011).

The major features of the upper circulation in Davis Strait and adjacent seas are presented in Fig. 2.2.1a, based on Fig. 1 in Curry et al. (2014), and Fig. 2.2.1b, based on analysis of CMEMS model data (Copernicus Marine Environmental Monitoring Service, marine.copernicus.eu). The major oceanic circulation between the northern Labrador Sea and the Baffin Bay is largely counter-clockwise, strongly intensified at the western boundary and with a weaker northward flow along Western Greenland (Fig. 2.2.1a) (Curry et al. 2014). Cold Arctic waters merge as *Arctic Water* (AW) flows southward along the western Baffin Bay and Baffin Island as the surface-intensified *Baffin Island Current* (BIC). Average current velocities associated with the BIC are up to 0.15 m/s (Fig. 2.2.1b), but instantaneous velocities can strongly differ between seasons and years (Curry et al. 2014). *Arctic Water* properties are strongly transformed before flowing through Davis Strait because of freshwater inputs from Baffin Island and Northwest Greenland, net surface heat loss, and mixing with underlying warmer, more saline waters of Atlantic origin (Beszczynska-Möller et al. 2011).

On the eastern side of Davis Strait, the northward flow consists of two different components of different origin. The *West Greenland Current* (WGC) is the westward extension of the *East Greenland Current* (EGC) with substantial supplies from the EGC coastal inflow and glacial runoff (Sutherland & Pickart 2008). As a consequence, the *West Greenland Current* carries cold and low salinity waters northward along the West Greenland shelf in the depth range 0 - 150 m. The *East Greenland Current* component loses its influence on the way northward, and at the latitude of Fylla Banke (64º N) there is no longer a strong and solid current. North of 65° N, WGC waters encounter additional freshening on their way north by injections of run-off waters from the various fjord systems, e.g. Nuup Kangerlua (Godthåbsfjorden). Average current velocities of the *West Greenland Current* do not exceed 0.05 m/s north of 64º N (Fig. 2.2.1b). The *West Greenland Slope Current* (WGSC) derives its water mass properties from source areas in the northern North Atlantic and Irminger Sea.

New research has revealed a more detailed 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 representative of the summer 2016 situation and describe a distinct north-south division of water masses and flow patterns, but also a separation of water mass properties between slope and coastal areas (Fig. 2.2.2, copied from Rysgaard et al. 2020). 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* (BBPW) and was not identified north of 64 °N. In contrast, *deep Subpolar Mode Water* (dSPMW) was found to continue northward via deep open pathways and enter coastal fjords. The blockage of *upper Subpolar Mode Water* in the *West Greenland Slope 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).

Further south at approximately 64° N, the bulk of the warmer waters of Atlantic origin passing Southern Greenland detaches from the slope and is deflected westward towards the northwestern Labrador Sea (Curry et al. 2014). In this area, the *Baffin Island Current* and western retroflection of warmer Atlantic waters merge with the Hudson Strait outflow to feed the southward flowing *Labrador Current* (e.g. Straneo & Saucier 2008).

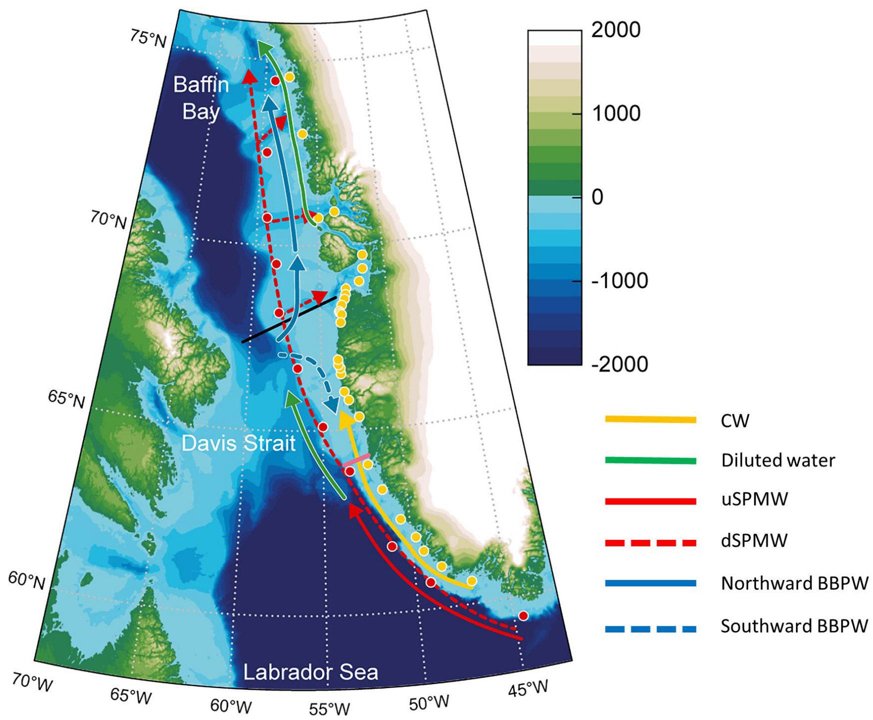
The *Arctic Water* outflow is strongest during spring and early summer (May-July). The inflow of relatively warm Atlantic water masses of the *West Greenland Slope Current* is strongest during autumn and winter. Mixing and heat diffusion of the two layers (The Polar and Irminger Currents) are important factors in determining temperature conditions in the assessment area. Years where the EGC and Irminger Current are strong will often be cold years (Nazareth & Steensboe 1998, Buch 2000, 2002, Hansen et al. 2004). South of Davis Strait, Rysgaard et al. (2020) found evidence of a previously undescribed southward coastal current carrying cold *Baffin Bay Polar Water* as far south as 64°N on the west Greenland continental shelf (Fig. 2.2.2).

A fifty-year long time-series of temperature and salinity measurements from West Greenland oceanographic observation points has revealed strong interannual variability in the oceanographic conditions off West Greenland (Mosbech et al. 2004b). 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, Mortensen 2015).

### 2.2.2 Fronts

Fronts are areas where different water masses meet with sharp boundaries and steep gradients between them. They can be upwelling events where cold nutrient water is forced upwards to the upper layers, fronts between different water

Figure 2.2.2. Currents and water mass distribution in the West Greenland coastal system based on recent measurements conducted in summer 2016 presented in Rysgaard et al. (2020). This figure is an extended copy of Fig. 1 in Rysgaard et al. (2020). Contours are in meters. 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.




masses and ice edges (inclusive the marginal ice zone). Upwelling often occurs along the steep sides of the shelf banks driven by the tidal current and therefore usually alternates with downwelling. Model simulations (Ribergaard et al. 2006) north of the assessment area predict that most frequent upwelling occurs west of the banks, both north and south of the Disko Bay entrance and at the slopes of Store Hellefiskebanke (Mosbech et al. 2007a and references therein).

The coexistence of cold, low saline Arctic water masses carried southwards by the *Baffin Island Current* and warmer, saltier Atlantic waters in the eastern Davis Strait constitutes a major frontal system. Fig. 2.2.3 shows the modelled mean annual cycle of water properties across Davis Strait, as modelled by Lu et al. (2014). The front between the Arctic and Atlantic Waters in the Davis Strait extends from surface to bottom and exists all year round. It is centered above the West Greenland slope in the eastern part of Davis Strait. The characteristics of the modelled along-strait water properties by Lu et al. (2014) are generally consistent with observations (Curry et al. 2014).

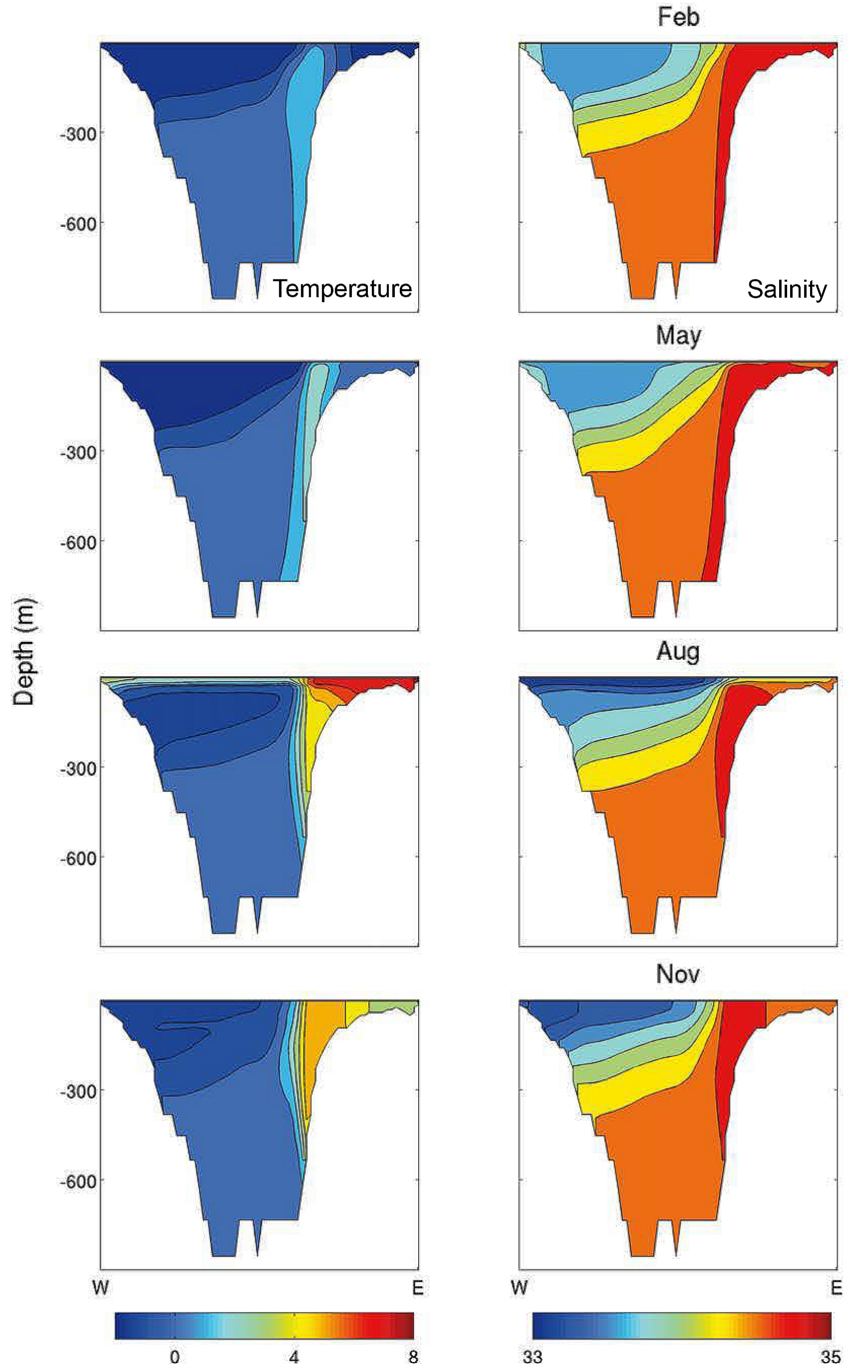
### 2.2.3 The coasts

The coastal zone between 62º-68º N is dominated by bedrock shorelines with many skerries and archipelagos. In sheltered areas small bays with sand or gravel are found between the rocks. Sandy beaches are found in the Marraq-Sermilik area and in the vicinity of the Frederikshåb Isblink glacier, where there are extensive sandy beaches and barrier islands (Mosbech et al. 1996).

## 2.3 Ice conditions

Sea ice of the following main types occurs in the Davis Strait: 'Storis', which is mainly multi-year drift ice of polar origin carried to Southwest Greenland by the *East Greenland Current* and occasionally in spring entering the assessment area from the south; the 'West ice', which is mainly first-year drift ice formed in Baffin Bay and the Davis Strait. Finally, ice anchored to the coast 'fastice' is formed in the innermost parts of the fjords during the coldest time of the winter.

**Figure 2.2.3.** Modelled cross-strait temperature (°C, left column) and salinity (psu, right column) averaged for February, May, August, and November in the period 1998–2007, taken from Lu et al. (2014). The transect extends from the western (W) to the eastern (E) Davis Strait.




The West ice is normally present in the assessment area from February to May (Fig. 2.3.1). This ice rarely reach the coast of the assessment area. It shows, however, strong annual variability in extent and concentration, primarily driven by wind, current patterns and low winter temperatures, and may in cold winters reach the coast as far south as Maniitsoq and Nuuk.

The usual ice free conditions in winter in the assessment area is caused by the relatively warm Atlantic water conveyed by the *West Greenland Current* (Brown et al. 2018a). This current inhibits ice formation close to the Greenland coast as far north as 67° N and all harbours in the assessment area are usually navigable throughout the year.

Sea ice cover has decreased in the Arctic during the past decades both in thickness, extent and duration (Perovich & Richter-Menge 2009, Perovich et al. 2019), a development also affecting the ice regime in the assessment area (Fig. 2.3.2).

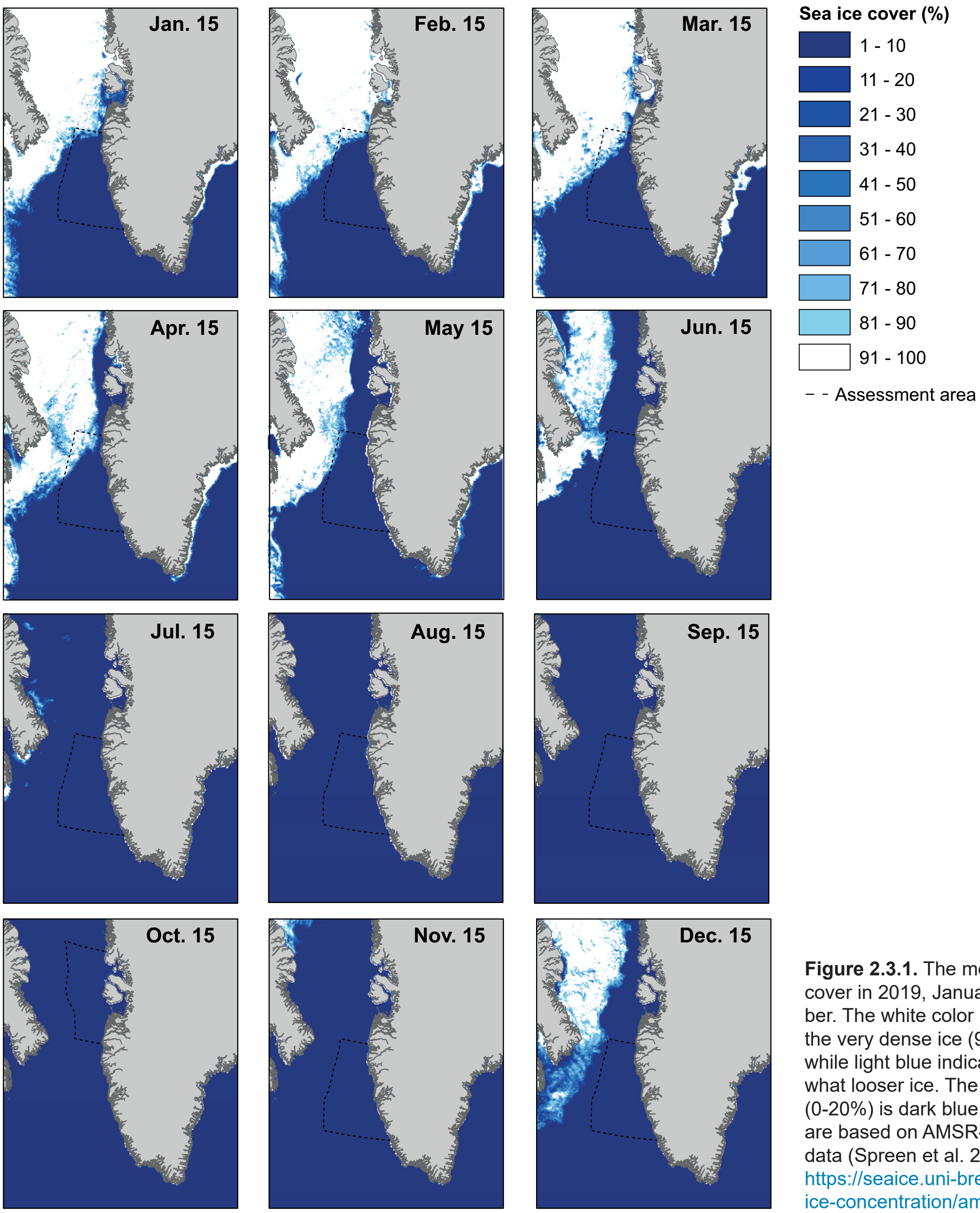



**Figure 2.3.1.** The monthly sea ice cover in 2019, January - December. The white color indicates the very dense ice (91-100%), while light blue indicates somewhat looser ice. The loosest ice (0-20%) is dark blue. The maps are based on AMSR-E satellite data (Spreen et al. 2008; see also https://seaice.uni-bremen.de/sea-ice-concentration/amsre-amsr2)

### 2.3.1 Icebergs

Icebergs are produced by glaciers calving into the sea. They show an extreme variation in size:

| 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 |

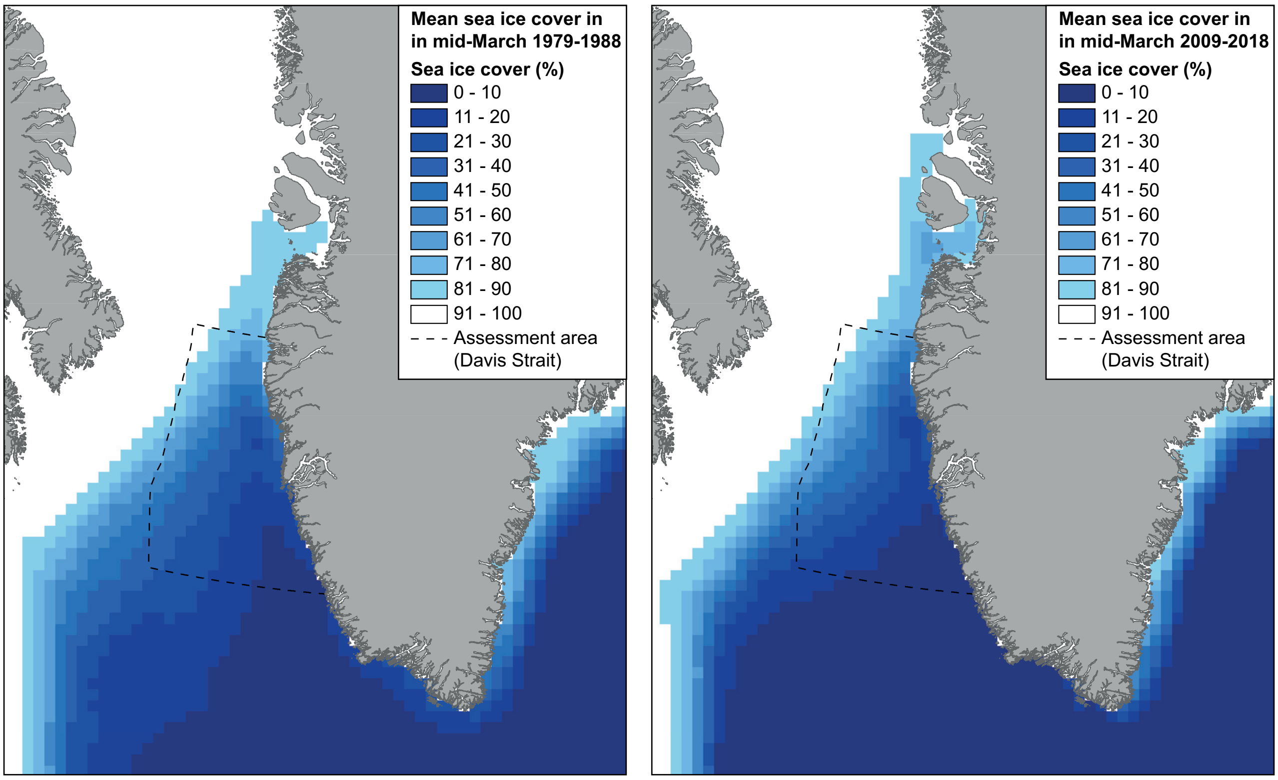



**Figure 2.3.2.** Left panel: Mean sea ice extent as percentage ice cover in West Greenland waters in March based on data from the period 1979-88. Derived from data from the NSIDC sea ice index. Right panel: Mean sea ice extent as percentage ice cover in West Greenland waters based on data in the period 2009-2018 (medio March). White colors indicate the highest percentage ice cover, while dark blue indicates the lowest percentage ice cover. Dense ice cover is encountered west of Disko Island while low ice cover is found south of Sisimiut in March. Data sources: NSIDC sea ice index (https://nsidc.org/data/seaice_index) & Fetterer et al. (2016).

Once an iceberg is free floating, meteorological and oceanographic factors begin to affect it. They are carried by sea currents directed by the integrated average of the water motion over the whole draft of the iceberg. However, wind also plays an important role, either directly or indirectly. Icebergs are always considered as a serious hazard to navigation and offshore activity.

### Iceberg sources

The glaciers which produce the most and the largest icebergs in Greenland are found north of the assessment area in for example Disko Bay, Uummannaq, Upernavik and Melville Bay and the icebergs from these glaciers move generally northwards and will rarely affect the assessment area. Large icebergs from glaciers in East Greenland occur on the other hand in the assessment area, but usually in low numbers (Nazareth & Steensboe 1998, Buch 2000, Karlsen et al. 2001). Local glaciers produce many small icebergs and bergy bits, however these have a short life span due to melting and rarely affect offshore areas (Karlsen et al. 2001) (Fig. 2.3.3).

### Iceberg dimensions

The characteristics of iceberg masses and dimensions off the west coast of Greenland are poorly investigated, and the following is mainly based on a study from 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 tonnes, with a maximum mass of 8.0 million tonnes. Average draft was 60-80 m and maximum draft was 138 m. In between 64° N and 66° N, average masses were

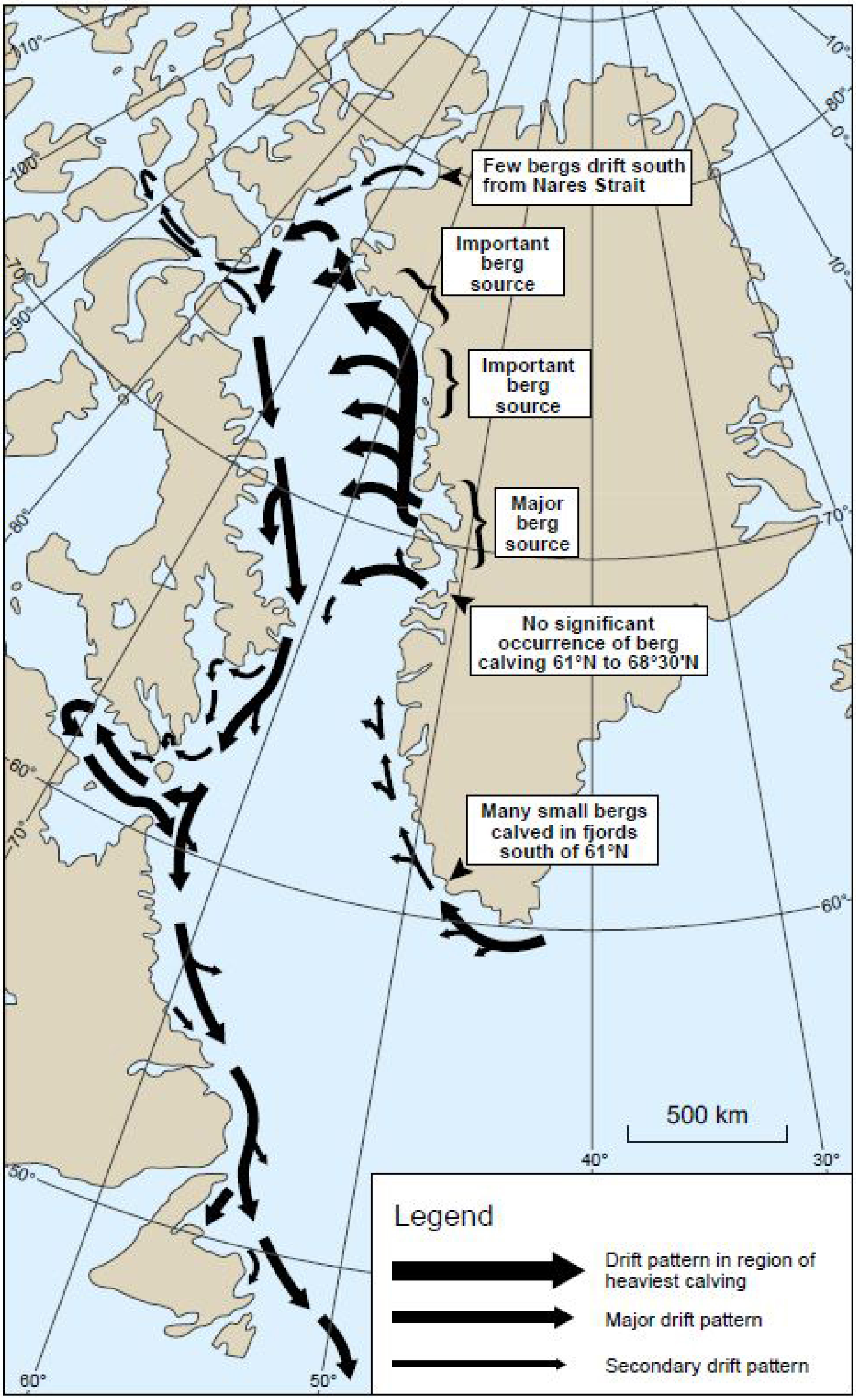



**Figure 2.3.3.** Major iceberg sources and general drift pattern in the West Greenland Waters. Data source: US National Ice Center (NIC) and figure from Valeur et al. (1996).

between 0.3 and 0.7 million tonnes with maximum mass of 2.8 million tonnes. Average draft was 50-70 m and maximum draft was estimated to be 125 m. The largest icebergs north of 66° N were found north and west of Store Hellefiskebanke. The average iceberg mass was about 2 million tonnes with a maximum mass of 15 million tonnes.

It is worth noting that many icebergs are deeply drafted and, due to the bathymetry, large icebergs will not drift into shallow water regions (Valeur et al. 1996, Karlsen et al. 2001). No systematic 'maximum draft measurements' exist and the extremes remain unknown. Several crushes or breaks of submarine cables 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 the Baffin Bay region are expected to have a maximum draft of about 250-300 m (Valeur et al. 1996, Karlsen et al. 2001).

# 3 Biological environment

## 3.1 Primary productivity

*Thomas Juul-Pedersen, Karl Zinglersen and Michael Dünweber*

### 3.1.1 General context

Arctic marine ecosystems in offshore waters are sustained by the primary productivity of phytoplankton. These microscopic algae (phytoplankton), therefore, determine the production capacity of these ecosystems up through the food web to zooplankton, fish, marine mammals and seabirds. Phytoplankton rely on sunlight for their photosynthesis, thus the annual cycle of solar input in high latitude systems sets the seasonal boundaries of their primary productive season. Nutrient availability is another factor controlling phytoplankton productivity, when seasonal sunlight is available, often determining the magnitude of the annual primary productivity (Tremblay et al. 2015). The primary productive season in Arctic marine ecosystems experiencing seasonal sea ice cover is typically initiated by a moderate under-ice and sea-ice primary production (Leu et al. 2015, Oziel et al. 2019). The subsequent sea-ice break-up in spring results in a sudden increase in solar input into the water column, which lead to a spike in phytoplankton production (Randelhoff et al. 2019). This abrupt increase in spring primary productivity, i.e. spring bloom, constitute a key event in Arctic marine ecosystems, which play a key role in the annual cycle of higher organisms such as zooplankton (see Chapter 3.2). The phytoplankton bloom can often be observed trailing the ice-edge as the sea-ice retreats. The intense spring bloom often depletes nutrients in surface waters forcing the phytoplankton deeper into the water column towards the lower limit of light availability (photic zone) (Randelhoff et al. 2019). Autumn in high latitude ecosystems is characterized by seasonally decreasing solar input resulting in declining primary production of the phytoplankton, which is already forced deep in the water column due to the surface nutrient depletion (Tremblay et al. 2015).

Arctic marine ecosystems generally have a lower diversity of phytoplankton species than lower latitude ecosystems (Ibarbalz et al. 2019). Nevertheless, regional species diversity of phytoplankton in Arctic waters typically encompasses hundreds of different species forming complex community structures. The species composition of phytoplankton change seasonally, mainly due to their short generation time, but also show variation between years (e.g. Krawczyk et al. 2015). Improved techniques for studying the diversity of phytoplankton is improving the understanding of phytoplankton communities, thus phytoplankton species composition is considered an important indicator of 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.g-e-m.dk).

### 3.1.2 Primary Productivity in Davis Strait

In most years, sea-ice (West Ice) covers the majority of Baffin Bay and the northern part of Davis Strait, while the southern part of the assessment area remains largely ice-free throughout winter. Sea-ice and under-ice primary production generally contributes a small fraction of the total annual production in the regions experiencing seasonal sea-ice cover (Oziel et al. 2019). The warm northward West Greenland Current influence the sea-ice extent and contributes to the ice-free conditions in the southern part of the assessment area (see Chapter 2.3).

The pelagic primary production starts in March/April in the southern part of the assessment area, when the ice-free conditions or early break-up promotes seasonal solar input into the water column (Fig. 3.1.1). This is several weeks before the onset of spring production in the ice-covered Baffin Bay (Randelhoff et al. 2019). At the ice edge, meltwater from sea-ice may have a stabilising effect on surface waters, which may promote early phytoplankton production. However, the main peak in spring productivity, i.e. the spring bloom, is often

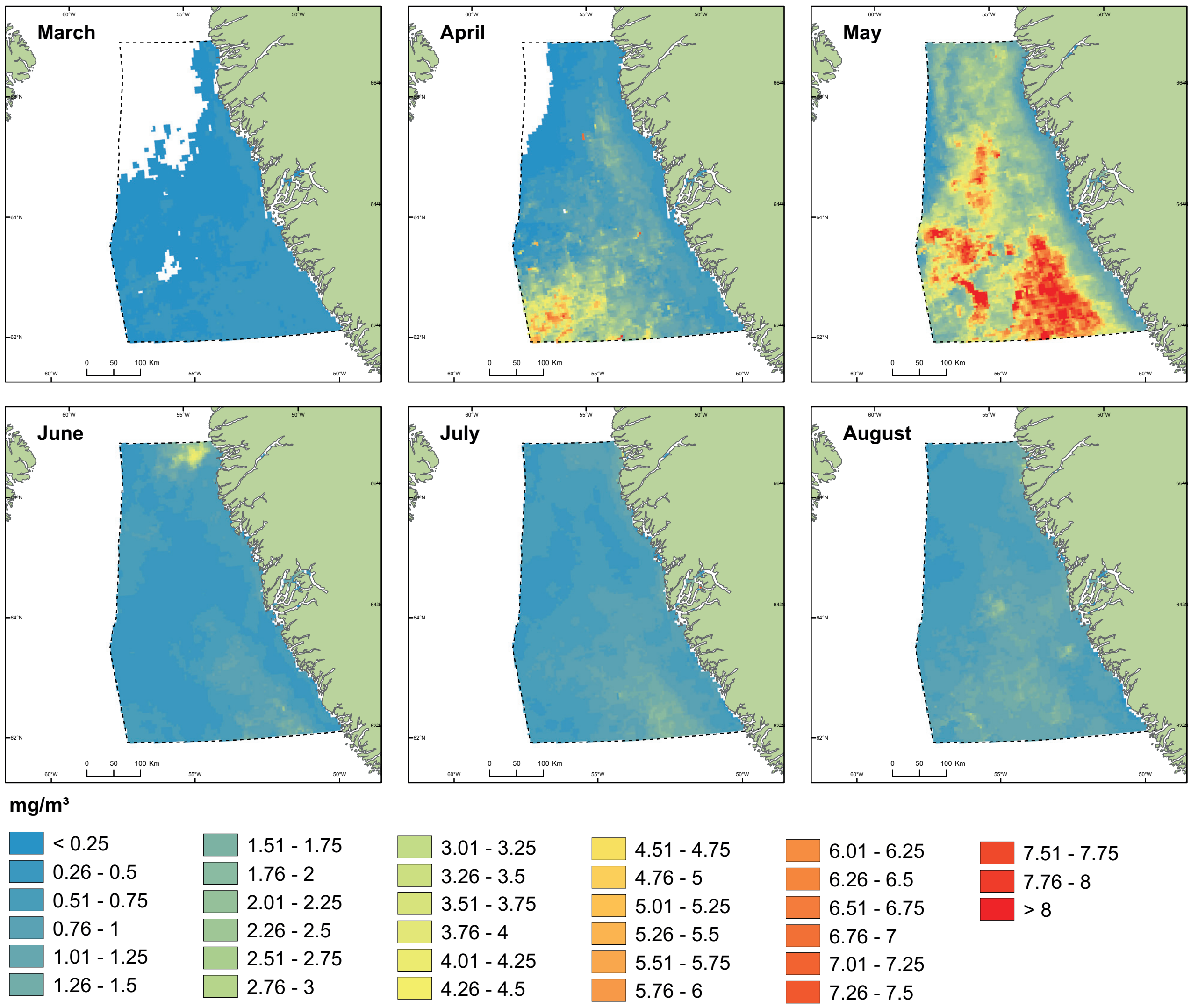



**Figure 3.1.1.** Monthly average sea surface chlorophyll *a* (chl. a) concentrations (mg m$^{-3}$) in March, April, May, June, July and August from 2015-19. Data are presented as a monthly average from MODIS level 3 aqua with a 4 km cell size. The colours indicate different chl. a concentrations: blue 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 2020/04/07).

observed during April/May. The timing and magnitude of the spring bloom may also vary across the Davis Strait. The West Greenland shelf region (assessment area) experiences a weak stratification of the water column allowing winter mixing of high-nitrate Atlantic-derived waters, which promotes the spring bloom (Randelhoff et al. 2019). In contrast, the Arctic-derived waters in the western part of Davis Strait reduce nutrient replenishment, due to a stronger stratification of the water column, which hampers the spring bloom.

The intense spring bloom depletes surface nutrients, which forces the phytoplankton deeper into the water column following the deepening nutrient (nitrogen) availability. This deepening of the phytoplankton compromises the light available, due to the light-attenuation in the water column, thus balancing between nutrient and light limitation. In Baffin Bay, the bulk of the phytoplankton biomass was observed at 40-50 m depth one month after the ice break-up, or 100 km away from the ice-edge (Randelhoff et al. 2019). Such deep phytoplankton biomass in summer remains largely undetectable on remote sensing (satellite) products (e.g. June-August in Fig. 3.1.1), thus potentially underestimating a significant fraction of the phytoplankton biomass and primary production in summer. In order to accurately estimate annual primary productivity, it is therefore necessary to use or supplement with *in situ* measurements covering this deeper production. 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 (Thomas Juul-Pedersen, unpubl. data).

A multidisciplinary ecological monitoring programme, the Greenland Ecosystem Monitoring (GEM), includes time series of key marine parameters on phytoplankton species composition, biomass and primary production from the inshore Nuup Kangerlua (Godthåbsfjord) system (www.g-e-m.dk). The marine subprogramme (MarineBasis-Nuuk) has recorded the same seasonal pattern in phytoplankton, i.e. spring production starting in March and peaking in April/May (Juul-Pedersen et al. 2015). As part of the monitoring programme, an annual transect survey is conducted from the innermost part of Nuup Kangerlua to the outer shelf-slope of Fyllas Banke situated at the centre of the assessment area (Fig. 3.1.2).

High phytoplankton biomass is frequently observed at the outer Fyllas Banke (Fig. 3.1.2, Arendt et al. 2010, Tang et al. 2011), where the northward flowing West Greenland Current and tidal forces upwelling and promote nutrient replenishment to the phytoplankton. The shallow banks also keep the phytoplankton in the photic zone where net growth is possible. Upwelling areas are, for example, found at the fishery banks in South and West Greenland, e.g. Fyllas Banke and Store Hellefiskebanke. Upwelling areas may, besides enhanced production, also retain copepods, which again are utilised by fish larvae (Simonsen et al. 2006). Therefore, the bank areas are important for increased primary productivity and carbon cycling caused by nutrient-rich upwelling events from wind and tidal motions in the Davis Strait.

Comparable estimates of annual primary productivity for Baffin Bay (60–120 gC $m^{-2}$ $yr^{-1}$; Stein & Macdonald 2004) and the inshore Nuup Kangerlua (85-139 g C $m^{-2}$ $yr^{-1}$; Juul-Pedersen et al. 2015) likely represent valid estimates for primary productivity of the assessment area, where no annual estimate exist, taking spatial and temporal variability into consideration. This regionally high primary productivity has a positive cascading effect up through the food web, sustaining highly productive marine ecosystems along Western Greenland.

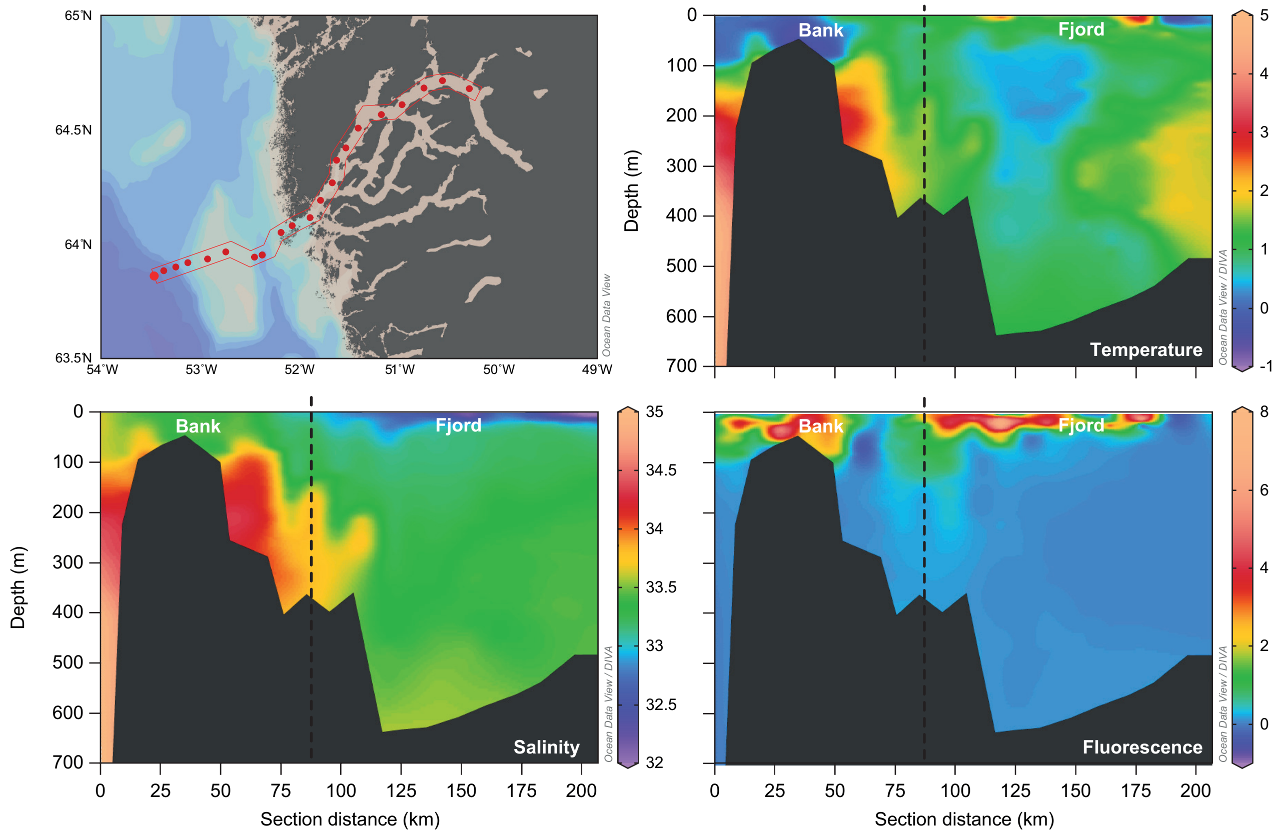



**Figure 3.1.2.** Map showing the annual sampling transect from the innermost part of Nuup Kangerlua (Godthåbsfjord) to the outer shelf-slope of Fyllas Banke, conducted as part of the marine subprogramme MarineBasis-Nuuk of the Greenland Ecosystem Monitoring (GEM) programme (www.g-e-m.dk). The entrance to Nuup Kangerlua is situated at ca. 75 km along the Section Distance (dashed vertical line). The plots depict temperature (°C), salinity and fluorescence (approximate µg chlorophyll *a* $L^{-1}$) sampling using a CTD profiler (Sea-Bird SBE19plus) equipped with a Seapoint chlorophyll fluorometer. Fluorescence (chlorophyll *a*) is a measure of the concentration of photosynthetic pigment in phytoplankton, i.e. a proxy for the phytoplankton biomass.

## 3.2 Zooplankton

*Eva Friis Møller and Michael Dünweber*

### 3.2.1 General context

Zooplankton plays an important role within marine food webs providing the principal pathway to transfer energy from primary producers (phytoplankton) to consumers at higher trophic levels e. g. fish and their larvae; whales, primarily the bowhead whale *(Balaena mysticetus*) (Laidre et al. 2007, Laidre et al. 2010); and seabirds, e. g. little auk (*Alle alle* (Karnovsky et al. 2003). Most of the higher trophic levels in the Arctic marine ecosystem rely on the lipids that are accumulated in the copepod *Calanus* (Lee et al. 2006, Falk-Petersen et al. 2009). Consequently, a great deal of the biological activity, e.g. spawning and growth of fish, is synchronised with the life cycle of *Calanus*. Zooplankton not only supports the large, highly visible components of the marine food web, but also the microbial community. Regeneration of nitrogen and carbon through excretion by zooplankton is crucial for bacterial and phytoplankton production (Daly et al. 1999, Møller et al. 2003). Zooplankton, mainly the *Calanus* copepods, also play a key ecological role in supplying the benthic communities with high quality food with their large and fast-sinking fecal pellets (Juul-Pedersen et al. 2006). Thus, vertical flux of fecal pellets sinking to the seabed sustains diverse benthic communities such as bivalves, sponges, echinoderms, anemones, crabs and fish (Turner 2002, and references therein). During winter, *Calanus* stay in deep layers of the water column to hibernate. This may also provide an important contribution to the benthic ecosystem and deep foraging predators.

### 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). *Calanus* feed on algae and protozoa in the surface layers and accumulate surplus energy in form of lipids, which are used to overwinter at depth and to fuel reproduction the following spring (Lee et al. 2006, Falk-Petersen et al. 2009, Swalethorp et al. 2011). Most of the higher trophic levels rely on the lipids accumulated in *Calanus* mainly as wax esters. These 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 whales (*Delphinapterus leuca*) and sperm whales (*Physeter microcephalus*), which feed on fish, shrimps and squid (Smith & Schnack-Schiel 1990, Dahl et al. 2000) and in the bowhead whale (*Balaena mysticetus*) and northern right whales (*Eubalaena glacialis*), which feed mainly on *Calanus* (Hoekstra et al. 2002, Zachary et al. 2009). In larvae of the Greenland halibut (*Reinhardtius hippoglossoides*) and sandeel (*Ammodytes* sp.) from the West Greenland shelf, various copepod 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 biomass of ingested prey (Simonsen et al. 2006).

Vertical distributions of the *Calanus* species are influenced strongly by ontogenetic vertical migrations that occur between the dark winter season and the light summer season. For the most of the light summer season *Calanus* is present in the surface waters. During summer and autumn, *Calanus* begins to descend to deep-water layers for winter hibernation, changing the plankton community structure in the upper water column from *Calanus* to smaller copepod and protozooplankton dominance. The grazing impact on phytoplankton by the smaller non-*Calanus* copepod community after *Calanus* has left the upper layer can be considerably higher than in spring. This is a result of shorter generation time and more sustained reproduction as well as relaxed food competition and predation by *Calanus* (Hansen et al. 1999, and references therein).

### 3.2.3 Zooplankton in the Davis Strait

Knowledge of zooplankton in the assessment area is based on studies covering a 34-year time series from the 1950s by Pedersen & Smith (2000) and recent studies covering mostly of the south-western coastal zone (Pedersen & Rice 2002, Head et al. 2003, Munk et al. 2003, Pedersen et al. 2005, Arendt et al. 2010, Tang et al. 2011, Arendt et al. 2013, Agersted & Nielsen 2014, Swalethorp et al. 2015). The coastal studies in Southwest Greenland clearly corroborate the hypothesis that most of the biological activity in the surface layer is present in the spring and early summer in association with the spring bloom

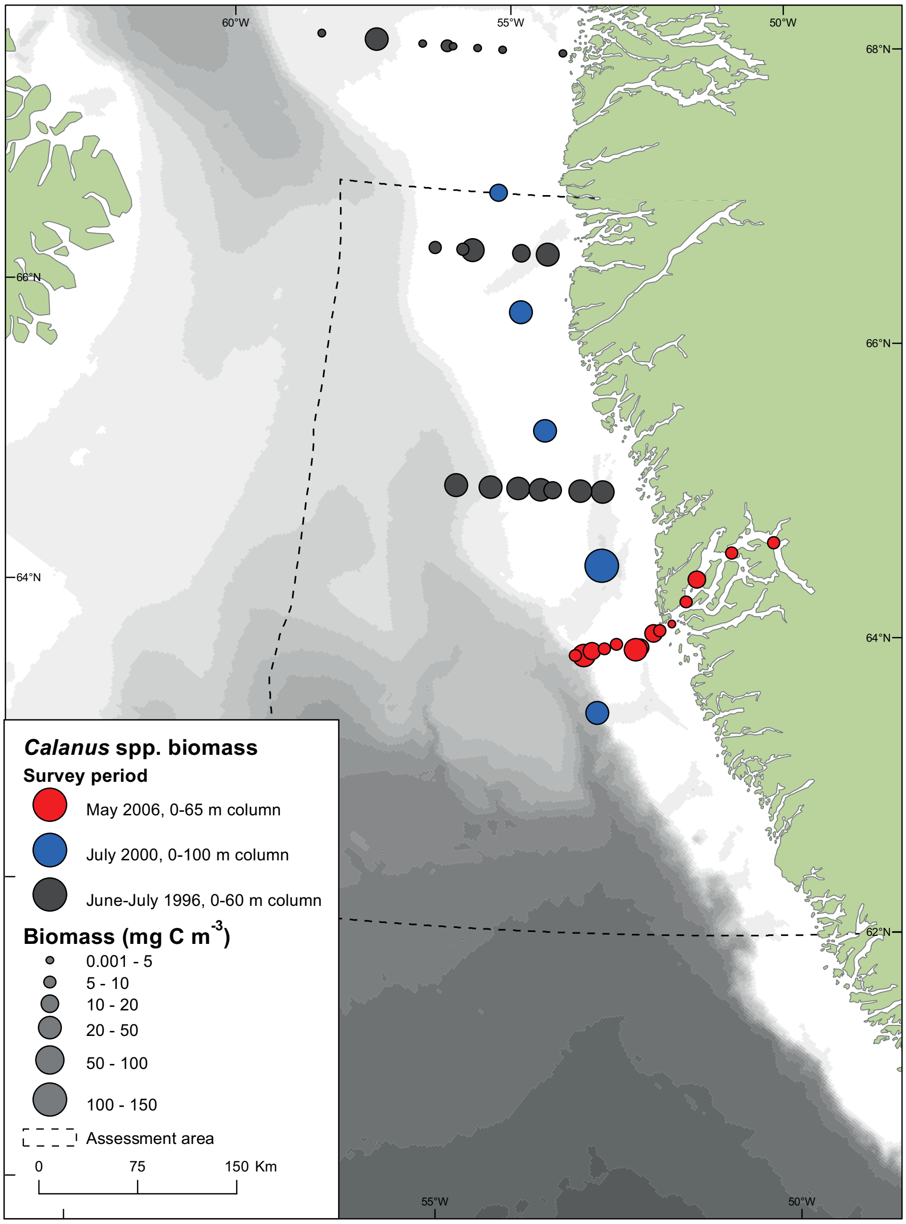



**Figure 3.2.1.** *Calanus* spp. biomass (mg C m$^{-3}$). The coloured dots represent biomass values from different studies; red dots: from May 2006 in the 0-65 m column (Arendt et al. 2010), blue dots: from July 2000 (Pedersen & Smidt 2000) at 0-100 m, dark grey dots: from June-July 1996 (Munk et al. 2003) at 0-60 m column. The biomass values of *Calanus* spp. summer and an autumn period show higher biomass values east and west of the fishery banks. Seasonal descent of *Calanus* towards winter hibernation is presumed to have begun in July-August. Note: Biomass values are calculated based on different length-carbon regressions and using different sampling gear e.g. net types vary between studies.

and appearance of the populations of the large copepods *Calanus*. *Calanus* occurrence is widespread in the West Greenland waters, where high biomass values have been recorded across the fishery banks in Southwest Greenland (Fig. 3.2.1), and is almost exclusively dominated by *C. finmarchicus* (Pedersen et al. 2005, Arendt et al. 2010).

In general, abundance of *C. finmarchicus* increases as you move from the Arctic region and further south to the sub-Arctic. This is because the drift of *C. finmarchicus* into the assessment area by means of the West Greenland current has strong implications for their distribution, life cycle and production, and for the succeeding link in higher trophic transfer, e.g. Atlantic cod (*Gadus morhua*). Transportation of *C. finmarchicus* from the North Atlantic into the South and West Greenland Waters can, depending on food availability, outnumber the true Arctic *C. glacialis* and *C. hyperboreus* by a factor of three throughout the year (Pedersen et al. 2005, and references therein).

There is a lack of knowledge of zooplankton from the offshore parts e.g. the licence areas. It is assumed that the zooplankton community in the assessment area is similar to that found in the coastal area in Southwest Greenland; however, there is expected to be a difference in biomass with lower density offshore (at drilling sites) than inshore/coastal areas, e.g. the Fyllas Banke area. Recently, it was observed that cold and relative saline Baffin Bay Polar Water reach the inner part of the banks, periodically reaching as far south as 64°N, suggesting the presence of an undescribed southward current at the Southwest Greenland continental shelf (Rysgaard et al. 2020). This could imply that Arctic zooplankton will be more important at the offshore parts than at the more studied coastal sites where Atlantic species dominates.

### 3.2.4 Zooplankton dynamics in the coastal areas

High occurrence of zooplankton species linked to the fishery banks, e.g. Fyllas Banke, are controlled by the hydrographic characteristics of the area and associated predator-prey interactions (Pedersen & Smidt 2000, Pedersen & Rice 2002, Pedersen et al. 2002, Buch et al. 2004, Ribergaard et al. 2004, Pedersen et al. 2005, Bergstrøm & Vilhjalmarsson 2007, Arendt et al. 2010, Laidre et al. 2010, Tang et al. 2011, Swalethorp et al. 2015). The frontal system occurring at the banks and the upwelling of deeper nutrient rich waters enhances the productivity of the plankton communities in those areas.

A model simulation by Pedersen et al. (2005) describing the linkages of hydrographical processes and plankton distribution demonstrated across the fishery banks (64-67º N) of the Southwest coast of Greenland that wind fields and tidal currents were important, creating temporally retention areas of the plankton. High copepod abundances, mainly *Calanus* spp. coincide with high chlorophyll *a* values just east and west of the banks. This agrees with model description of upwelling, which occurs mainly west and to a lesser extent east of the banks, increasing the plankton productivity in the bank areas. Munk et al. (2003) found a close link of plankton distribution with hydrographical fronts, and apparently specific plankton communities were established in different areas of the important fishery banks of West Greenland. Ichthyo- (fish) and zooplankton communities differed in species composition in the north-south distribution of polar versus temperate origin. It seems that flow of major currents and establishment of hydrographical fronts are of primary importance to the structure of plankton communities in the West Greenland shelf area, influencing plankton assemblage and the early life stages of fish.

Recently an analysis of 13 years of data from Disko Bay, Western Greenland, north of the assessment area from the period 1992 to 2018 were carried out. This showed a significant change in the *Calanus* community composition re-

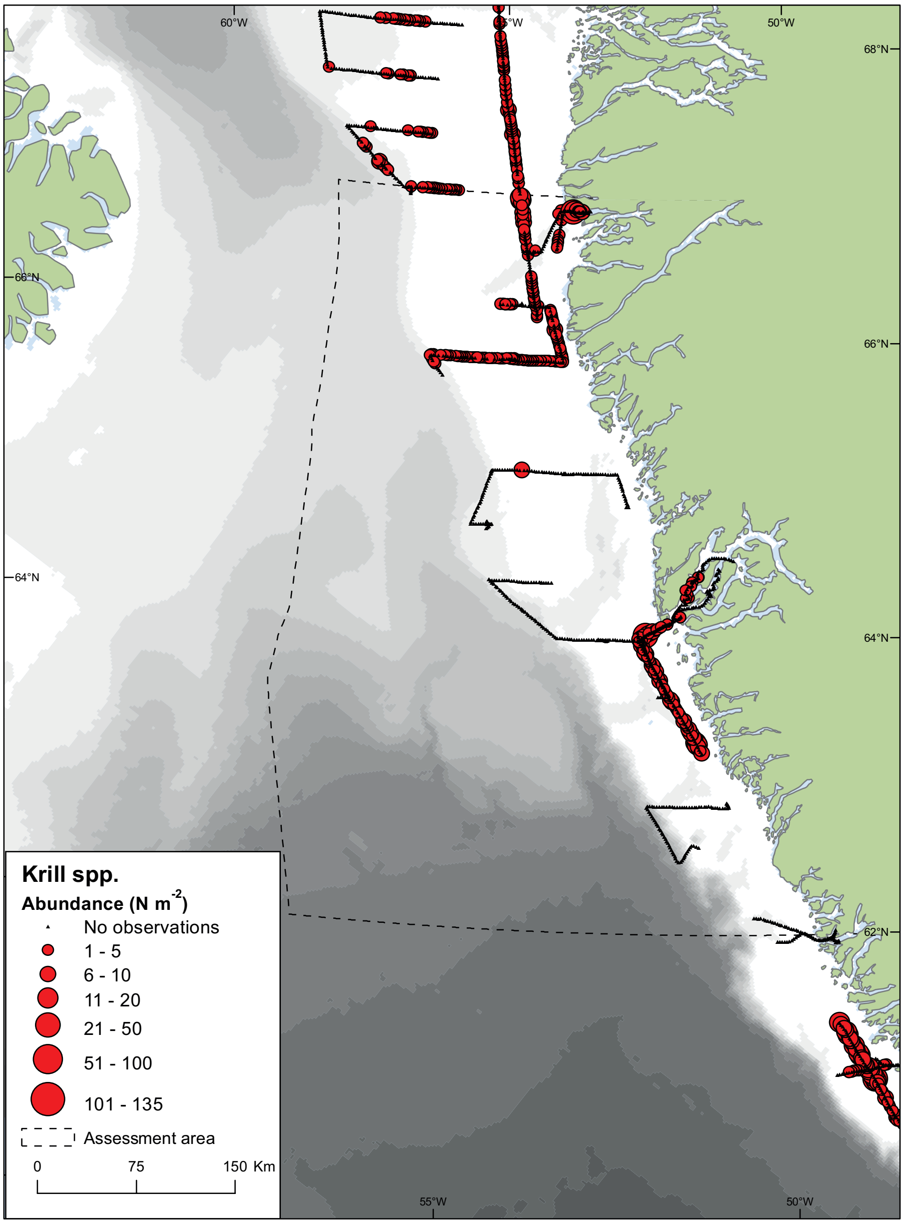



**Figure 3.2.2.** Krill abundance (N m$^{-2}$) from acoustic measurements from September 2005 in the 0-50 m column (Bergstrøm & Vilhjalmarsson 2007). High krill abundance, mostly *Meganyctiphanes norvegica*, is evident near the coastal areas.

lated to the relative importance of Atlantic waters and the extent of sea ice. Furthermore, during the last decade there has been a large annual variation in copepod population size with up to 10 times differences (Møller & Nielsen 2019). Similarly, in the Nuup Kangerlua system a five-year study showed high inter-annual variation, which was suggested to reflect the varying contribution offshore water masses (Arendt et al. 2013).

### 3.2.5 Higher trophic levels – large zooplankton and fish larvae

Large zooplankton species such as the krill species (*Meganyctiphanes norvegica*) were examined in September 2005 by the Greenland Institute of Natural Resources (GINR) (Bergstrøm & Vilhjalmarsson 2007) as well as in association with large baleen whales in West Greenland (Laidre et al. 2010) and from the Nuup Kangerlua across Fyllas Bank (Agersted & Nielsen 2014). Krill were

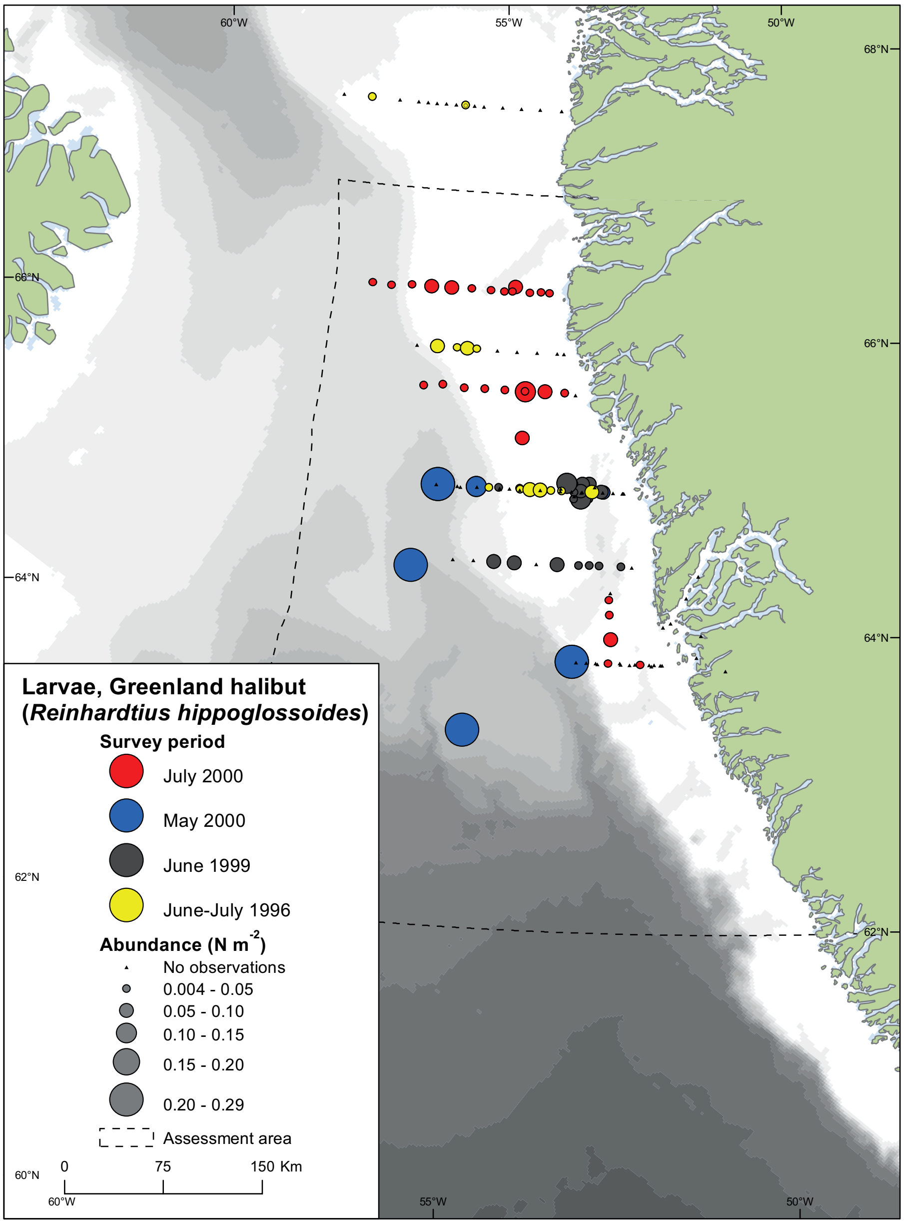



**Figure 3.2.3.** Greenland halibut (*Reinhardtius hippoglossoides*) larvae abundance (N m-2). The coloured dots represent abundance values from different studies; red, blue, dark-grey and yellow dots: from surveys in May-July 1996-2000 (Munk et al. 2000, Munk et al. 2003, Munk pers. comm. and REKPRO-data from C. Simonsen and S.A. Pedersen pers. comm.). The Greenland halibut from various studies in summer periods. There are indications of relatively high abundances offshore compared with inshore/coastal areas.

found in scattered aggregations in most of the area with a pronounced increased prevalence between 62° to 65° N (Fig. 3.2.2). The relative importance of krill in relation to copepods were found to be highest in the fjords compared to the offshore bank area (Agersted & Nielsen 2014).

Fish larvae are important components of plankton, and movements and behaviour have been studied for some of the commercially utilised species. Pedersen & Smidt (2000) analysed fish larvae data sampled along three transects during summer in West Greenland waters over 34 years. Peak abundance fish larvae were also observed in early summer in association with the peak abundance of their plankton prey.

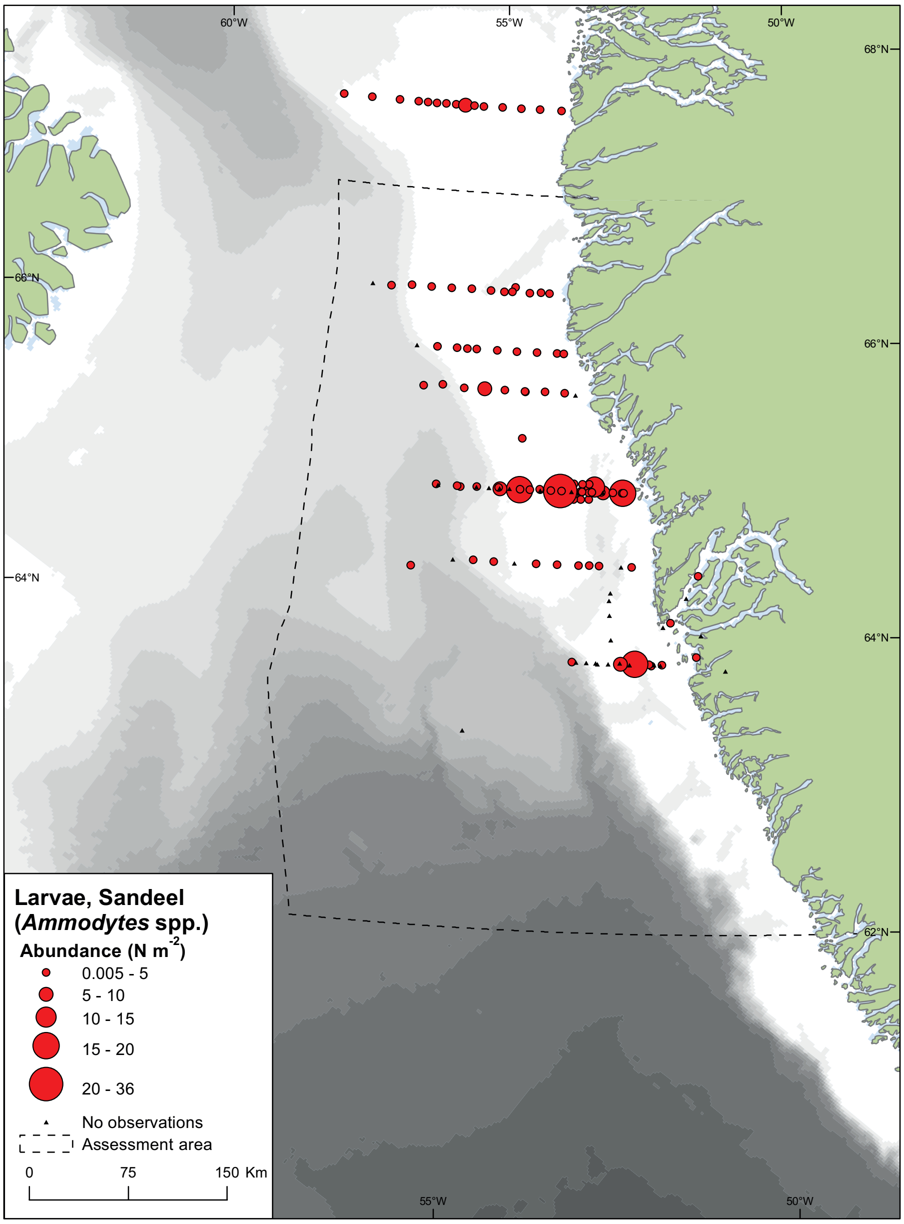



**Figure 3.2.4.** Sandeel (*Ammodytes* sp.) larvae abundance (N m$^{-2}$) June-July from 1950 to 1984 (Pedersen & Smidt 2000). A relatively high abundance of sandeel was found at Fyllas Banke.

Several surveys have investigated the horizontal distribution of fish larvae (Born et al. 2001, Munk et al. 2003, Simonsen et al. 2006) in relation to oceanography and their potential prey along West Greenland (Fig. 3.2.3, 3.2.4, 3.2.5). They document that the important sites for the development of fish larvae are the slopes of the banks and the shelf break, where the highest biomass of their copepod prey is also located (Simonsen et al. 2006).

Greenland halibut larvae concentrations in the upper water column are relatively high south of 68° N in May, while within the major part of the assessment area they are low in June-July, based on Fig. 3.2.3. Other fish larvae that have been studied include sandeel (*Ammodytes* spp.), which were very numerous particularly on some of the banks (Fig. 3.2.4) (Pedersen & Smidt 2000).

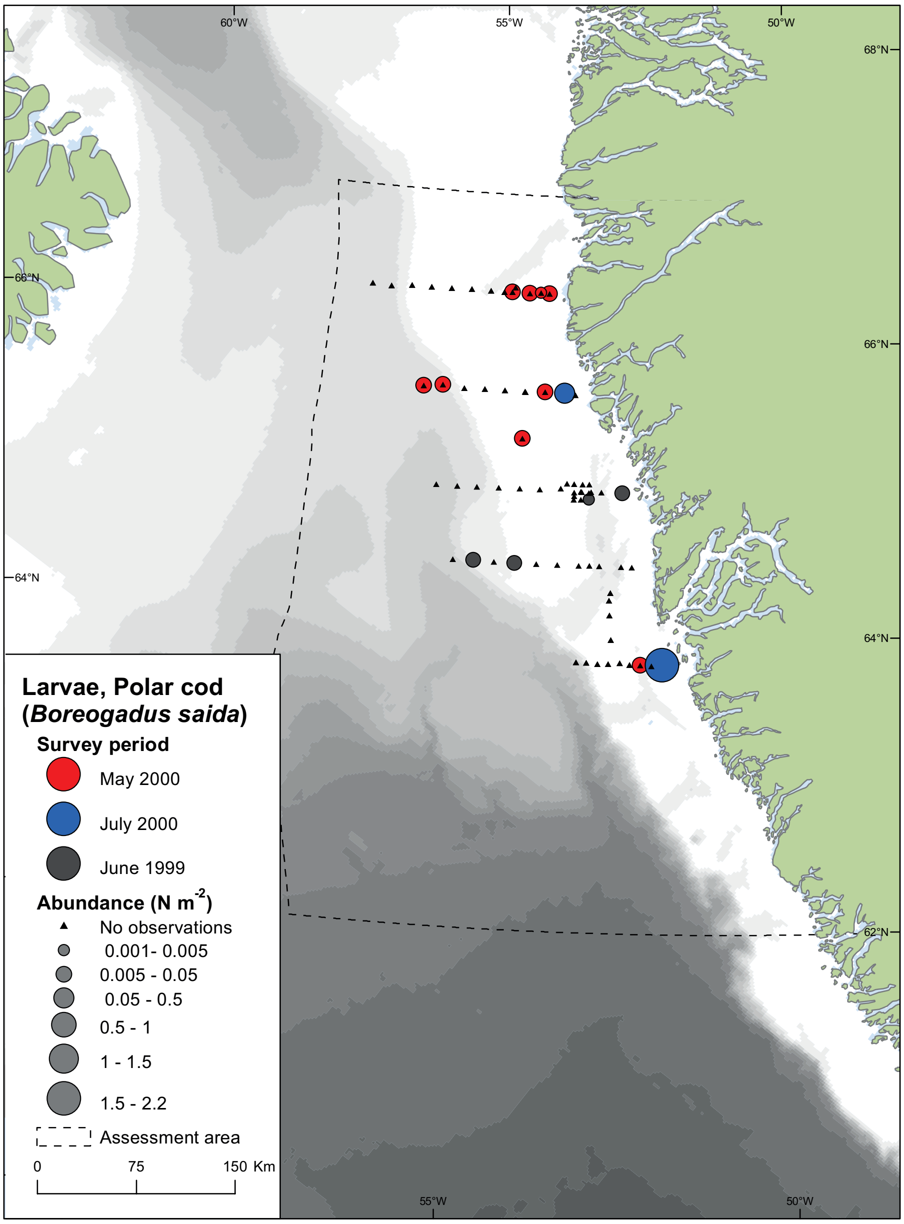



**Figure 3.2.5.** Juvenile polar cod (*Boreogadus saida*) abundance (N $m^{-2}$). The coloured dots represent abundance values from different studies; red, blue and dark grey dots: from surveys in May-July 1996-2000 (Munk et al. 2000, Munk et al. 2003, Munk pers. comm. and REKPRO-data from C. Simonsen and S.A. Pedersen pers. comm.). The juvenile polar cod from different studies in summer and an autumn period all indicate relatively high abundance in the coastal areas and east and west of the fishery banks.

In 1996-2000 studies on fish larvae in West Greenland waters were carried out (Munk et al. 2000, Munk et al. 2003, Munk pers. comm., and REKPRO-data from C. Simonsen and S.A. Pedersen pers. comm.). These studies did not find the sandeel larvae concentrations as reported by Pedersen & Smidt (2000). They found large interannual variation in abundance of polar cod larvae and confirmed the distribution of Greenland halibut larvae as reported by Pedersen & Smidt (2000) (Fig. 3.2.3, 3.2.5). Recurrent concentrations areas of fish larvae were not located, and generally there seems to be large variation in distribution and abundance of fish larvae between years. Still there seem to be retention areas over the banks, where plankton is concentrated and entrapped for periods (Pedersen et al. 2005).

## 3.3 Macrophytes

*Susse Wegeberg (AU)*

Shorelines with a rich macroalga 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 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 of less ecological importance. 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 General 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 coast. 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 algae species such as *Ascophyllum nodosum* and *Fucus* spp. The majority of the macroalgal species grows, however, below the low water mark, and 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 a general context as well as check-list and distribution of the marine algae in the Davis Strait area were compiled by Wegeberg (2012).

In this particular assessment area, the benthic vegetation also includes the sea grass, Zostera marina, eel grass. This species constitutes dense meadows on soft and sandy sea beds in fjord arms around Nuuk (Olesen et al. 2015).

Investigations of the marine benthic flora in the assessment area is still limited, but studies in the area around Nuuk as well as along the west (and east coast) of Greenland, which include or are relevant for the assessment area, have been performed in recent years.

Studies of marine vegetation in the area date back to the late 18$^{th}$ 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) and (1898).

More recent studies and monitoring programmes have focused on ecological and climatic drivers and included studies on biodiversity (Schoenrock et al. 2018), depth distribution, production (biomasses and growth rates), and recruitment.

**Sublittoral vegetation**

The fjord systems around Nuuk are relatively intensively used and better studied than most other Greenland coastlines, and more rarely observed sublittoral species or assemblies are observed in this area. Christensen (1981) and (1975) worked in the Nuuk area describing the macroalgal vegetation, and from here he has the sole registration of the geniculate coralline red algae *Corallina officinalis* in Greenland. Also, accumulations of loose-lying branched species of coralline red algae, rhodoliths, are observed (Schoenrock et al. 2018). Such areas dominated by rhodoliths are also reported from a couple of other localities in Greenland; in the Disko Fjord and close to Qaqortoq. The locality in Qaqortoq is of the same type as those identified close to Nuuk, i.e. stony sea floor with encrusting coralline red algae and rhodoliths intermixed, while in Disko Fjord larger rhodoliths with diameters of up to 13 cm are accumulated on a soft and muddy bottom (Düwel & Wegeberg 1990, Thormar 2006, Wegeberg 2012). Further, the registrations of the seagrass, *Zostera marina*, in the fjords of the Nuuk area, are the only confirmed in Greenland (Olesen et al. 2015). Eelgrass is a red listed species in Greenland (Boertmann & Bay 2018).

The extension of the kelp belt depth increases (from c. 20 to 40) m from north towards south along Greenland's west coast in parallel to the increase in the ice free period (Krause-Jensen et al. 2012). The depth of the photic zone and hence the depth limit of macroalgal communities vary considerably along the west coast due to local outfall of turbid melt water from the glaciers and due to variation in sea ice cover (Krause-Jensen et al. 2019). The submerged vegetation is restricted to depths with sufficient light, and hence the length of the ice-free period is an important controller of the light reaching the sea floor (Krause-Jensen et al. 2011). Although global warming leads to an increase in the ice-free period, lowered salinity and increasing water turbidity, as a result of an increase in freshwater runoff, could also impoverish growth conditions in some areas (Krause-Jensen et al. 2019).

**Figure 3.3.1.** Frozen fucoid macroalgae (*Ascophyllum nodosum*, *Fucus* spp.) in Nuup Kangerlua (Godthåbsfjord).

Photo: Ole Geertz-Hansen.

Production of kelp in the upper sub-littoral zone (≤20 m) increases along the West Greenland coast from Qaanaaq in the north to Nuup Kangerlua (Godthåbsfjorden) at lower latitude, correlating with longer open water period (Krause-Jensen et al. 2012), to levels of about 175 g dw year$^{-1}$ per mature kelp individual in the assessment area in Nuup Kangerlua (Krause-Jensen et al. 2012) (Ørberg et al. 2018a){Krause-Jensen, 2012 #296}. Kelp biomass has been investigated in southern Greenland and in Northeast Greenland (Wegeberg 2007, Wegeberg et al. 2020b). In general, though, the biomasses, where kelp forest was present, were quite similar across regions and reached 10-15 kg wet weight m$^2$, which is therefore probably also the case in the assessment area.

**Littoral vegetation**

An investigation of the littoral zone communities along the Greenland west coast from Cape Farewell to Upernavik, including the Nuuk area, showed that the mean biomasses in the mid littoral zone was highest in Nuuk, with a level of about 500 g wet weight 0.0625 m$^{-2}$ and dropped markedly between southern Disko (69°N) and Uummannaq (71°N (Thyrring et al. 2020). 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. 2020).

Although the coastal zone of the assessment area normally has open water year-round, it may be impacted by drift ice as well as fjords can be ice covered, e.g., Kobbefjord near Nuuk. The sea ice is a complex drive 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). Provided that the ice foot melts without scouring and hence disrupting the vegetation, the macroalgal vegetation remains intact as observed in more sheltered localities, e.g., the inner part of Kobbefjord in the assessment area (Fig. 3.3.1). In Kobbefjord, 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 insolated against low temperatures (Ørberg et al. 2018b).

Climate change will probably affect the macroalgal vegetation by increased growth and distribution area due to longer season with open water, and with that a reduced impact from ice scouring and shading. The growth rates of *Ascophyllum nodosum*, correlates positively with temperature and annual ice-free days and an increase in growth and northern distribution edge can therefore be expected with warming (Marbà et al. 2017). 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. (Submitted), 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 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 & Nanette Hammeken Arboe (GINR)*

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 40 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 communities can be very species rich with up to more than 100 different macro-invertebrate species of infauna per $m^2$ in undisturbed soft sediments (Sejr et al. 2010b). On hard substrates, large epifauna can contribute to the structural complexity of habitats and support a rich associated fauna. Three benthic invertebrate species are fished 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* sp.).

The coastline in Southwest Greenland between 62 and 67°N, i.e. the assessment area, 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 most often extends >100 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 northern part of the assessment area consists of the Davis Strait sill (<1000 m depth), bordering on the Labrador basin (up to >2500 m depth) to the south.

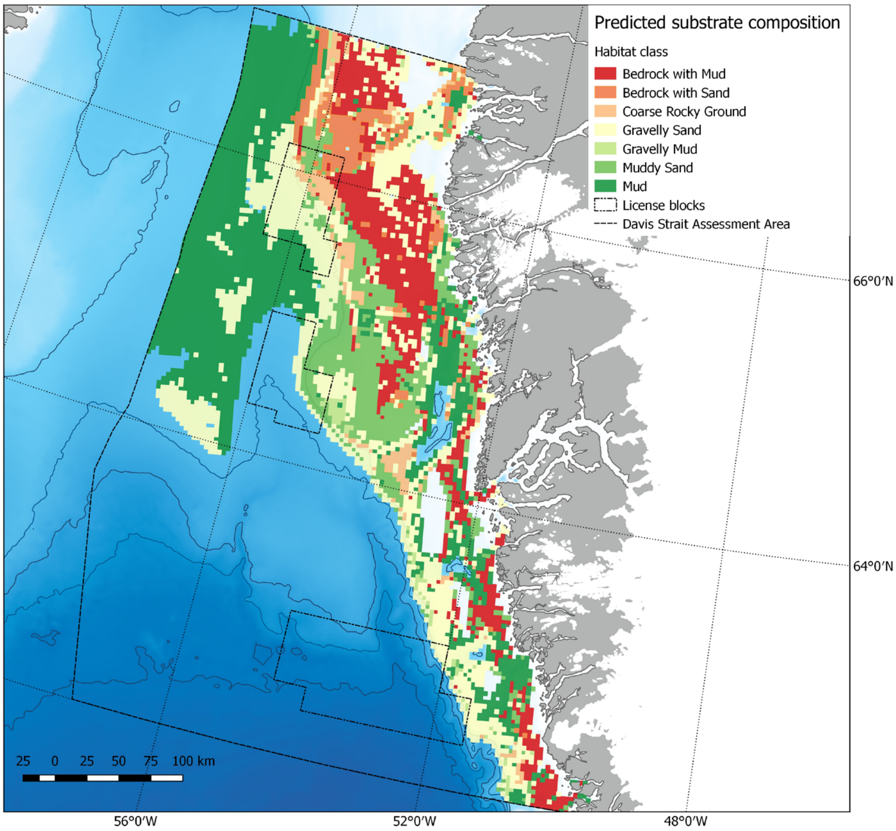
The benthic fauna community is affected by a multitude of different biological and physical parameters; with depth, temperature, food input, substrate composition, particle load, disturbance level (e.g. ice scouring, trawling) and hydrographical regime being the most prominent (e.g. Gray 2002, Wlodarska-Kowalczuk 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**

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, Anon 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 macrobenthos 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). Consequently, high production is expected to be found in areas where sea ice cover is minimal or at shallow depths where benthic primary production is considerable and pelagic production can be transferred efficiently to the sea floor.

Figure 3.4.1. Map of predicted surface substrates in the Davis Strait Assessment Area developed with an image survey and an SVM habitat classification model approach. Grid cell size is 3.5×3.5km. Redrawn from Gougeon et al. (2017).



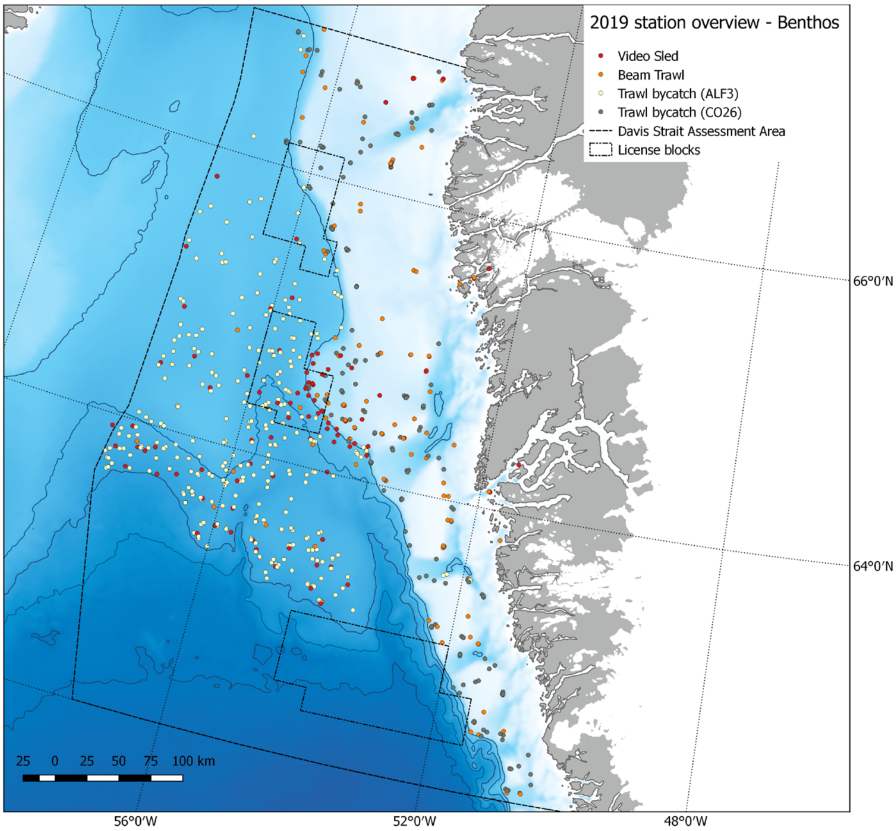

Moreover, it has been suggested that low individual energy requirements at low temperatures contribute to a positive energy budget despite low and/or highly seasonal primary production (Clarke 2003, Blicher et al. 2010).

**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 Arthropoda, Mollusca and Polychaeta 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 Davis Strait assessment area has the largest number of historical sampling stations and holds more than 1000 registered species of benthic invertebrates. 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 0.1m² grab sample (Sejr et al. 2010a, Sejr et al. 2010b, Hansen et al. 2012b).

Figure 3.4.2. Overview of benthos sampling stations in the Davis Strait 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 and a towed video sled.




## Habitat

The complex topography and hydrography of the assessment area also result in a highly heterogenous 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 (200-700m depth, up to 72°N) (Fig. 3.4.1; Gougeon et al. 2017). The resolution and quality of environmental variables limited predictions to single habitat classes in 3.5x3.5km grid cells, which are likely to encompass multiple habitats. Still, the model underlines the heterogeneity of the seabed. The hitherto approach to benthos sampling has 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 0.1m$^2$ 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.

Such an example was described recently, when 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. 1000m depth on the continental slope in South Greenland (60.36°N, 48.45°W) (Kenchington et al. 2017). The area is designated as a Vulnerable Marine Ecosystem (VME); a term which is used to identify areas or habitats vulnerable to anthropogenic disturbance, based on its uniqueness, functional significance, fragility, recovery potential and structural complexity (FAO 2008).

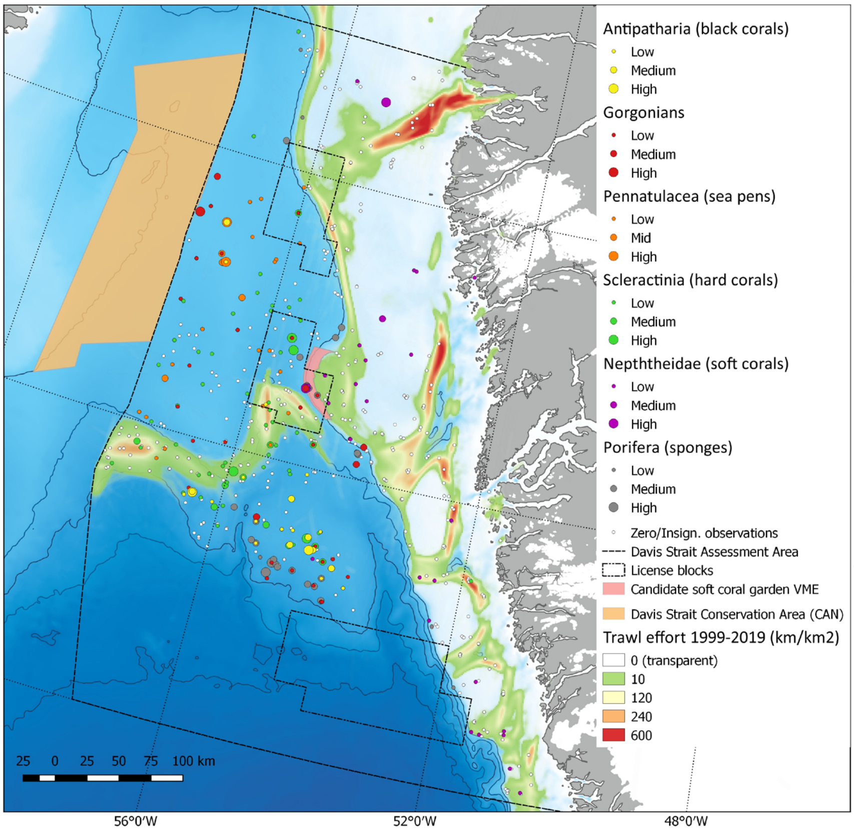
### 3.4.2 Recent studies and current monitoring of benthic fauna in the assessment area

As mentioned 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 motile 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 and commercial activities on the marine ecosystem and 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 analyzed 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 Vulnerable Marine Ecosystems (*VME*), valuable ecosystem components or areas subject to dramatic changes (e.g. biodiversity hotspots, 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). 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 (Fig. 3.4.2). One such project is an ongoing collaboration between GINR and the Institute of Zoology at ZSL, London, 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 fisheries. Several fisheries in Greenland have been, or are currently being, evaluated according to the sustainability principles defined by the Marine Stewardship Council (MSC.org). Data from

**Figure 3.4.3.** Bubble diagram showing relative densities of corals and sponges (Porifera) in the Davis Strait 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 light red polygon indicates a recently proposed VME area (see below and fig. 3.4.5 and 3.4.6). The Davis Strait Conservation Area in the Canadian EEZ is indicated with an orange polygon.




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.

By 2019, a total of more than 700 benthos invertebrate species/taxa have been registered within the Davis Strait assessment area in GINR's sampling program, at depths ranging from 50 to 1500m. 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. However, 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 (Vulnerable Marine Ecosystems, according to FAO criteria for vulnerability to bottom trawling) (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 benthos 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 benthos VME indicator taxa have been scarce for West Greenland until the implementation of GINR's benthos monitoring program. Fig. 3.4.3 is intended to give a preliminary overview, up to 2019, of observations of five main groups of corals (Gorgonians, Antipatharia, Scleractinia, Pennatulacea, Nephtheidae) and large-sized sponges (Porifera) 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

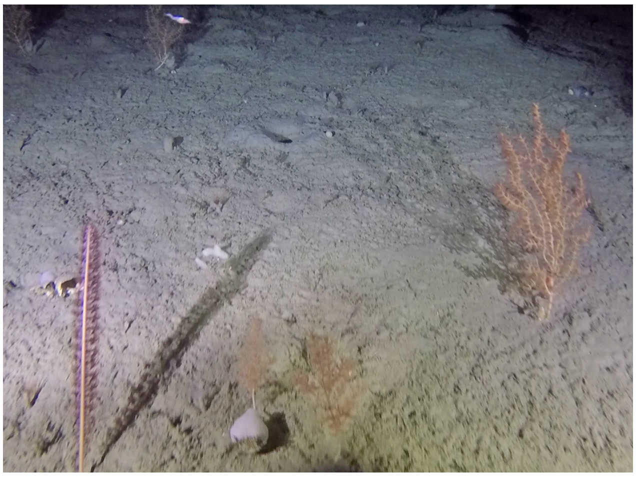


**Figure 3.4.4.** Example stills/photos of the habitat found east of the Canadian Davis Strait Conservation Area in the Greenland EEZ at 6-700m depth. Vulnerable Marine Ecosystem indicator species on images: sea pens *Anthoptilum grandiflorum* (top left image) and *Halipteris finmarchica* (bottom left), bamboo coral *Acanella arbuscula* (top right, bottom left), stony coral *Flabellum alabastrum* (top right), carnivorous sponge *Chondrocladia grandis* (top left).

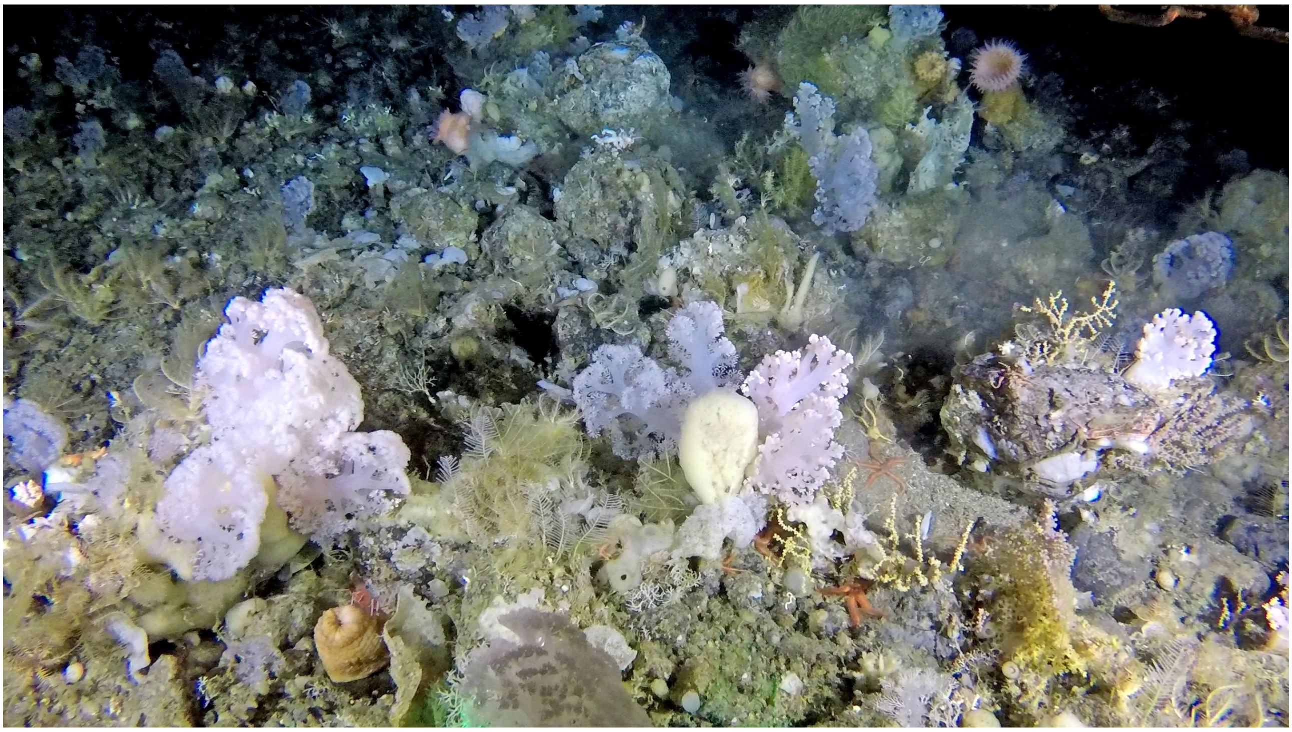


**Figure 3.4.5.** Example still showing the structural complexity of the soft coral garden habitat on rocky ground at a depth of 585m, on the continental slope off Toqqusaq Bank, West Greenland. Nephtheidae, Crinoidae, gorgonians corals, Porifera, Actinaria, Hydrozoa and calcified Bryozoa, are present with a rich associated fauna. Laser dots (green) are 20cm apart, the left-hand dot is partially obscured.

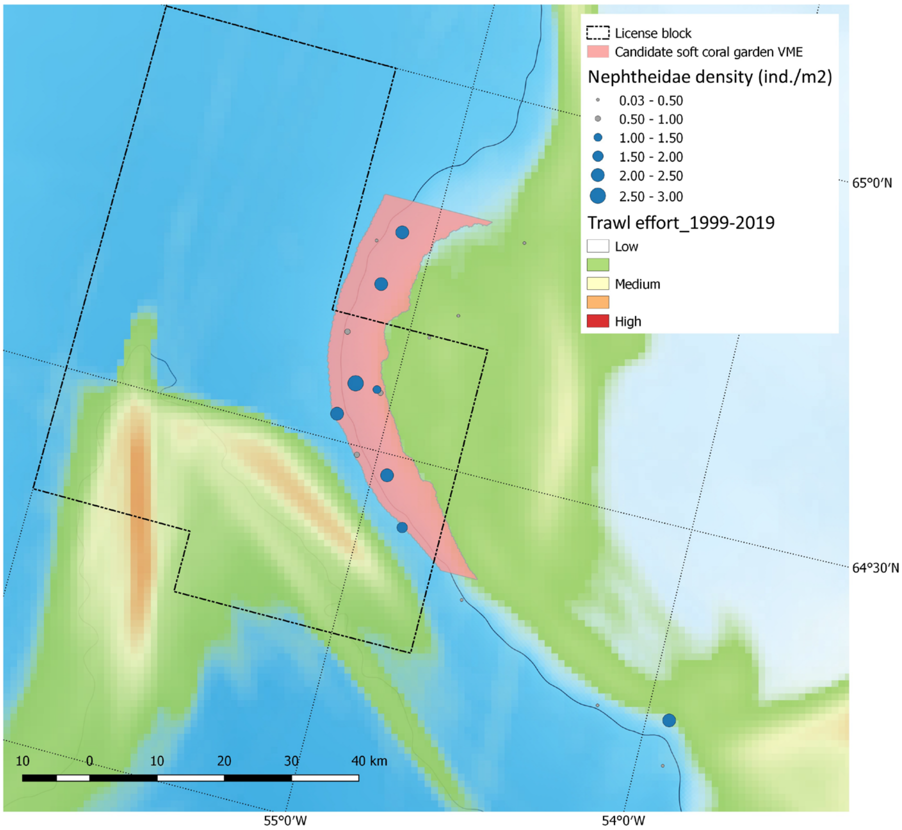



**Figure 3.4.6.** Map showing licence block 2019/2 and the 486 km² proposed soft coral garden vulnerable marine ecosystem (VME) (light red), on the continental slope of the Toqqusaq Bank, West Greenland. The mean density of Nephtheidae colonies is shown (circles), obtained from video imagery, with those stations exhibiting a density ≥1 m² highlighted in blue (<1 m² grey). Fishing effort is based on haul by haul logbook data from 1999-2019, used to determine the number of km trawled per km², for the halibut fishery (>700 m) and the prawn/cod fishery (<500 m). Redrawn from Long et al. In press.

possible to point out localities or areas with higher concentrations of focus taxa, or other special features. The preliminary data indicate that an area between 63 and 64°N and 1000 to 1500m depth has relatively high occurrences of Scleractinia (i.e. cup coral *Flabellum alabastrum*), Antipatharia and large Porifera. This area, which is south of the existing fisheries footprint for Greenland halibut, is part of an ongoing PhD study, which includes a thorough analysis of species and community distribution (see comment above). The area is north of the most southern licence block, 2017/14, from which GINR currently has no data. Data are also relatively scarce from the most northern licence block, 2019/01, and the present data only hold few significant observations of VME indicator taxa. However, trawl bycatch data indicate relatively high occurrences of sea pens, Pennatulacea (*Halipteris finmarchica* and *Anthoptilum grandiflorum*) and gorgonian corals (*Acanella arbuscula* and *Paragorgia arborea*) at some localities in the 6-700 m depth range to the west of block 2019/01. This is likely to correspond to a benthic community observed in the Canadian EEZ, which recently led to the designation of the 17,298 km² large Davis Strait Conservation Area (Fig. 3.4.3; http://dfo-mpo.gc.ca/oceans/oeabcm-amcepz/refuges/davisstrait-detroitdavis-eng.html.). This seemed to be confirmed by video material from a few adjacent stations, in the Greenland EEZ, showing aggregations of sea pens and gorgonian corals together with other benthos VME indicator species (Fig. 3.4.4). But more documentation is needed to outline the geographical extent of this habitat. 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. Untrawled 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.

For licence block 2019/2 that borders on the Toqqusaq bank, GINR holds a considerable amount of information about the benthos community. In a new study, catches of Gorgonians, Nephtheidae and large-sized Porifera on the slope off the Toqqusaq bank, immediately adjacent to existing trawl fisheries, were followed up by targeted video sampling for a detailed habitat description. Results showed a habitat where benthic megafauna contribute to notable structural complexity (Fig. 3.4.5).

Quantitative analyses of imagery provide 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 guidelines (FAO 2008) and wider literature. The study proposed a 486 km$^2$ area spanning ~60 km of continental slope as a VME. The area can be described as the area with depths of 300-600m between 64°50′ N and 64°22′ N on the western edge of the Toqqusaq Bank (Long et al. In press). Fig. 3.4.6 shows the overlap between the suggested VME and the licence block, 2019/02. By the time of writing this report, the suggestion had not yet been presented to the authority responsible for designating VME areas in Greenland.

### 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)*

The 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 the ice 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 fauna 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 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 cods 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. 2018b), which emphasizes the importance of sea ice algae for all trophic levels in the Arctic.

Strong patchiness of the sea ice algae is commonly reported (Fig. 3.5.1), 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 sites within the assessment area and one site just north of) that the patchiness of algal biomass was strongly controlled by the

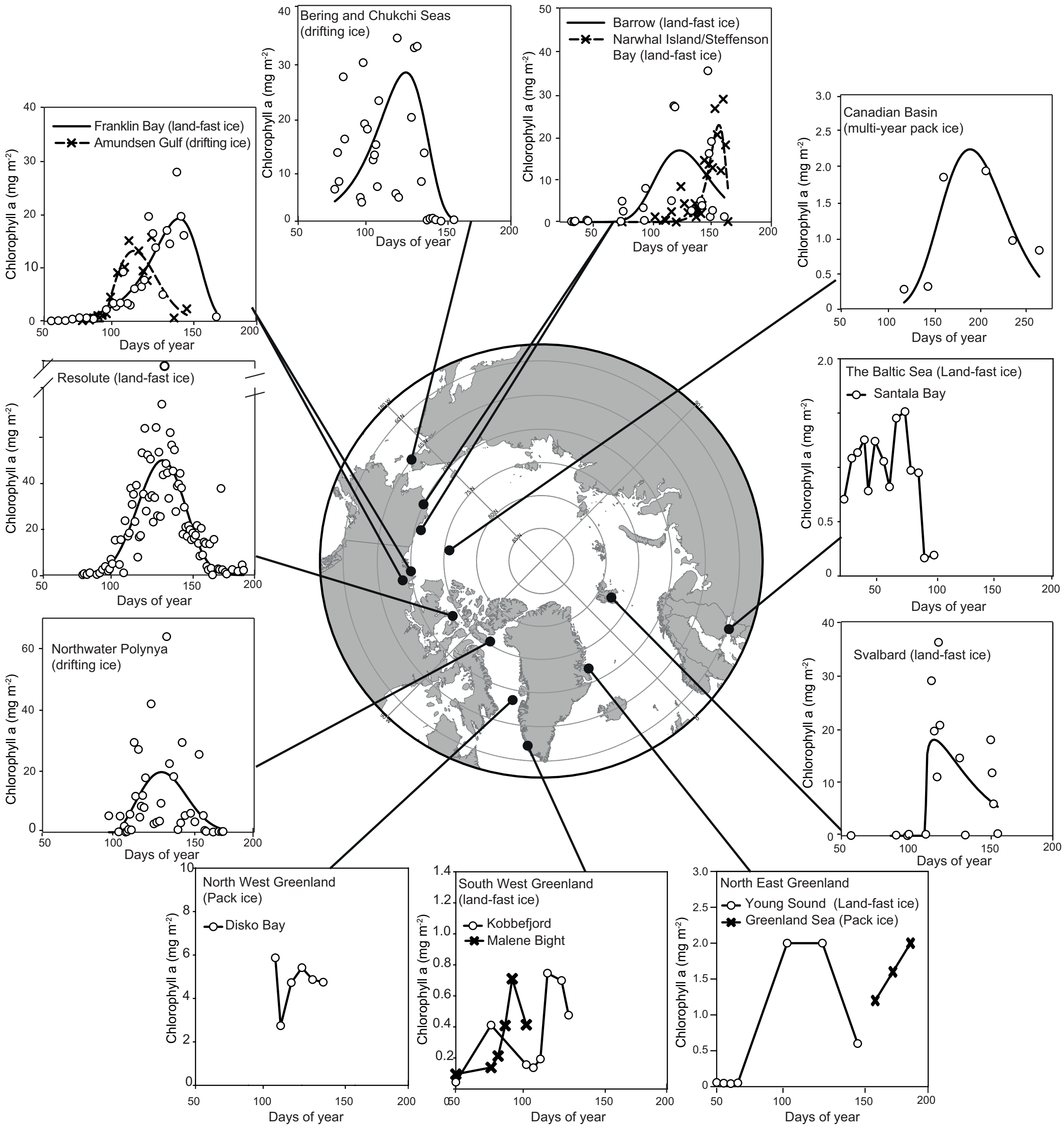



**Figure 3.5.1.** Seasonal development of Chl *a* concentrations in sea ice in different regions of the Arctic (modified from Lund-Hansen et al. 2020). One of the studies was carried out in Disko Bay, north of the assessment area, and two inside the assessment area.

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* $m^{-2}$, which is similar to values measured in sea ice in the central Arctic Ocean and the Baltic Sea (Fig. 3.5.1). 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 (Fig. 3.5.1). 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) (Fig. 3.5.2). 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* (Tab. 3.5.1). This diatom is found to be either very dominant or rare/absent (Gutt 1995); 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 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

**Table 3.5.1.** 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 |

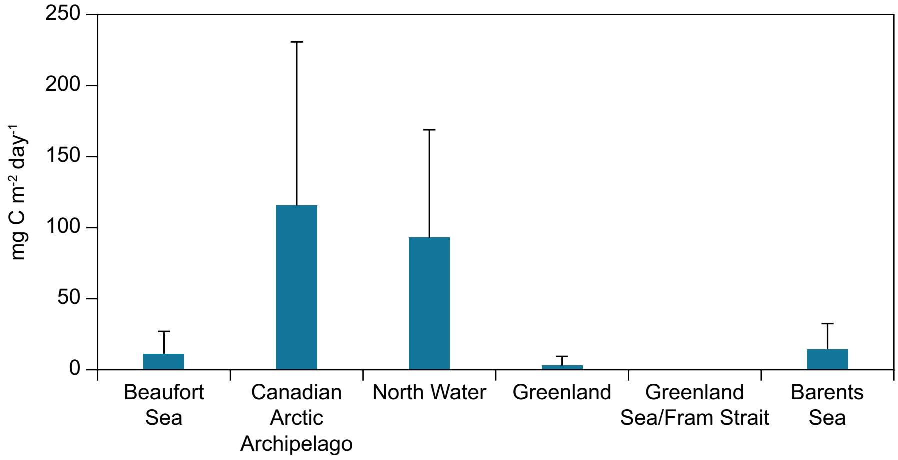
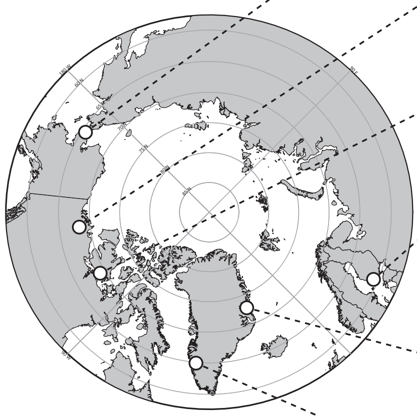



**Figure 3.5.2.** Sea ice algae primary production average with standard deviation at sites in the Arctic Region. Compiled from Barber et al. (2015), Leu et al. (2015) and Arrigo (2017). Modified from Lund-Hansen et al. (2020).

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) (Fig. 3.5.3). Few combined measurements of bacterial and algal productivity exist in the assessment area, making it difficult to assess the spatial and temporal impact of these processes (Fig. 3.5.2). In general, the annual succession follows the same pattern with a winter stage characterized by a net heterotrophic activity and remineralization 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



**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 3.5.3.** Sea ice bacterial and sea ice algal productivity compiled for different Arctic locations (modified from Lund-Hansen et al. 2020). The studies in South West Greenland was carried out within the assessment area.

et al. 1999). Diatoms are the main primary producers, and contribute with up to 60% of total algal biomass. *Melosira arctica*, together with the pennate diatom, *Nitzshia frigida*, tend to be the dominant diatom species off Northeast Greenland/Barents Sea (Gutt 1995, Gosselin et al. 1997, Quillfeldt et al. 2009), and when the ice melts, it is supposed that the diatom sinks to the bottom and thereby may constitute a relatively large input of organic material to the pelagic grazers and benthic communities (Gutt 1995, Michel et al. 2002). However, flagellated algal cells were also found to be of significance (Gradinger et al. 1999, 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

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Many different shellfish and fish species are of common occurrence in the assessment area. Most are demersal i.e. living near the sea bottom. Species among shellfish include coldwater shrimps, snow crabs, scallops, blue mussels and among marine vertebrates the Greenland halibut, salmon, cod, Atlantic halibut, wolfish, redfish, capelin, lumpsucker and other species. The marine shelf is important fishing grounds and is characterised by relatively few dominant species, with strong interactions (Pedersen & Kanneworff 1995).

### 3.6.1 Selected species

**Shrimp, *Pandalus borealis***
*Biology:* The key species, northern shrimp (*Pandalus borealis*) dominates in West Greenland waters. The striped pink shrimp (*Pandalus montagui*) is also found in the area, but is much less abundant (Kanneworff 2003). Both shrimp species have a life strategy called protandric hermaphroditism, which means that the species grow up as males and then go through a transition to female. Right before the females extrude the eggs the male attaches a spermatophore to the female. On extrusion of the eggs the females carry them on their legs for approximately 6-9 months.

*Distribution:* The northern shrimp is an expansive species (Bergström 2000) with a circumpolar occurrence. In West Greenland shrimps are distributed along the entire coastline and are most common at 100-600 m in depth. In recent years the extension area for northern shrimp has moved northwards (Burmeister & Rigét 2019c) and the main biomass is now concentrated north of 66°N, but there is still a significant amount of shrimp biomass with in the assessment area.

*Movements:* The shrimps are highly mobile both horizontally and vertically and have a diurnal migration where they forage at the bottom during daytime and in the pelagic food web at night (Horsted & Smidth 1956).

*Breeding distribution:* The shrimps migrate horizontally into the inshore shallow areas in order to spawn (Hjort & Ruud 1938, Horsted & Smidth 1956, Haynes & Wigley 1969, Bergstrøm 1991) and the northern shrimp spawns in Greenland waters during April (Horsted 1978).

*Population size:* The northern shrimp stock in West Greenland is assessed as a single population. The total biomass of northern shrimp in West Greenland has increased since the early 1990s, reaching its highest level in 2003 and 2004. In the following years the stock declined to a low level in 2014, but have since increased and have been stable since 2017 (Burmeister & Rigét 2019b, c). The recruitment of northern shrimp has been variable since 1988, in some years considerably above mean for the entire time series and in other years below or close to the mean (Burmeister & Rigét 2019c). The reason for this recruitment variability is unknown. Pedersen and Storm (2002) and Koeller et al. (2009) suggest that the recruitment of shrimps is dependent on food availability, but other ecological parameters might have an influence as well.

Buch et al. (2003) has shown a tight relationship between the occurrence of cod and the disappearance of shrimps. Nevertheless, in recent years the estimated biomass of cod has been very low. It would be reasonable to look into the match-mismatch theory for shrimp egg hatching and the peak of phytoplankton bloom in order to investigate possible correlations (Wieland & Hovgaard 2009) and other ecological factors.

**Snow crab, *Chionoecetes opilio***

*Biology:* Snow crab (*Chionoecetes opilio* O. Fabricius; Brachyura, Majidae) has a wide distribution and is considered to be of arctic-boreal biogeographic affinity, because it does not usually extend north of the Arctic Circle into the High Arctic (Squires 1990); although there are two exceptions (Paul & Paul 1997, Burmeister 2002). Snow crab mainly inhabits grounds of mud or sand-mud substrate at depths from 30 to 1,400 m, where bottom temperature remains –1.5 to 4°C year round (e.g., Squires 1990, Dawe & Colbourne 2002). Snow crab may be physiologically constrained to these temperatures as its energy budget becomes negative outside of the range due to reduced feeding and rising metabolic costs (Foyle et al. 1989, Thompson & Hawryluk 1990).

As with other brachyuran crabs, the snow crab life cycle features a planktonic larval phase and a benthic phase with separate sexes. The mating system is complex, with a distinct male dominance hierarchy resulting from intense sexual competition favouring larger males (Donaldson & Adams 1989, Elner & Beninger 1995, Sainte-Marie et al. 1999, Sainte-Marie & Sainte-Marie 1999). Females can reproduce several times in their lifetime, may be quite polygamous and have a pair of spermathecae for extended storage of sperm (Elner & Beninger 1995, Sainte-Marie et al. 2000). It is accepted that female snow crab may produce more than one viable brood from spermatophores stored in their spermathecae (Sainte-Marie 1993, Sainte-Marie & Carriere 1995). Eggs are incubated beneath the female's abdomen and hatching, and larval release occur during late spring or early summer just prior to extrusion of the new clutch of eggs, which may or may not be preceded by mating.

The larvae proceed through three planktonic stages (zoeae I-II, megalops) and settle on the bottom in autumn at a carapace width (CW) of approximately 3 mm. The snow crab spends the rest of its life on the sea floor, where it preys on fish, clams, polychaetes and other worms, brittle stars, shrimp, other crabs and its own congeners (Lefebvre & Brêthes 1991, Sainte-Marie et al. 1997). Crabs grow by moulting, in late winter or spring in the case of larger crabs, and both males and females have a terminal moult to adulthood (i.e. functional sexual maturity), which occurs over a wide size interval (Conan & Comeau 1986, Sainte-Marie & Hazel 1992, Sainte-Marie 1993, Sainte-Marie et al. 1999). There is a large sexual size/age dimorphism at adulthood, with males living up to approximately 15–16 years and females up to about 11–12 years after settlement (Sainte-Marie et al. 1995, Alunno-Bruscia & Sainte-Marie 1998, Comeau et al. 1998). The males enter the fishery approximately 8-9 years after settlement to benthic stage.

*Distribution:* The most northerly record of snow crab is from Greenland, where the species is distributed along the west coast between 60°C and 74°N in both offshore and inshore (fjords) locations (Burmeister 2002), thus throughout the assessment area. Greenland fjord populations are possibly isolated at the benthic stage, as appears to be the case in Canadian fjords (Conan & Comeau 1986, Bernard Sainte-Marie, MLI, Canada, pers. comm.). In Greenland, snow crab is generally found at depths between 100 and 800 m and at bottom water temperatures ranging from about –1.0°C to about 4.5°C.

*Movements:* The Greenland coastal system consists of fjords and basins. Fjord populations of snow crab in the benthic phase are partially or completely isolated from one another and from offshore populations by sills (Burmeister & Sainte-Marie 2010). Early life history of snow crab including larval drift between offshore and inshore sites, nursery grounds, settling and occurrence of benthic stages is unknown or poorly understood in the assessment area. Genetic analysis showed that snow crab in West Greenland waters differ significantly from those in western part of Davis Strait (Atlantic Canada), whereas no difference was found between inshore and offshore site subpopulations within this assessment area (Puebla et al. 2008).

*Population size:* The population occurring in the assessment area had an unfavourable conservation status from 2005 and until 2012 due to years of high fishing pressure, but over the recent years the population has stabilised at a low level (Burmeister, 2019).

**Greenland Halibut, *Reinhardtius hippoglossoides***

*Biology:* Greenland halibut is a slow-growing and long-living deep-water flatfish, that matures late at ages 8-10 years. The assessment constitutes the main spawning ground, which is assumed to be located south of 67º in the central part of the Davis Strait, south of the sill between Greenland and Baffin Island where spawning takes place in early winter. This assumption is based on the development of ovaries (Jørgensen 1997a, Gundersen et al. 2010) and observation of eggs (Smidt 1969). Most sampling has been conducted at depths down to about 1,500 m, but no females in spawning conditions have ever been observed and it is possible that spawning takes place at depths greater than 1500 m, probably around 62°30'N - 63°30'N. From the spawning grounds, eggs and larvae drift through the assessment area with the West Greenland Current towards the settling areas. Early stage eggs are found between 240-640 m (Smidt 1969) and larvae are primarily found at 13-40 m (Simonsen & Gundersen 2005). The pelagic stage lasts more than six months (Smidt 1969). The larvae settle in August-September when they have reached a length of about 6-8 cm. Store Hellefiskebanke, Disko Bay and Disko Bank west of Disko Island are well-documented settling and nursery areas (Smidt 1969, Stenberg 2007) but larvae are also brought into the Baffin Bay by the West Greenland Current and to the East Coast of Canada (Bowering & Chumakov 1989) by a branch of the West Greenland Current that flexes towards west at the sill between Greenland and Baffin Island. This drift pattern has been strongly supported by observations of egg and larvae and by models simulating the drift of Greenland halibut eggs and larvae (Stenberg 2007). The assessment area therefore covers a major part of both the assumed spawning and the known nursery areas for Greenland halibut. Elsewhere in the Northwest Atlantic spawning has only been observed sporadically in the Baffin Bay and inshore in the Northwest Greenland fjords (Simonsen & Gundersen 2005) and along the east coast of Canada (Bowering & Brodie 1995). The Greenland halibut populations in the Davis Strait, Baffin Bay, inshore areas in Northwest Greenland and the east coast of Canada area are therefore believed to be recruited from the spawning stock in the Davis Strait.

*Distribution*: The assessment area includes the main spawning ground for Greenland halibut and the Greenland halibut is distributed in deep waters circumpolar around the Arctic between 200 to 2000 m. In the North-western Atlantic it is distributed around the Baffin Bay, Davis Strait and Labrador Sea and inshore areas along the entire west coast of Greenland and inshore areas at eastern Canada.

*Migration:* Since 1964 more than 100,000 Greenland halibut have been tagged with conventional external tags in national programs over the entire North

Atlantic. Tagging studies from eastern Canada (Bowering 1984) and West Greenland (Boje 2002) and unpublished data from Greenland Institute of Natural Resources, together with studies based on survey data (Jørgensen 1997a), show that Greenland halibut gradually migrates towards greater depths and towards the presumed spawning area as they grow, reaching the spawning area as adults. One- and to some extent two-year-old fish feed on zooplankton in the water column while older fish feed on shrimps, fish and squids that are taken either at the sea bottom or during irregular feeding migrations into the water column (Jørgensen 1997b).

**Atlantic cod, *Gadus morhua***
*Biology:* The Atlantic cod is an epibenthic-pelagic species (Coad & Reist 2004) and is distributed in a variety of habitats from the shoreline to the continental shelf. The cod is an omnivorous species eating anything from invertebrates to fish, including younger members of its own species. Atlantic cod spawns once a year in batches (Murua & Saborido-Rey 2003). Old and large female cod produce more eggs of better quality per female compared to young and small female cod. Eggs from old and large females also have a higher probability of surviving (Kjørsvik 1994). In Greenland Atlantic cod spawns in spring (April-May). The eggs and later the larvae drift with the currents and the larvae settle in the autumn at lengths of 5-7 cm. Temperature has an impact on the abundance as well as the development and survival of the eggs (Buckley et al. 2000).

*Distribution and spawning stocks:* The Atlantic cod found in Greenland is derived from four separate 'stocks' that each is labelled by their spawning areas: I) offshore West Greenland spawning grounds ; II) spawning grounds in West Greenland fiords; III) inshore Icelandic spawning grounds; and IV) offshore East Greenland and offshore Icelandic spawning grounds (Therkildsen et al. 2013). Offspring from the offshore Icelandic spawning grounds are occasionally transported in significant quantities with the Irminger current to Greenland waters. The Icelandic offspring generally settle off East and South Greenland, whereas offspring from the Greenland offshore spawning is believed mainly to settle off the West Greenland coast (Wieland & Hovgaard 2002). The assessment area is therefore a potential nursery area for young cod originating from both the Icelandic and the offshore Greenlandic stocks. Tagging experiments and genetic analysis have shown that the offshore stocks migrates to the coastal zone and mixes with the inshore stocks (Storr-Paulsen et al. 2004, Christensen 2019).

Over the past two decades there have been weak signs of temporary recolonization of the offshore West Greenland spawning grounds. If this becomes more permanent there is a possibility that the assessment area once more will become an important recruitment area for Atlantic cod in the West Greenland

**Lumpsucker, *Cyclopterus lumpus***
*Biology:* Mature lumpsucker adults (3-5 years of age) arrive along the Greenland coastline throughout the assessment area in early spring (Mosbech et al. 2004b) and spawn in the following months in shallow waters (Muus & Nielsen 1998). The male guards and ventilates the approximately 100,000-350,000 eggs for a couple of months (Muus & Nielsen 1998, Sunnanå 2005). Based on Norwegian data, the offspring probably spend the first two years in the near shore kelp. The adult fish reside in deeper waters outside the spawning season, but it is unknown if and to where they migrate outside the spawning season. They are, however, occasionally caught in near shore shelf areas in bottom trawls (Greenland Institute of Natural Resources, unpublished data).

The feeding behaviour of Greenland lumpsucker is unknown, but due to its poor swimming capabilities it is most likely restricted to jellyfish and other slow-moving organisms (Muus & Nielsen 1998). Lumpsuckers may constitute a significant prey resource to sperm whales in the area, as seen elsewhere (Kapel 1979, Martin & Clarke 1986).

*Distribution:* The common lumpsucker is distributed throughout the assessment area, and also found at both higher and much lower latitudes (i.e. North Sea). Hence, climatic changes will most likely not negatively affect the lumpsucker in the assessment area through direct temperature effects. However, as little is known about lumpsucker migrations and dependency on other ecosystem components, it is unclear how the species would respond to climatic changes.

**Salmon, *Salmo salar***

*Biology and distribution:* Atlantic salmon migrates to Greenland from countries around the North Atlantic. In Greenland, the only known spawning population of Atlantic salmon is located in the Kapisillit river in the inner part of Nuup Kangerlua, West Greenland (Nielsen 1961). Other rivers that could potentially hold a salmon population exist, but in general the rivers of Greenland are short, steep and cold (Jonas 1974). Although persistent, the contribution of the small Kapisillit population to the salmon fishery around Greenland must be regarded as insignificant compared to the numerous salmon undertaking feeding migrations to Greenland from other regions in the North Atlantic, including North America and European stocks. Salmon from stocks around the North Atlantic migrate to Greenland to prey on capelin, Themisto, squid and other pelagic prey in the surface layers. Salmon can be found in the waters around Greenland throughout the year, but abundance seems to peak in the autumn from August to October. In West Greenland the northern distribution varies from year to year, but salmon can be found as far north as the Upernavik district around 72$^{o}$ N.

*Population size:* In recent years the overall size of the stocks of both North American and European origin, which contributes to the West Greenland fishery is among the lowest recorded, and as a result the abundance of salmon in Greenland waters is thought to be low compared to historic levels. Electrofishing and mark recapture experiments in the Kapisillit River in 2016, revealed high concentrations of parr (individuals below 25 cm) in the river consisting all year classes from 1-6 with no obvious missing year classes. Parr concentration in river sections 1-4 ranged between 0,25-1,01 parr/m2. Although high, the concentrations are still below similar experiments conducted during the 1950's (Hedeholm et al. 2018). Genetic studies have shown that the stock is very isolated from other stocks in the North Atlantic (Krohn 2013, Arnekleiv et al. 2019).

**Capelin, *Mallotus villosus***

*Distribution:* Capelin has a circumpolar distribution and in Greenland it is found from the southern tip to 73˚N and 70˚N on the west and east coast, respectively. Although not thoroughly documented, known differences in maximum length, progressive spawning and well separated fjord systems suggest that individual fjord systems contains separate capelin stocks (Sørensen & Simonsen 1988, Hedeholm et al. 2010).

*Biology:* 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. wherein the fjords, they form dense schools prior to spawning. Spawning takes place in shallow water (<10 m) and often on 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 spawns typically at 3-5 years of age (Hedeholm et al. 2010). Although not strictly semelparous a large proportion of the spawning stock dies, especially males, suggesting that the stock should be considered as one-time spawners (Huse 1998, Friis-Rødel & Kanneworff 2002). Outside the spawning season capelin reside primarily in the upper pelagic (0-150 m), but concentrations are sometimes found in deeper waters down to 600 m (Huse 1998, Friis-Rødel & Kanneworff 2002). As elsewhere, Greenland capelin form a crucial energy converting link from lower to higher trophic levels, making it an ecosystem key species (Hedeholm 2010). Hence, in South Greenland capelin feed (depending on size) primarily on copepods, krill and amphipods (Hedeholm 2010). Typical of Arctic food chains, these fatty prey result in capelin also having a high energy content (Hedeholm 2010), which makes it high quality prey to various apex predators such as cod (Hedeholm 2010), harp seals (Kapel 1991), whales and various seabirds (Friis-Rødel & Kanneworff 2002, Vilhjálmsson 2002) .

**Sandeel, *Ammodytes* spp.**

*Biology:* Sandeels (or sand lance) are small bentho-pelagic fish with a central position in many marine food webs. Two species occur in Greenland: the lesser sandeel (*Ammodytes marinus*) and northern sandeel (*A. dubius*). They are extremely similar and difficult to distinguish, and most surveys have recorded sandeels simply as *Ammodytes* spp. Where they occur in high abundance, sandeels are typically a key prey for many seabirds, marine mammals and larger fish species. They feed on zooplankton in the pelagic zone, mainly copepods, particularly *Calanus finmarchicus*. Sandeels spend a large part of their time buried in sandy sediments and are most active during the night, when they swim into the water column to feed. Most of the feeding occurs during spring and summer. Sandeels are thus habitat specialists, and the highest abundances are found on major sand banks at up to 100 m depth. However, smaller areas with suitable sandy sediments, e.g. around islands where currents are strong, are also likely to be sandeel habitat.

*Distribution:* During a large sandeel survey in 1978, exploring the potentials for a commercial fishery in Southwest Greenland, the highest sandeel concentrations were found at the western and southern edge of Store Hellefiskebanke (just north of the assessment area), at the southern edge of Toqqusaq Banke (just north of Fyllas Banke), at Fyllas Banke and Fiskernæs Banke (Andersen 1985). During a benthic cruise in 2009 very high densities of sandeels (on average 9 indv. $m^{-2}$) were found at Store Hellefiskebanke (J. Hansen, unpubl.), but no sampling was done within the assessment area. Information about the occurrence of sandeel larvae is available from zooplankton surveys conducted in June-July in the period 1950 - 1984 (Pedersen & Smidt 2000). The larvae were found throughout most of the shelf in the assessment area, with the highest abundance at Fyllas Banke, Sukkertoppen Banke and Lille Hellefiskebanke (see also Chapter 3.2.5 and Fig. 3.2.4).

**Redfish, *Sebastes mentella* and *Sebastes Norvegicus***

*Distribution:* Four species of redfish live in the North Atlantic but only deep-sea redfish (*Sebastes mentella*) and golden redfish (*Sebastes Norvegicus*) are common in West Greenland waters (Moller et al. 2010). Redfish are found off the coast from 0-1000 m and juveniles found on the banks, in fjords, and inshore waters.

*Biology:* Both deep-sea redfish and golden redfish are slow growing with long lifespan. Both species are ovoviviparous with internal fertilization. Females give birth to live pelagic larvae. Annual growth increments of 4 cm indicated by repeatedly pronounced peaks in length compositions at 7-8 cm and 12 cm probably corresponding to age 1 and 2. Feed on euphausiids, hyperiids, cephalopods, chaetognaths and small fishes.

*Population size:* From 1992 to 1996 the Greenland shrimp survey revealed high numbers of juvenile redfish in the northern parts of the shelf area, including the northern half of the assessment area, but in general the abundance of redfish has decreased substantially since then. During the last decade the biomass of redfish has gradually been increasing along the shelf in West Greenland, either due to increased survival of redfish with the implementation of sorting grids in the shrimp fishery in 2002 or immigration from East Greenland waters. The assessment area covers the known important nursery grounds for redfish in West Greenland.

**Wolffish, *Anarhichas minor*, *Anarhichas lupus* and *Anarhichas denticulatus***
*Biology:* Wolffish inhabit rocky bottoms, sometimes over sand or mud, from 1-500 m both on the banks and in fjords. Feeds on fishes, hard-shelled molluscs, crabs, sea urchins and other echinoderms. Males guard a clutch of eggs right up to the time of hatching.

*Distribution:* Three species of wolffish live in the waters off Greenland. Spotted wolffish (*Anarhichas minor*), Atlantic wolffish (*Anarhichas lupus*), and northern wolffish (*Anarhichas denticulatus*) are all distributed with in the assessment area. All three species of wolffish are occurring across the North Atlantic from USA to Spitsbergen and the Barents Sea and along the coasts of northern Europe. Only Atlantic wolfish and spotted wolffish is of commercial interest. Atlantic wolffish has a more southern distribution and seems more connected to the offshore banks and the coastal areas in west Greenland. Spotted wolffish can be found further north and both inshore and offshore but is the dominant species of wolffish in the coastal areas and inside the fjords. Atlantic wolfish has a shallower depth distribution (0-400m) than spotted wolffish (0-600m). The assessment area covers the majority of both the present and particularly the historic wolffish fishery, which nowadays is at a low level.

*Population size:* Survey indices indicate that the biomass of Atlantic wolffish and spotted wolfish has been increasing in recent years (Nygaard & Nogueira 2020). At the same time Atlantic wolffish has shifted its distribution further north than previously.

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**American plaice, *Hippoglossoides platessoides***
American plaice is distributed throughout the North Atlantic from the coast of Murmansk to the southern Labrador and USA. Survey indices indicate that the biomass of American plaice in West Greenland water is low compared to the 1980s (Nygaard & Nogueira 2020).

**Thorny skate, *Amblyraja radiata***
Thorny skate is distributed throughout the North Atlantic, from Hudson Bay along the coast to USA, Greenland to Iceland, the English Channel, the Bal-

tic, Svalbard and the Barents Sea. Survey indices indicate that the biomass of thorny skate in West Greenland has decreased substantially since the 1980s (Nygaard & Nogueira 2020).

## 3.7 Seabirds

*David Boertmann, Flemming Merkel, Anders Mosbech, Georgina Scholes, Kasper Johansen & Daniel Clausen (AU)*

Seabirds are an important component in the marine ecosystem of the assessment area. The numbers of breeding seabirds are, however relatively low compared to the coastal area and fjords further north in Greenland, in Disko Bay, Upernavik and Qaanaaq Districts. The huge breeding colonies found there do not occur in the Davis Strait assessment area (Boertmann et al. 1996, Labansen et al. 2010, Merkel et al. 2014). However, the assessment area is an extremely important winter quarter for seabirds from the entire North Atlantic (Boertmann et al. 2004, Merkel et al. 2019, see also http://seatrack.seapop.no/map/).

Seabirds constitute an important resource to the Greenlanders, and seabird hunting is a popular spare time activity. There are also fulltime hunters in the assessment area, who sell their products incl. seabirds on the local open-air markets. The seabird hunting is described in chapter 5. The most hunted species are thick-billed murre (*Uria lomvia*), common eider (*Somateria mollissima*) and black-legged kittiwake (*Rissa tridactyla*).

The bird hunt is regulated by the governmental order on protection and hunting of birds, the most recent one was issued on 28 October 2019.

### 3.7.1 Breeding seabirds

Most of the breeding seabirds are colonial breeders and many breeding colonies are found dispersed along the coast of the assessment area (Fig. 3.7.1 and 3.7.2). Colonies vary in size and in species composition, from a few pairs to more than 20,000 individuals and from only a single species up to ten different species. The seabirds usually forage relatively close to the breeding sites, however, two species may potentially undertake much longer foraging trips, although not studied within the assessment area. In other areas of Greenland thick-billed murres have been recorded to fly more than 100 km to find food (Falk et al. 2000, Frederiksen et al. 2017b, Mosbech & Johansen 2020), and the northern fulmar (*Fulmarus glacialis*) is known to undertake exceptionally long foraging trips lasting several days (e.g., Falk & Møller 1997).

A total of 20 species of seabirds are known to breed regularly along the coasts of the assessment area. Of these most are more or less colonial, breeding on steep sea-facing cliffs or on low islets (Boertmann et al. 1996). The only seabird not breeding in distinct colonies is the Arctic skua (Tab. 3.7.1). In addition, a number of species breed at freshwater habitats (and feed in the marine environment) or at sheltered coasts.

It should be noted that the breeding colonies shown in Fig. 3.7.1 and 3.7.2 represent only a minimum of the true number of colonies present. For some species the number of small colonies could easily be twice as many. Extensive survey activity was conducted in the archipelago north and south of Nuuk in 2009-2011 and resulted in a large number of new colonies registered (Rasmus-

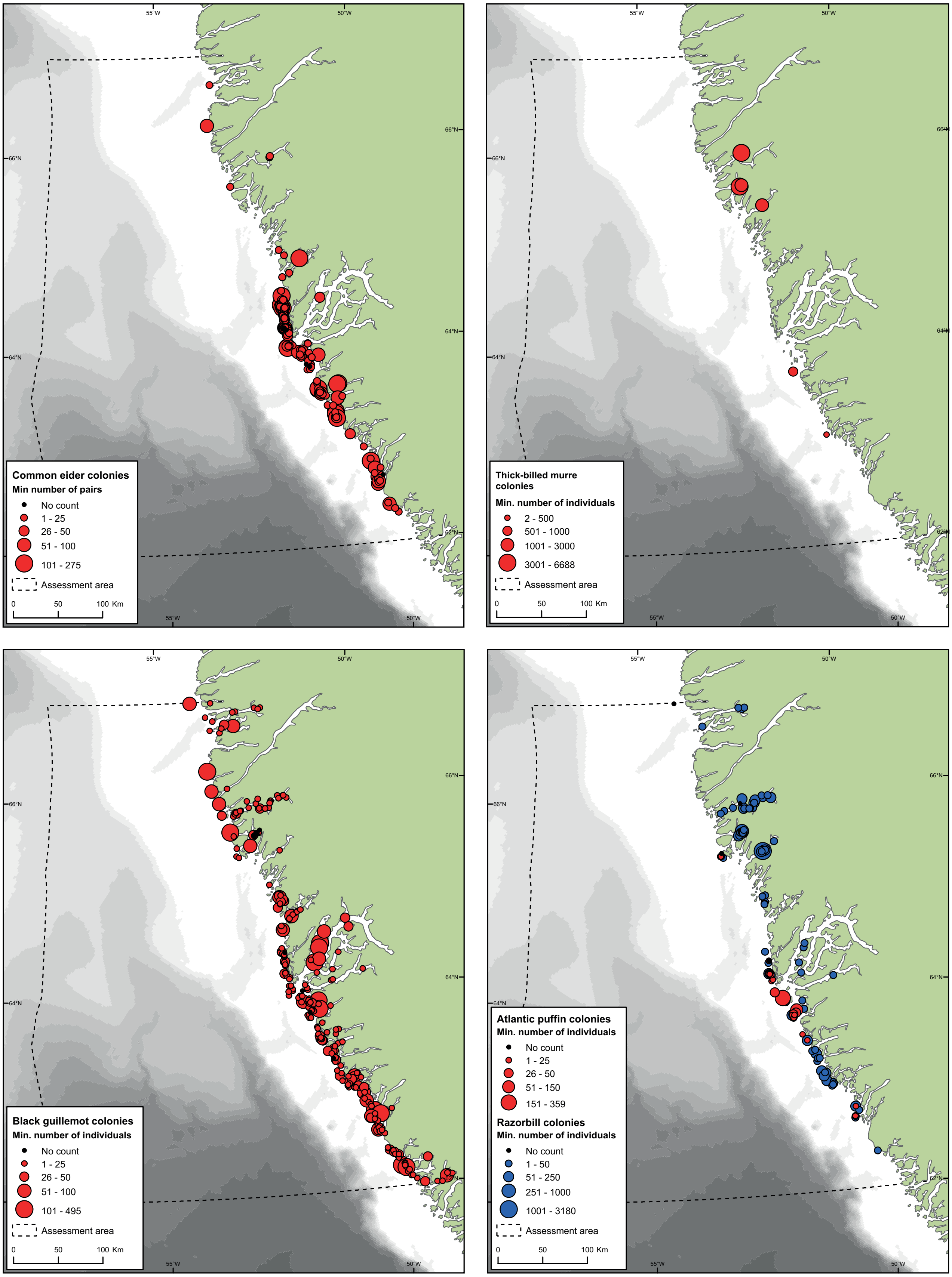



**Figure 3.7.1.** Distribution of seabird breeding colonies of common eider, thick-billed murre, black guillemot, Atlantic puffin and razorbill in the assessment area. Maps are based on data from AU and GINR (the Greenland Seabird Colony Register).

**Table 3.7.1.** Overview of birds associated with the marine environment of the assessment area (b = breeding, s = summering, w = wintering, m = migrant visitor, c = coastal, o = offshore), the "Importance of study area to population" in a national and international context as defined by Anker-Nilssen (1987) and the Red-list status in Greenland (Boertmann & Bay 2018).

| Species | Occurrence | | Distribution | Red-list status in Greenland | Importance of study area to population |
|---|---|---|---|---|---|
| Great northern diver | m/s | spring, summer, autumn | c | near threatened (NT) | medium |
| Red-throated diver | b/m/s | spring, summer autumn | c | least concern (LC) | medium |
| Fulmar | b/s/w | year-round | c & o | least concern (LC) | low |
| Great shearwater | s | July-October | o | least concern (LC) | low |
| Great cormorant | s/w | year-round | c | least concern (LC) | high |
| Light-bellied brent goose | m | autumn | c | vulnerable (VU) | low |
| Mallard | b/w | winter | c | least concern (LC) | high |
| Common eider | b/s/m/w | year-round | c | least concern (LC) | high |
| King eider | w | Oct.-May | c | least concern (LC) | medium |
| Long-tailed duck | b/m/w | year-round | c | least concern (LC) | medium |
| Red-breasted merganser | b/m/w | year-round | c | least concern (LC) | high |
| Harlequin duck | m/w | year-round | c (rocky shores) | least concern (LC) | high |
| Arctic skua | b | summer | c | least concern (LC) | low |
| Black-legged kittiwake | b/s/w | year-round | c & o | Vulnerable (VU) | high |
| Herring gull | b | summer | c | Not applicable (NA) | low |
| Glaucous gull | b/s/w | year-round | c & o | least concern (LC) | medium |
| Iceland gull | b/s/w | year-round | c & o | least concern (LC) | high |
| Great black-backed gull | b/s/w | year-round | c & o | least concern (LC) | medium |
| Lesser black-backed gull | b | April-Sept. | c | least concern (LC) | medium |
| Arctic tern | b | May-September | c | near threatened (NT) | low |
| Thick-billed murre | b/w | year-round | c & o | vulnerable (VU) | high |
| Common murre | b/w | year-round | c & o | Endangered (EN) | high |
| Razorbill | b/w | year-round | c & o | least concern (LC) | high |
| Atlantic puffin | b/w | year-round | c & o | Vulnerable (VU) | high |
| Black guillemot | b/w | summer<br>winter | c<br>c & o | least concern (LC) | high |
| Little auk | w | September-May | o | least concern (LC) | low |
| White-tailed eagle | b/w | year-round | c | vulnerable (VU) | high |

sen 2011). Some colony information shown in Fig. 3.7.1 and 3.7.2 is more than 25 years old and may be outdated.

### 3.7.2 Summering seabirds

During summer the shelf waters of the assessment area are utilised by non-breeding seabirds. Numerous individuals from breeding populations all over the North Atlantic – mainly black-legged kittiwakes and northern fulmars (*Fulmarus glacialis*) – move into the Greenland waters in summer (Lyngs 2003). Also occurring here are great shearwaters (*Ardenna gravis*) breeding in the southern hemisphere. In coastal areas other non-breeding seabirds utilise the region in summer – ducks arriving from breeding sites in Canada and inland Greenland assemble and moult along the outer coast and in some fjords. Harlequin ducks (*Histrionicus histrionicus*) are found at exposed rocky islands, while long-tailed ducks (*Clangula hyemalis*) and red-breasted mergansers (*Mergus serrator*) moult in shallow fjords and bays (Boertmann & Mosbech 2001, 2002) (Boertmann 2008a).

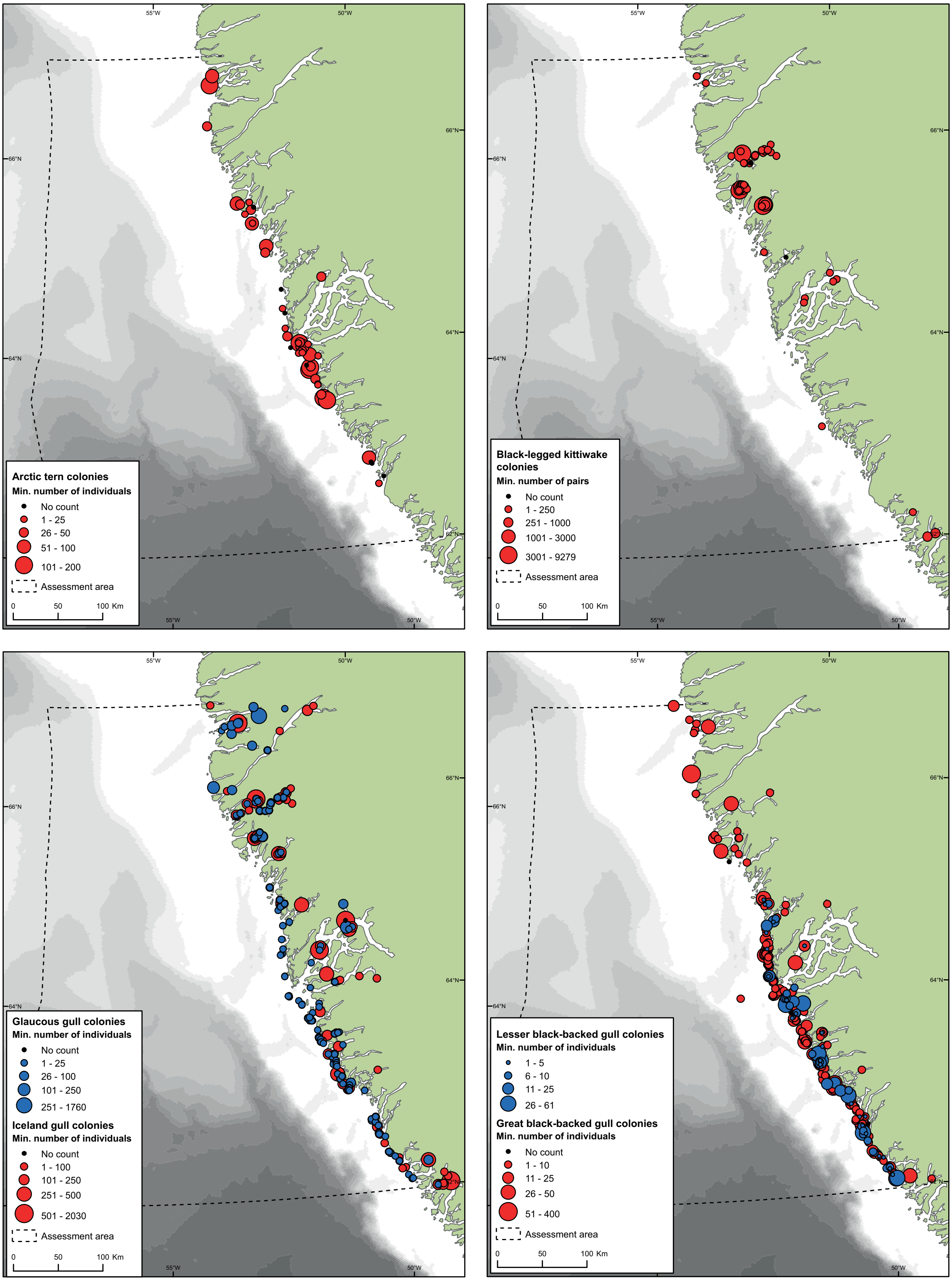



**Figure 3.7.2.** Distribution of seabird breeding colonies of Arctic tern, black-legged kittiwake, glaucous gull, Iceland gull, lesser black-backed gull and great black-backed gull in the assessment area. Maps are based on data from AU and GINR (the Greenland Seabird Colony Register).

### 3.7.3 Inland birds

Inland birds, breeding in freshwater habitats also utilise the marine waters, mainly in winter and during migration. These comprise mallards (*Anas platyrhynchos*), long-tailed ducks, red-breasted mergansers, harlequin ducks, red-throated divers (*Gavia stellata*) and great northern divers (*Gavia immer*) (Tab. 3.7.1). As mentioned above, some of the ducks may also breed at sheltered coasts, while divers often find their food in the marine environment, performing regular flights between inland breeding sites and the coast.

The white-tailed eagle (*Haliaeetus albicilla*) is also relevant to this assessment as it feeds mainly in the marine environment.

### 3.7.4 Wintering seabirds

As mentioned above, the waters of the assessment area constitute very important winter quarters for seabirds. This is due to the fact that sea ice usually does not occur in winter – the region is often referred to as the 'Open Water Area' because the harbours are navigable throughout the year. Seabirds from Russia, Iceland, Svalbard and Canada assemble here October-May (Boertmann et al. 2004, Boertmann et al. 2006, see also Link) and it is estimated that more than 3.5 million birds winter along the coasts of the Open Water Area. To this figure an unknown, but probably very large number (several million) of little auks (*Alle alle*) should be added (Boertmann et al. 2004).

The seabird wintering sites in the assessment area are therefore of high international importance. The most numerous species in winter are common eider, king eider (*Somateria spectabilis*), thick-billed murre, black-legged kittiwake, puffin (*Fratercula arctica)* and the large gull species. The distribution of the wintering seabirds was surveyed in the coastal area of West Greenland in 1999 and 2017 (Merkel et al. 2002, Boertmann et al. 2004, Merkel et al. 2019).

Recent tracking of seabirds (see the Norwegian SEATRACK-data), confirm that seabirds breeding in Norway, Svalbard, Iceland, Russia and Northwest Greenland move to the waters off West Greenland for the winter or use these waters on their way to winter quarters off northeast Canada e.g., Atlantic puffin from Norway and Iceland, black-legged kittiwake from Russia, Norway and Iceland and thick-billed murre from Norway, Svalbard, Iceland and northwest Greenland (Frederiksen et al. 2012b, Frederiksen et al. 2016, Fayet et al. 2017). These studies also have improved the knowledge on habitat use of the wintering seabirds and the factors governing their distribution.

### 3.7.5 Selected species

A number of seabird species important for the assessment area are briefly described in the following pages. For some species, the at-sea distribution is shown for different seasons of the year, based on systematic ship and aerial survey data collected between 1988 and 2017 by DCE/GINR or by Marine Mammal and Seabird Observers (MMSO) on-board seismic vessels. In total, 55 ship surveys and 7 aerial surveys were included in the analysis. 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 interpola-

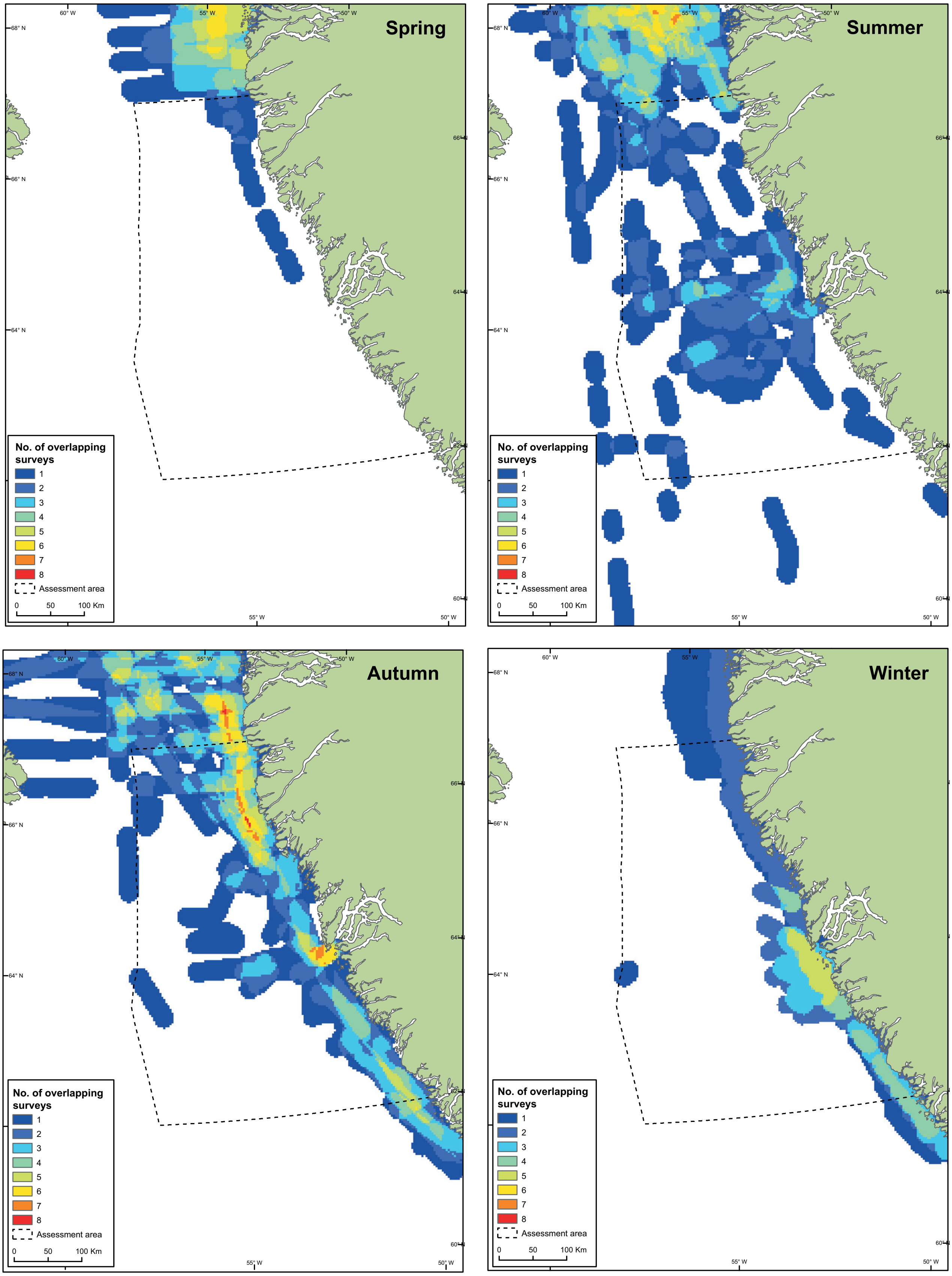



**Figure 3.7.3.** The number of systematic ship or aerial surveys on which the average at-sea seabird densities are based during spring (Apr.-May), summer (Jun.-Aug.), autumn (Sep.-Dec.) and winter (Jan.-Mar.). Areas with no survey activity are shown as white. The maps do not necessarily include all surveys conducted in the assessment area, 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.

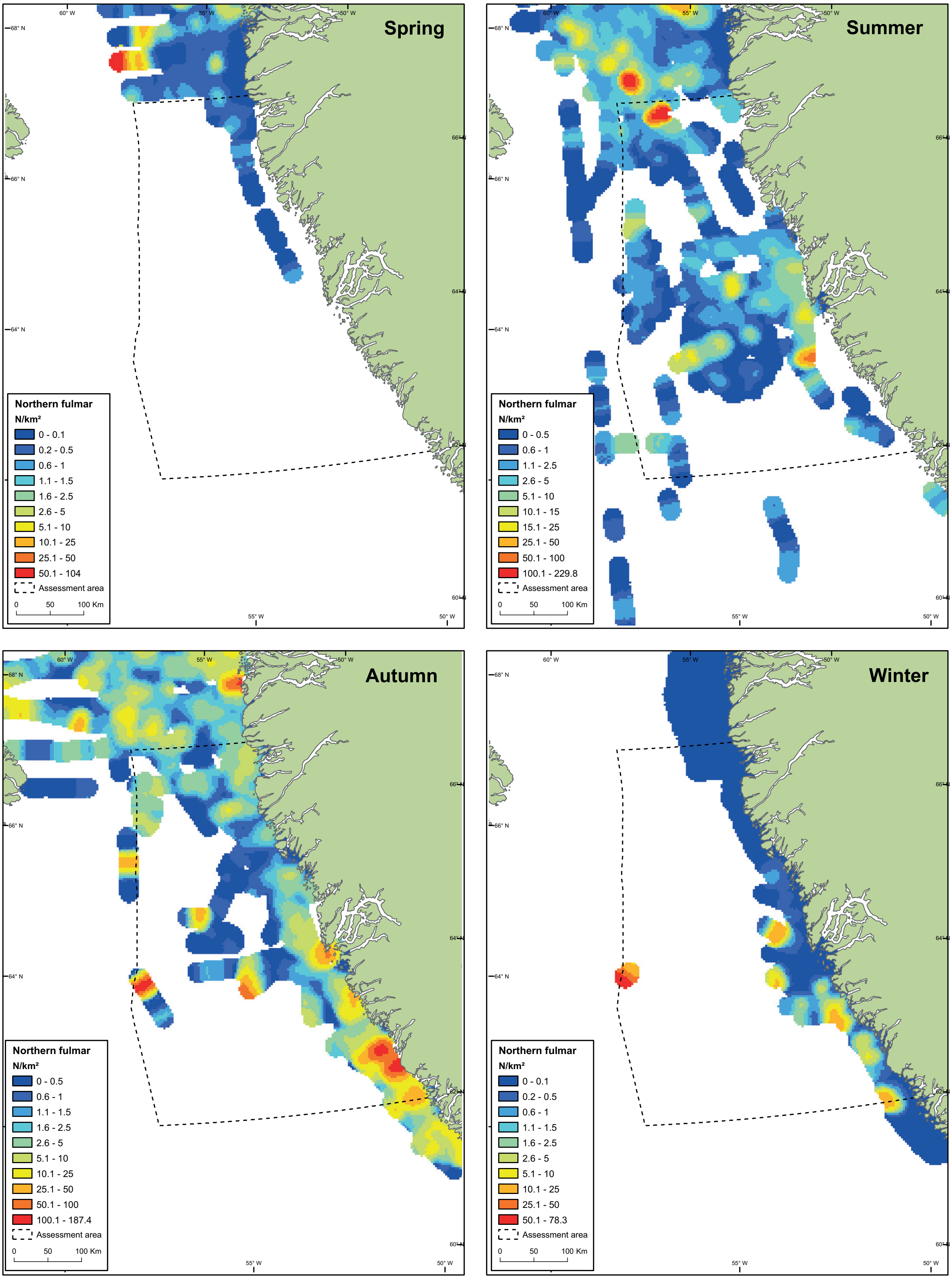



**Figure 3.7.4.** At-sea distribution of northern fulmar in the assessment area during spring (Apr.-May), summer (Jun.-Aug.), autumn (Sep.-Dec.) and winter (Jan.-Mar.) based on available ship survey and aerial survey data collected between 1988 and 2017. Note that survey coverage and density scale varies between seasons.

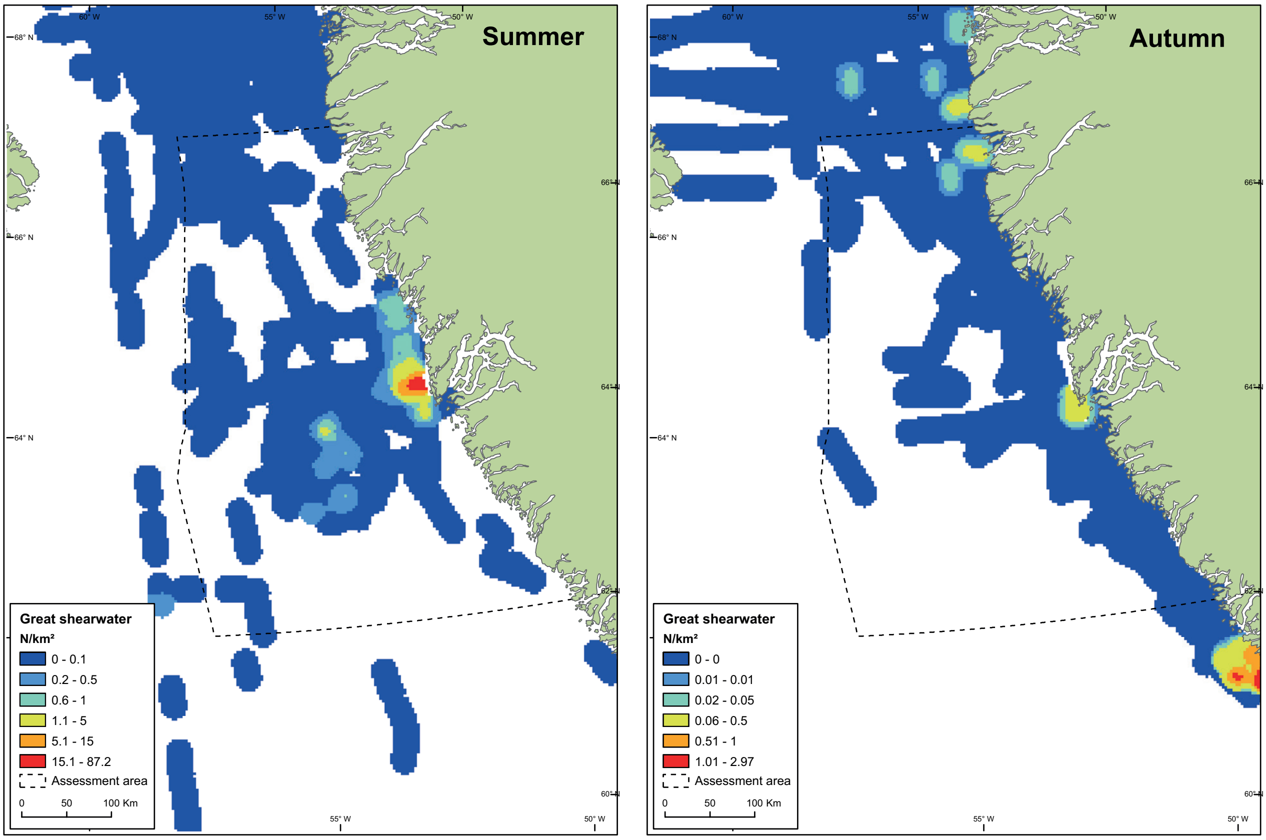



**Figure 3.7.5.** At-sea distribution of great shearwater in the assessment area during summer (Jun.-Aug.) and autumn (Sep.-Dec.) based on available ship survey and aerial survey data collected between 1988 and 2017. Note that survey coverage and density scale varies between seasons.

tion (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 3x3 km cell represents the mean value of all cells within a 9 km radius). As can be seen from Fig. 3.7.3, the number of surveys on which the average bird densities are based varies markedly between seasons and areas.

**Northern Fulmar, *Fulmarus glacialis***
The number of breeding fulmars in the assessment area is very low, probably no more than a few hundred pairs, and, moreover, the few colonies seem to be unstable in time and space (Boertmann et al. 1996).

In the offshore areas fulmars are numerous and occur almost everywhere, except for in winter when only few are present (Fig. 3.7.4). They usually avoid areas with high ice coverage. Concentrations are linked to foraging areas and such may occur at ice edges, upwelling areas and areas with commercial fisheries.

Fulmars have medium sensitivity to oil spills both on an individual level and a population level. Breeding colonies are among the most sensitive areas, because fulmars often rest on the water surface here. Recurrent offshore concentration areas are not known, but may occur e.g. at upwelling areas.

**Great shearwater, *Ardenna gravis***
This is a visitor from the southern hemisphere where it breeds on the islands of Tristan da Cunha. The birds migrate in the southern winter to the northern hemisphere's summer, where they stay, mainly on the Grand Banks and the West Greenland banks until September.

They occasionally occur in high densities in the assessment area (Fig. 3.7.5), although their numbers seem to vary a great deal from one year to another.

High numbers of moulting birds with reduced flying abilities have been reported (Salomonsen 1950) and such concentrations will be highly sensitive to oil spills.

**Great Cormorant,** ***Phalacrocorax carbo***
The cormorant breeds in small colonies usually with less than 100 pairs. Within the region these are found in the northern half, with Evighedsfjorden as the most important area. In 1995 the population numbered about 160 pairs (Boertmann & Mosbech 1997), but this is probably much higher today. At least the population has expanded to the south and coverage now includes the Nuup Kangerlua (Godthåbsfjord) (AU unpubl.).

The outer coast of the assessment area is an important winter habitat for cormorants, including breeding birds from areas further north in West Greenland (Lyngs 2003). A significant part of the entire Greenland population is found within the assessment area (Boertmann et al. 2004).

The cormorant population in Greenland is probably isolated from other populations, of which the nearest are in Iceland and Newfoundland.

The population has a relatively low sensitivity to oil spills due to the many dispersed colonies and a high recovery potential. Furthermore, cormorants spend relatively little time on the sea surface, as they do not rest on the water like other seabirds. This has to do with their plumage not being completely waterproof.

**Mallard,** ***Anas platyrhynchos***
The mallard breeds mainly in freshwater habitats, but also at sheltered marine shores. However, in winter the mallards are dependent on the marine environment. They assemble along shallow coasts where they would be very sensitive to oil spills. In March 2017, scattered occurrences of mallards were observed (aerial survey) along the coastline of Southwest Greenland. When common in the coastal area, they were usually also frequently observed in the adjacent fjords. Within the assessment area, high-density clusters of mallards were observed between Maniitsoq and Paamiut. The total abundance estimate for wintering mallards in Southwest Greenland in 2017 was app. 7600 birds (95% CI: 4700–13500), including a minimum of 1821 birds in the fjords (Merkel et al. 2019).

The Greenland population of mallard constitutes a distinct and endemic subspecies.

Although sensitive to oil spills, the Greenland mallard population would probably recover quickly from increased mortality. This appears to be the case when the mallard population occasionally suffers from high winter mortality due to harsh winters.

**Common eider,** ***Somateria mollissima***
This duck is closely associated with the marine environment. It breeds both dispersed and in colonies on low islands and feeds in shallow coastal waters throughout the assessment area (Fig. 3.7.1).

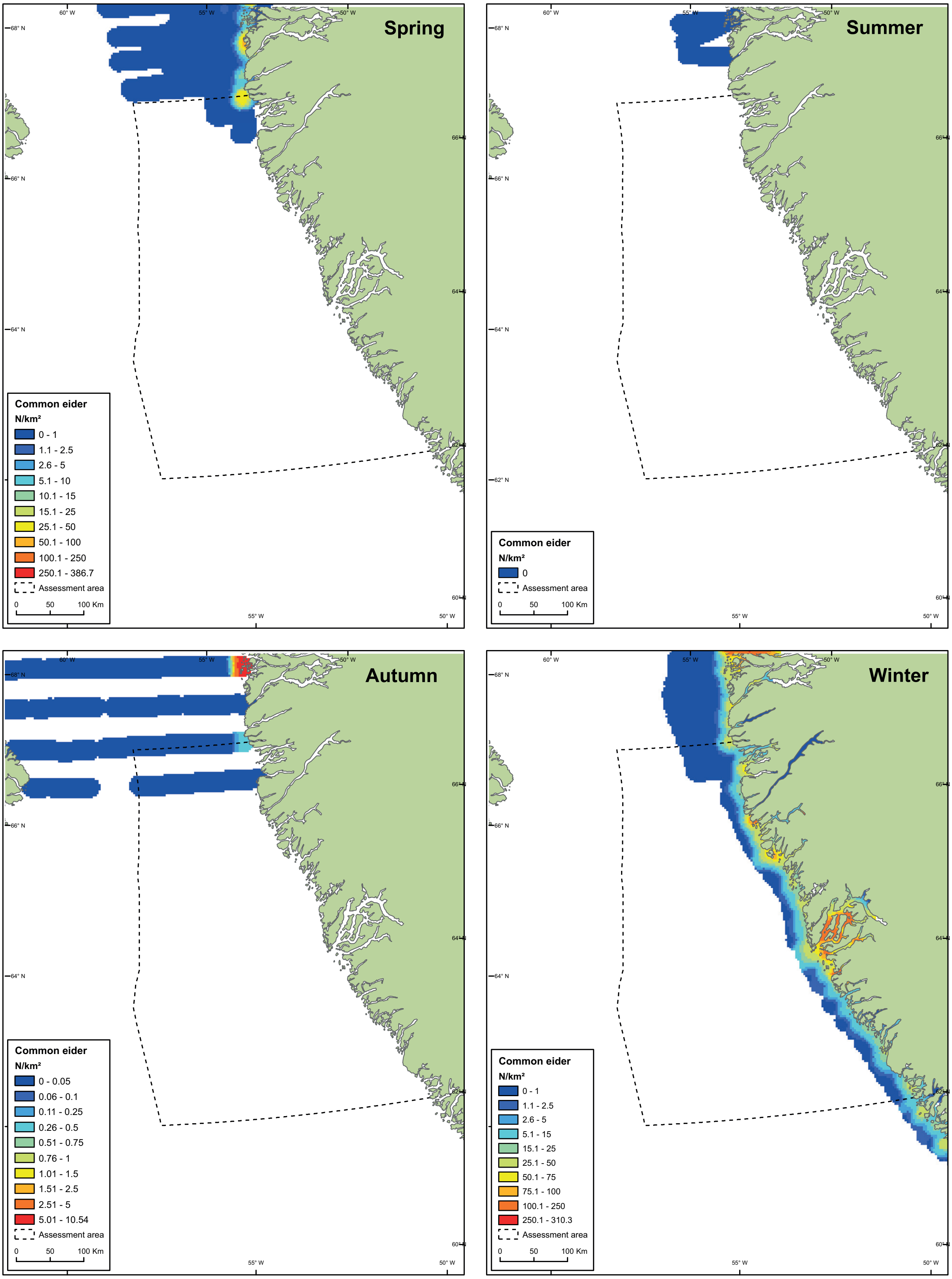



**Figure 3.7.6.** At-sea distribution of common eider in the assessment area during spring, summer (note, no survey effort), autumn and winter based only on aerial surveys (due to the evasive behavior of this species during ship surveys). In the map for winter, total count surveys in fjords from Merkel et al. (2002) and Merkel et al. (2019) are exceptionally included in the analysis.

Throughout West Greenland, males assemble in moulting concentrations in remote fjords and archipelagos while females incubate. Females (failed breeders) follow the males somewhat later and most birds moult within 100 km from the breeding site (Mosbech et al. 2006b). As in other ducks, the flight feathers are moulted simultaneously, which means that the birds become flightless for about three weeks. After moulting the eiders migrate to wintering areas in the open water region of Southwest Greenland, including the assessment area (Lyngs 2003, Mosbech et al. 2007a).

The total number of breeding birds in the assessment area is unknown, but numbers probably amount to some thousand pairs (Rasmussen 2011). The population declined considerably in West Greenland during the 1900s due to non-sustainable harvest (Gilliland et al. 2009). But recently, after hunting in the spring was prohibited in 2001, population recovery has been evident in the districts of Ilulissat, Upernavik and Qaanaaq, where active management and monitoring using local stakeholders has been applied. An annual population increase of 12-15% has recently been estimated for these breeding areas (Merkel 2008, 2010, Burnham et al. 2012). Within the assessment area the breeding population may also have increased, but regular monitoring was not started until 2009. Results from 2010–2020 indicate a fluctuating but overall stable breeding population in the central part of the assessment area (F. Merkel, unpublished).

Until recently the common eider population in West Greenland had an unfavourable conservation status due to the previous decline. It was therefore listed as 'Vulnerable' (VU) on the previous Greenland Red List (Boertmann 2007). However, the status has now changed to Least Concern (LC) (Boertmann & Bay 2018).

Breeding colonies, moulting areas and staging areas during migration and wintering are sensitive to oil spills, as large number of birds may stay on the water in such areas. Especially during winter, the density of common eiders is high in the coastal zone of the assessment area (Fig. 3.7.6), as large numbers of breeding birds from Northwest Greenland and eastern Canada spend the winter in Southwest Greenland (Lyngs 2003, Mosbech et al. 2006b). In 2017 the winter population of common eiders was estimated to 443,000 birds (95% CI: 405,000–488,000), including a minimum of 211,000 birds in the fjords (Merkel et al. 2019). A large proportion occurred within the assessment area, and particularly the fjords and bays around Nuuk are important wintering areas (Blicher et al. 2011, Merkel et al. 2019).

**King eider, *Somateria spectabilis***

The king eider is mainly a winter visitor to the assessment area, although a few may occur also in summer. The birds arrive from breeding grounds in Canada and moulting grounds in NW Greenland during October. The most important winter area is the Store Hellefiskebanke just north of the assessment area (Fig. 3.7.7). To some extent the wintering king eiders are also found along the coasts and on some of the offshore banks of the assessment area, especially Fyllas Bank. In winters with heavy ice conditions birds are forced to leave Store Hellefiskebanke and seek alternative winter habitats within the assessment area. An aerial survey in March 1999 (Merkel et al. 2002) resulted in an estimate of 153,000 king eiders in the coastal areas of Southwest Greenland, of which a large proportion occurred in the assessment area (Merkel et al. 2002). In March 2017 this survey was repeated, but found only 21,000 birds (95% CI: 13,500 – 31,500) in the coastal area. In contrast, more than a million birds (1,078,000; 95% CI: 472,600 – 2,462,300) was located at Store Hellefiskebanke (Merkel et al. 2019). This offshore bank was not surveyed in 1999.

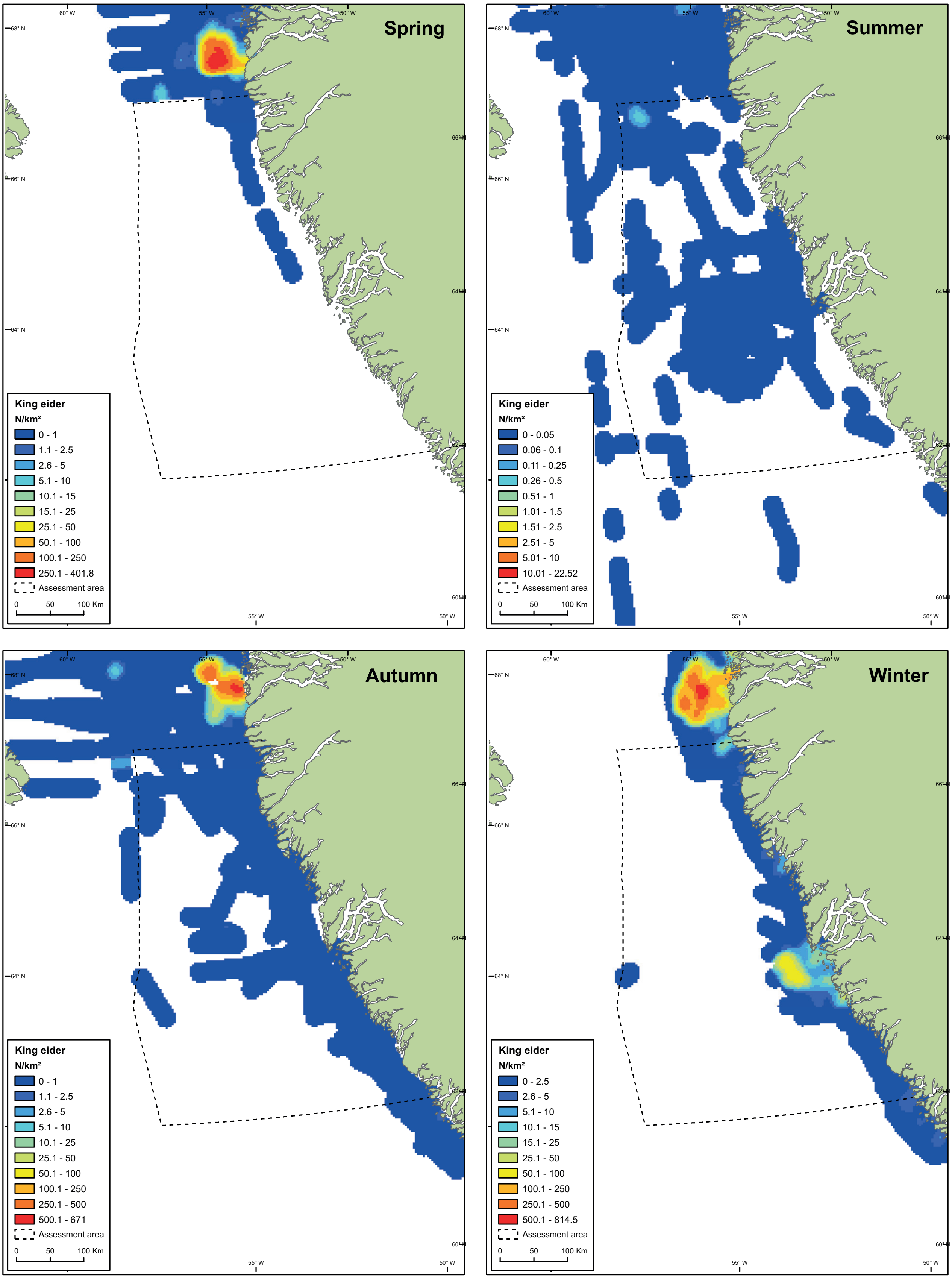
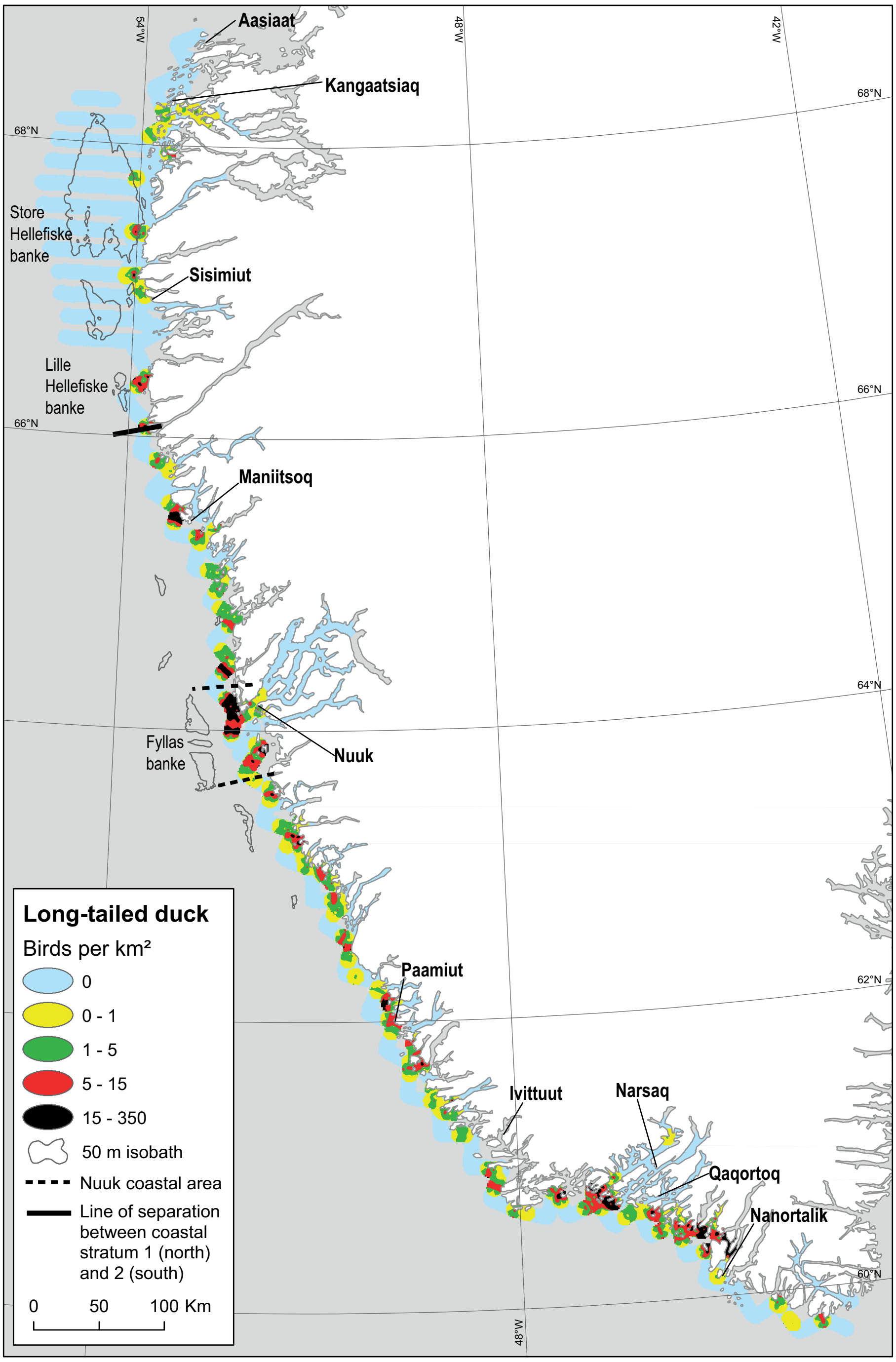



**Figure 3.7.7.** At-sea distribution of king eider in the assessment area during spring (Apr.-May), summer (Jun.-Aug.), autumn (Sep.-Dec.) and winter (Jan.-Mar.) based on available ship survey and aerial survey data collected between 1988 and 2017. Note that survey coverage and density scale varies between seasons.

Figure 3.7.8. Distribution and interpolated densities of long-tailed duck in Southwest Greenland based on aerial surveys in March 2017 (Merkel et al. 2019).




Satellite tracking of king eiders confirms that a part of the population use the assessment area in winter (Mosbech et al. 2006a).

King eiders have been recorded in very large flocks (>30,000 indvs.) in leads in the drift ice and such concentrations are very sensitive to oil spills, as a large fraction of the entire population may be exposed to oil.

**Long-tailed Duck, *Clangula hyemalis***

This duck breeds scattered along sheltered coasts and at inland lakes, and there are no major concentrations of moulting birds known from the assessment area. But in winter the ducks, at least from Iceland, Northeast Greenland and maybe also from Canada, winter in the assessment area together with local birds (Lyngs 2003, Mosbech & Johansen 2020). A survey in March 1999 resulted in an estimate of 94,000 wintering long-tailed ducks in Southwest Greenland, with a high density area located in the coastal zone west of Nuuk where 13,000 birds

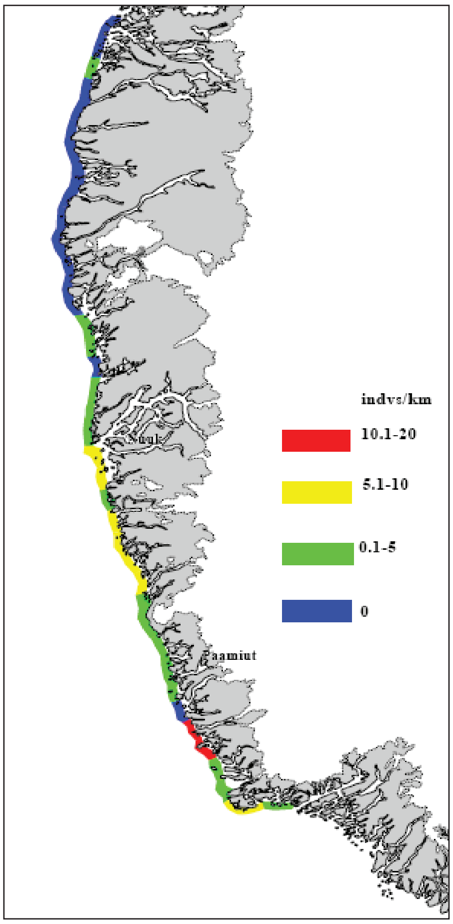



**Figure 3.7.9.** The density of moulting harlequin ducks recorded in July 1999 expressed as the number of birds recorded per km surveyed coastline (Boertmann & Mosbech 2002). The moulting period is July to September.

were present (Merkel et al. 2002). However, during a repeated winter survey in 2017 only 41,600 birds (95% CI: 31,400 – 55,200) were present in Southwest Greenland (Merkel et al. 2019). The coastal zone of Nuuk was still an important high-density wintering area with estimated 11,200 birds (95% CI: 6,600 – 19,900) (Fig. 3.7.8). The overall smaller winter population of long-tailed ducks in Southwest Greenland coincide with information about declining breeding populations in Iceland and Canada (Merkel et al. 2019).

Wintering long-tailed ducks are sensitive to oil spills and in high density areas, as in the case west of Nuuk, many birds may be exposed.

The long-tailed duck is listed as Least Concern on the Greenland red List (Boertmann & Bay 2018), but was recently listed as Vulnerable (VU) on the global list, due to reported population declines (IUCN 2020).

**Harlequin duck, *Histrionicus histrionicus***
The harlequin duck breeds at inland rivers. However, they also occur in marine habitats: non-breeding individuals and post-breeding males assemble from July at exposed rocky coasts and skerries and in winter all birds are found in these extreme habitats. A few non-breeding birds may stay at these coasts also before the moulting period.

The breeding population in Greenland is low, numbering probably only a few thousand pairs (Boertmann 2008a)EndNote>. However, Canadian birds also use the Greenland coasts for moulting and wintering (Robert et al. 2008). In July 1999 the population of moulting birds was surveyed from aircraft (Fig. 3.7.9) and the resulting estimate was 5,000-10,000 males (Boertmann & Mosbech 2002, Boertmann 2003, 2008a). The winter population has not been surveyed, but is estimated at roughly more than 10,000 birds (Boertmann et al. 2006).

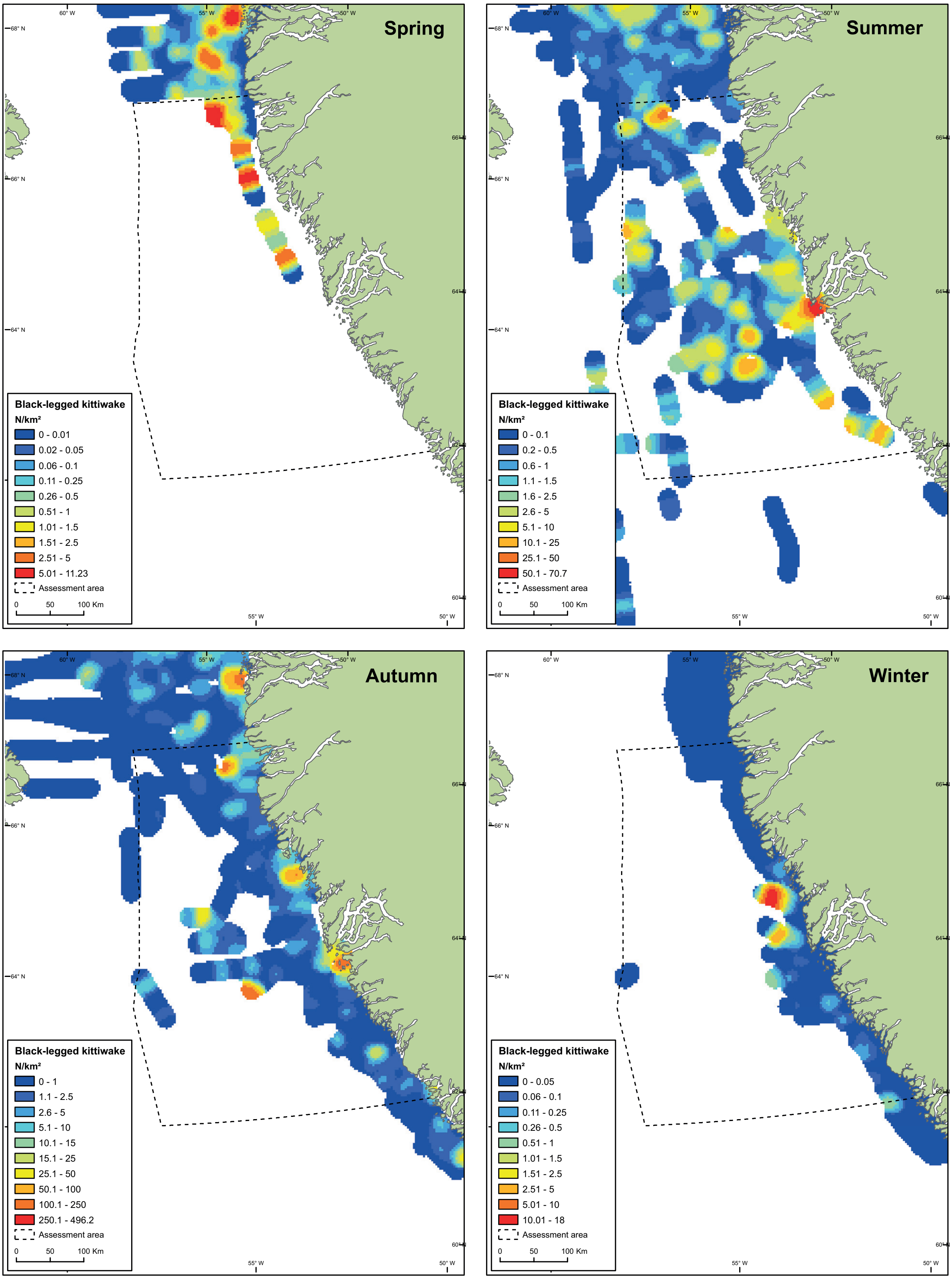



**Figure 3.7.10.** At-sea distribution of black-legged kittiwake in the assessment area during spring (Apr.-May), summer (Jun.-Aug.), autumn (Sep.-Dec.) and winter (Jan.-Mar.) based on available ship survey and aerial survey data collected between 1988 and 2017. Note that survey coverage and density scale varies between seasons.

The moulting and wintering birds are very sensitive to marine oil spills due to their preference for exposed habitats along the outer coastline (Fig. 3.7.9). The highest concentrations of moulting birds within the assessment area was in 1999 found just south of Nuuk, while the distribution of the wintering birds is not known (Boertmann & Mosbech 2002, Boertmann 2003).

**Red-breasted merganser, *Mergus serrator***
This is a breeding bird in fjords and on sheltered coasts. Especially moulting birds assemble in high concentrations in some fjords, where they are sensitive to potential oil spills (Boertmann & Mosbech 2001). However, the known moulting sites are far from the outer coast where it is unlikely that oil spills from Davis Strait can reach. During winter a larger proportion of the birds are distributed in the coastal area, making winter the most sensitive period for mergansers with respect to oil spills. During an aerial survey in March 2017 the winter population in Southwest Greenland was estimated to 3,200 bird (95% CI: 2,300 – 5,110), including a minimum of 1,400 birds in the fjords (Merkel et al. 2019). Within the assessment area, the highest concentrations of birds were found in the area around Nuuk and Paamiut.

The Greenland population is probably isolated from neighbouring populations in Iceland and Canada.

**Black-legged kittiwake, *Rissa tridactyla***
This small gull is a numerous breeder in the assessment area, with the breeding colonies centred in Maniitsoq district (Fig. 3.7.2), which constitute one of the most important breeding areas in Greenland, only outnumbered by the breeding population in Qaanaaq, Northwest Greenland. The most recent survey of the breeding population in Greenland lists 35 occupied colonies holding approximately 34,000 breeding pairs (Labansen et al. 2010) within the assessment area. The breeding colonies are usually found in the fjords, and the birds often forage in the open sea, commuting in and out of the fjord. Breeding birds arrive to the colonies in the period March to May and leave again during August when the chicks are fledged.

Kittiwakes are abundant in the shelf waters of the assessment area (Fig. 3.7.10) and many of these are non-breeding birds from populations breeding elsewhere in the North Atlantic (Lyngs 2003, Frederiksen et al. 2012b). Kittiwakes spend the winter in offshore parts of the North Atlantic, and several hundred thousands occur in the Davis Strait, but very few were observed during the winter surveys in 1999 and 2017 due to a very limited offshore coverage (Merkel et al. 2002, Merkel et al. 2019). Frederiksen et al. (2012b) and the Norwegian SEATRACK-data show that kittiwakes from Russia, Norway, Svalbard, Iceland and Faroe Islands may spend the winter in the waters of the assessment area.

Kittiwakes are most vulnerable to oil spills at breeding colonies where large numbers of birds often assemble on the sea surface. There may also be concentrations at feeding areas, e.g., in the marginal ice in spring and early summer or at upwelling sites, but these are not predictable in time and space.

Due to a substantial decrease in the breeding population (Labansen et al. 2010), the kittiwake is listed as Vulnerable (VU) on the Greenland Red List (Boertmann & Bay 2018).

**Ivory gull, *Pagophila eburnea***
Ivory gulls breeding in the northeast sector of the Arctic Atlantic (Northeast Greenland, Svalbard and the Russian Arctic) move south in autumn in the drift ice off East Greenland to winter quarters mainly in the marginal ice zone in the Labrador Sea and the Davis Strait, where they arrive in December (Orr & Parsons 1982, Gilg et al. 2010). This probably means that a large proportion of the northeast Atlantic population of the ivory gull moves through the assessment area in early December (Gilg et al. 2009, Gilg et al. 2010). In years when the drift ice in winter moves into the assessment area from the west, ivory gulls will be present, but the fraction of the population is unknown. In spring, most of the gulls probably move the same way back through the assessment area; although it has been shown that they can migrate northwards in the Davis Strait and across the Greenland Ice Sheet to North East Greenland (M. Frederiksen & O. Gilg, pers. comm.). Observations from 2011 show that adult ivory gulls are present in Julianehåb Bugt as early as late October (Boertmann 2014) a fact not revealed by the satellite-tracked birds. Ivory gulls can probably therefore also be present in the assessment area around this time or slightly later.

The ivory gull is of high conservation concern (Gilg et al. 2009, Gilg et al. 2010), being listed as near threatened (NT) on the international Red List (IUCN 2020), as vulnerable (VU) on both the Greenland and the Svalbard red lists (Kålås et al. 2010, Henriksen & Hilmo 2015, Boertmann & Bay 2018), and as endangered by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC 2006b).

**Iceland gull, *Larus glaucoides***
This gull is the most abundant of the large gulls in the assessment area. Numerous breeding colonies are found there, on steep cliffs and small islands (Fig. 3.7.2).

The assessment area is also an important winter habitat for this gull, and both local breeding birds and birds from northern areas assemble here (Lyngs 2003, Boertmann et al. 2006). In March 2017 a combined winter estimate for Iceland gull and glaucous gull arrived at 76,000 birds (95% CI: 45,700 – 136,100; Merkel et al. 2019). Both species are common in the assessment area, but densities were especially high around the larger cities, i.e. Sisimiut, Maniitsoq and Nuuk. It should be noted that the 2017 survey only covered the near-coastal distribution area, so the true winter population size is probably larger.

Iceland gulls are most sensitive to oil spills at the breeding colonies. These colonies, however, are generally small and the population is spread widely along the coasts and population sensitivity is therefore relatively low compared to other much more concentrated seabirds.

The Greenland population of Iceland gull constitutes a distinct and endemic subspecies (Boertmann & Bay 2018).

**Glaucous gull, *Larus hyperboreus***
This gull is widespread in the region, but generally not as numerous as the Iceland gull (Fig. 3.7.2). It breeds in colonies often together with other colonial seabirds and both on steep cliffs and on low islands.

In winter, glaucous gulls are numerous along the coasts of the open water region and it is possible that birds from Svalbard and Canada also assemble here (Boertmann et al. 2004). In March 2017 a combined winter estimate for Iceland gull and glaucous gull arrived at 76,000 birds (95% CI: 45,700 – 136,100), with the highest densities around Sisimiut, Maniitsoq and Nuuk (Merkel et al. 2019). See also the text for Iceland gull.

Glaucous gulls are most sensitive to oil spills at the breeding colonies. These colonies, however, are generally small and the population is spread widely along the coasts and therefore population sensitivity is relatively low compared to other much more concentrated seabirds.

**Great black-backed gull, *Larus marinus***
This gull is common and widespread along the coasts of the assessment area (Fig. 3.7.2). It breeds both in colonies and as dispersed as pairs – usually on small islands.

In winter, the entire population of Greenland great black-backed gull is found along the coasts of the open water area in Southwest Greenland. The aerial survey conducted in March 2017 estimated a minimum winter estimate of 6,100 birds (95% CI: 4,900 – 7,700), with the with the highest densities around Sisimiut, Maniitsoq and Nuuk (Merkel et al. 2019).

The conservation status is favourable (Tab. 3.7.1) and the population is probably increasing, at least it has extended the range northwards in recent decades.

**Lesser black-backed gull, *Larus fuscus***
The lesser black-backed gull has immigrated to Greenland within the past 30 years (Boertmann 2008b) and it is now a relatively common breeder in the assessment area (Fig. 3.7.2). It is usually found in small colonies among other gull species on small islands. The lesser black-backed gulls are migratory, leaving Greenland for the winter.

This species is increasing in Greenland, both in range and number and its conservation status is favourable (Tab. 3.7.1).

**Arctic tern, *Sterna paradisaea***
Relatively few breeding colonies of Arctic tern are present in the assessment area, compared with coasts further north in West Greenland, and long extents of coastline are completely without breeding terns (Fig. 3.7.2).

Arctic terns are highly migratory, wintering in the southern hemisphere (Egevang et al. 2010)ÿÿÿþ. They arrive to the breeding colonies during May/ early-June and leave again during August/September. They spend most of the time in coastal waters close to breeding colonies. Terns feed on fish and crustaceans by plunge diving, and they usually do not rest on the water surface, making them less exposed than other seabirds to marine oil spills.

The West Greenland Arctic tern population had at least until 2001 an unfavourable conservation status and was decreasing due to excessive egg collecting. It was therefore listed as Near Threatened (NT) on the national Greenland Red List, a listing which is still current (Boertmann & Bay 2018). Egging was banned in 2001.

**Black guillemot, *Cepphus grylle***
This auk is the most widespread of the breeding colonial seabirds in the assessment area (Boertmann et al. 1996). There are colonies in most fjords, bays and coasts, and their numbers range from a few pairs to several hundred (Fig. 3.7.1). The total breeding population within the assessment area is unknown,

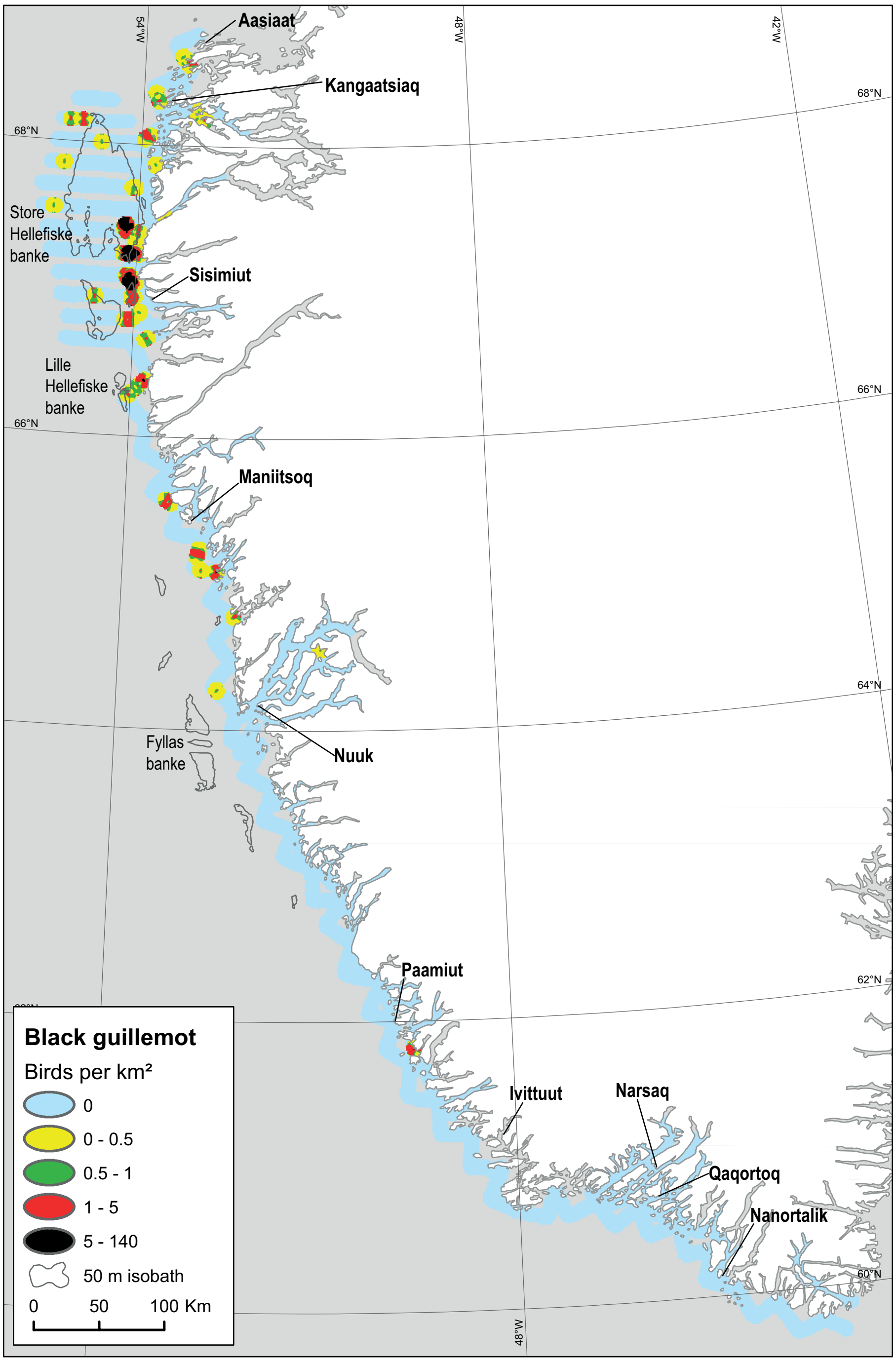



**Figure 3.7.11.** Distribution and interpolated densities of black guillemot in Southwest Greenland based on aerial surveys in March 2017 (Merkel et al. 2019).

but numbers at least several thousand pairs. During the breeding time they primarily stay in coastal waters, but in winter they disperse over the shelf and are often found in waters with drift ice (Mosbech & Johnson 1999).

Black guillemots are more or less migratory and birds from further north in Greenland move to the assessment area for the winter. During an aerial survey in 1999 a total of 12,000 black guillemots were estimated in the coastal zone between the southern tip of Greenland and Disko Bay (Fig. 3.7.11) (Merkel et al. 2002). Based on a repeated winter survey in 2017 only 5,300 birds (95% CI: 2,700 – 10,400) were estimated for Southwest Greenland (Merkel et al. 2019). Furthermore, in 2017 birds were confined to the coastal survey area north of Nuuk and Store Hellefiskebanke, while birds were dispersed throughout most of the coastal survey area in 1999. It is unknown if this change reflects a real population decline or just a change in distribution between coastal areas and offshore areas. Only a small fraction of the latter is covered during aerial winter surveys.

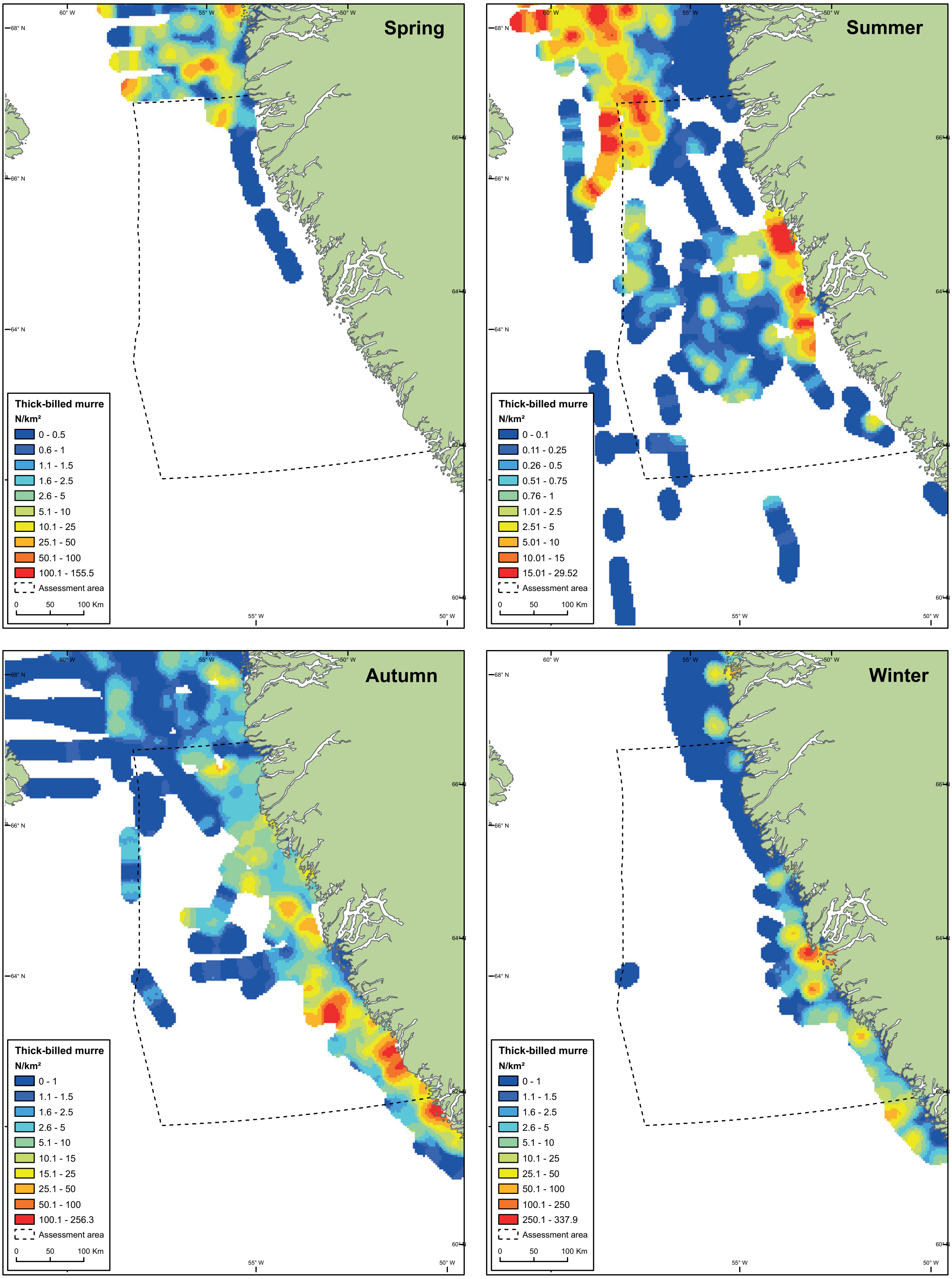


**Figure 3.7.12.** At-sea distribution of thick-billed murre in the assessment area during spring (Apr.-May), summer (Jun.-Aug.), autumn (Sep.-Dec.) and winter (Jan.-Mar.) based on available ship survey and aerial survey data collected between 1988 and 2017. Note that survey coverage and density scale varies between seasons.

Vulnerable concentrations occur mainly in the summer time near the breeding colonies. However, due to the wide dispersion of the colonies, black guillemot sensitivity on a population level is relatively low.

**Thick-billed murre, *Uria lomvia***

This auk is a relatively numerous breeder in the assessment area. However, the breeding sites are few and very localised: Two colonies south of Nuuk and four in the Maniitsoq area (Fig. 3.7.1). The most recent surveys sum up to 15,800 individuals present in the breeding colonies within the assessment area (GINR & AU unpubl. data).

In winter, thick-billed murres from mainly Iceland and Svalbard congregate in the open water area and the population then is assessed at >1.5 million birds (Frederiksen et al. 2016), making it the most numerous seabird in the assessment area during winter (Fig. 3.7.12), except for the little auks, which potentially may occur in higher numbers.

Murres spend very long time on the sea surface and only come on land in the breeding season. When the chicks are approximately three weeks old and far from fully grown or able to fly, they leave the colony in company with the adult male and swim/drift to offshore waters. Adults then shed all flight feathers and become flightless for some weeks and start migration southwards by swimming. This swimming migration goes through the assessment area in late summer and early autumn (Fig. 3.7.12).

The West Greenland murre population has an unfavourable conservation status because it is decreasing. This decline is ascribed to non-sustainable harvest, chronic oil spills caused by trans-Atlantic shipping in the winter quarters of Newfoundland, and more recently also to unfavourable oceanographic conditions during the winter period (Falk & Kampp 1997, Wiese et al. 2004, Descamps et al. 2013).

Murres are very sensitive both to oil spills and disturbance at the breeding colonies, where large proportions of the total population can be impacted by a single incident. Vulnerable offshore concentrations occur at feeding grounds, but they are highly vulnerable especially during the period of flightlessness and swimming migration.

Due to the population decline the thick-billed murre is listed as Vulnerable (VU) on the Greenland Red List (Boertmann & Bay 2018).

**Common murre, *Uria aalge***

The common murre is only found breeding at one site in the assessment area (Boertmann et al. 1996), in the colony of thick-billed murres southwest of Nuuk. The highest number recorded there in recent years is approximately 75 birds.

The species is listed as endangered on the Greenland Red List, as the population in other colonies south of the assessment area has decreased (Boertmann & Bay 2018).

**Razorbill, *Alca torda***

The razorbill is a widespread breeding bird in the assessment area. Several colonies holding from five to 3000 individuals are found both in the fjords and at the outer coasts. The main part is found in Maniitsoq district (Fig. 3.7.1).

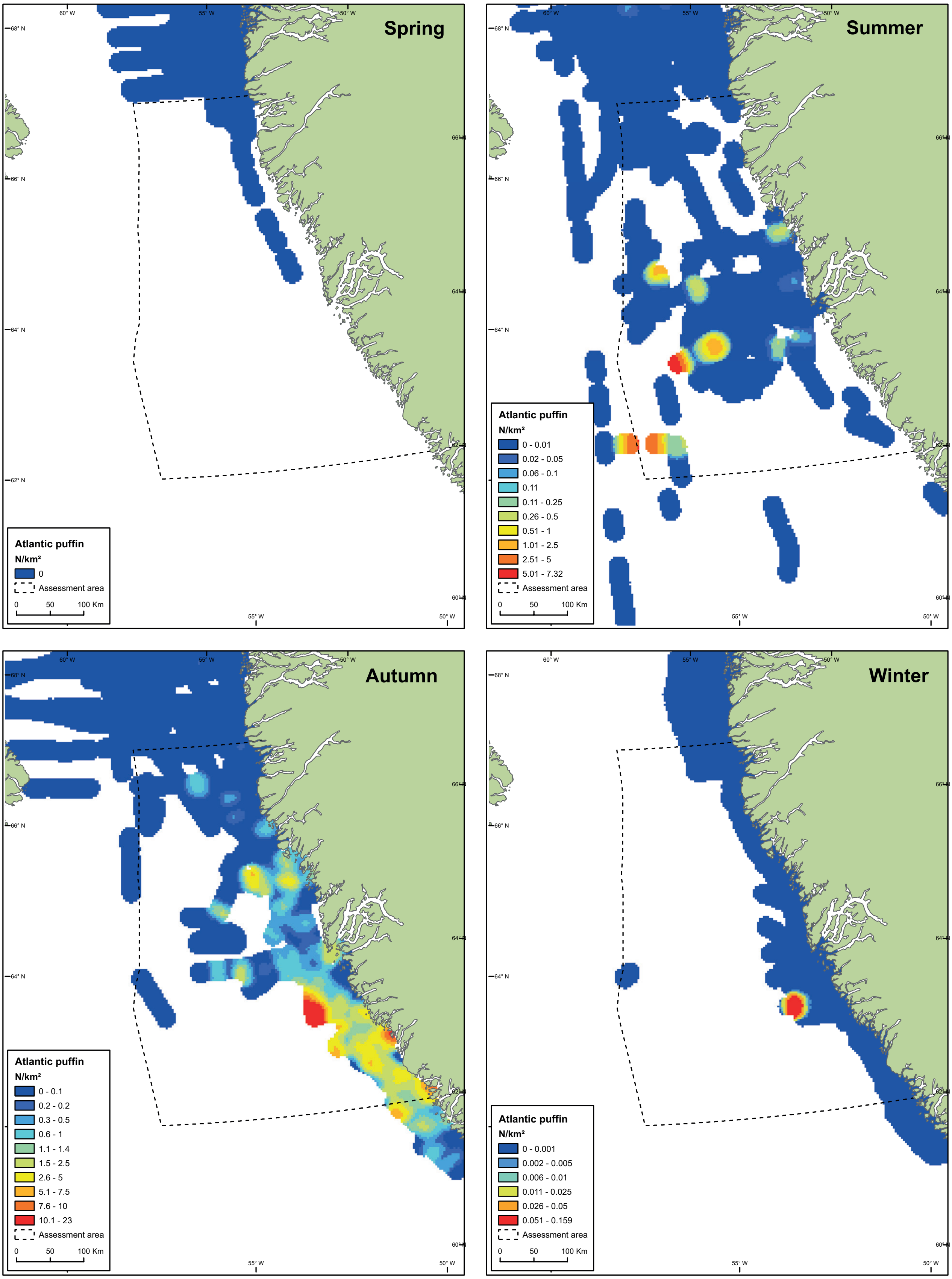



**Figure 3.7.13.** At-sea distribution of puffin in the assessment area during spring (Apr.-May), summer (Jun.-Aug.), autumn (Sep.-Dec.) and winter (Jan.-Mar.) based on available ship survey and aerial survey data collected between 1988 and 2017. Note that survey coverage and density scale varies between seasons.

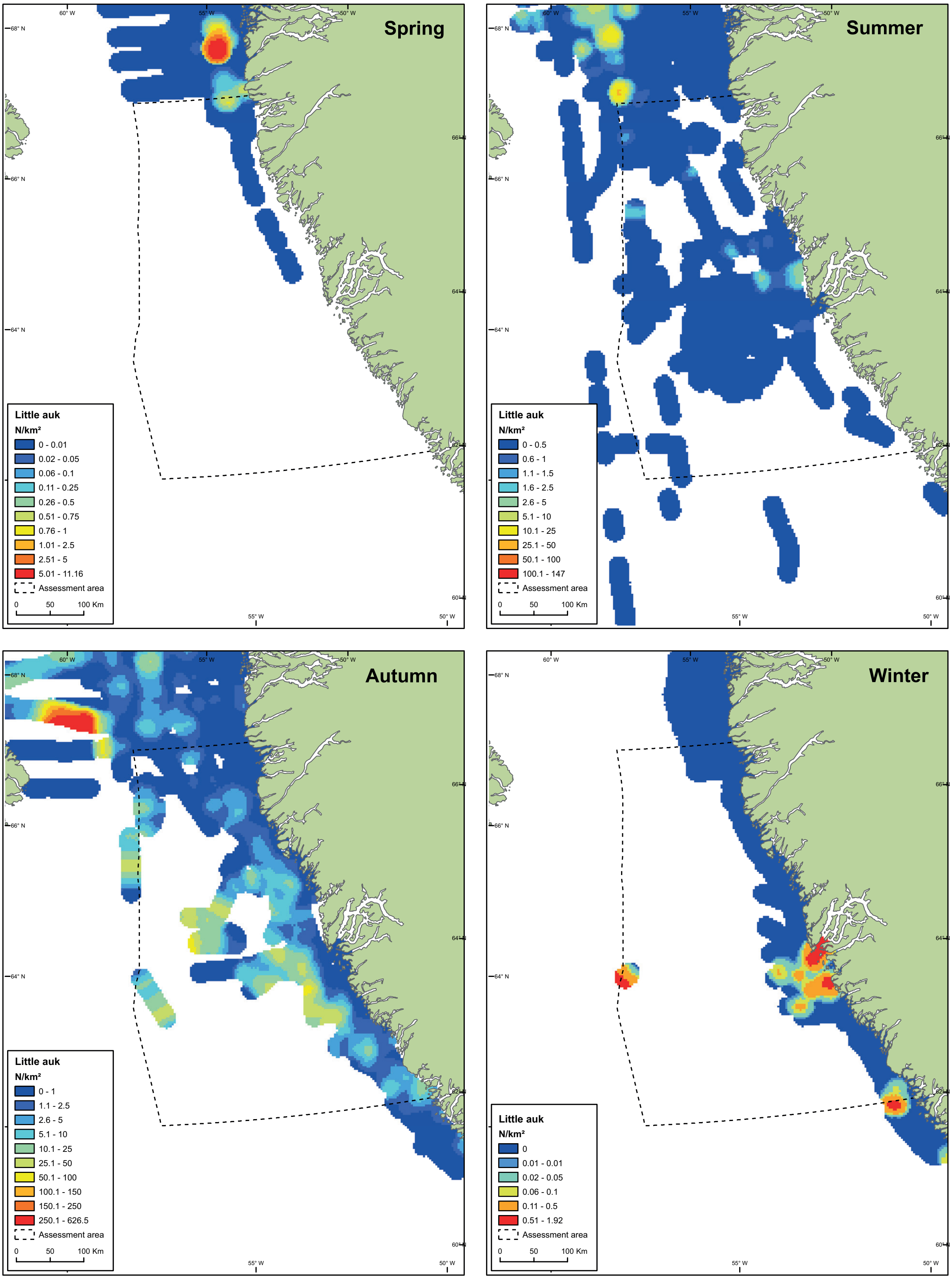
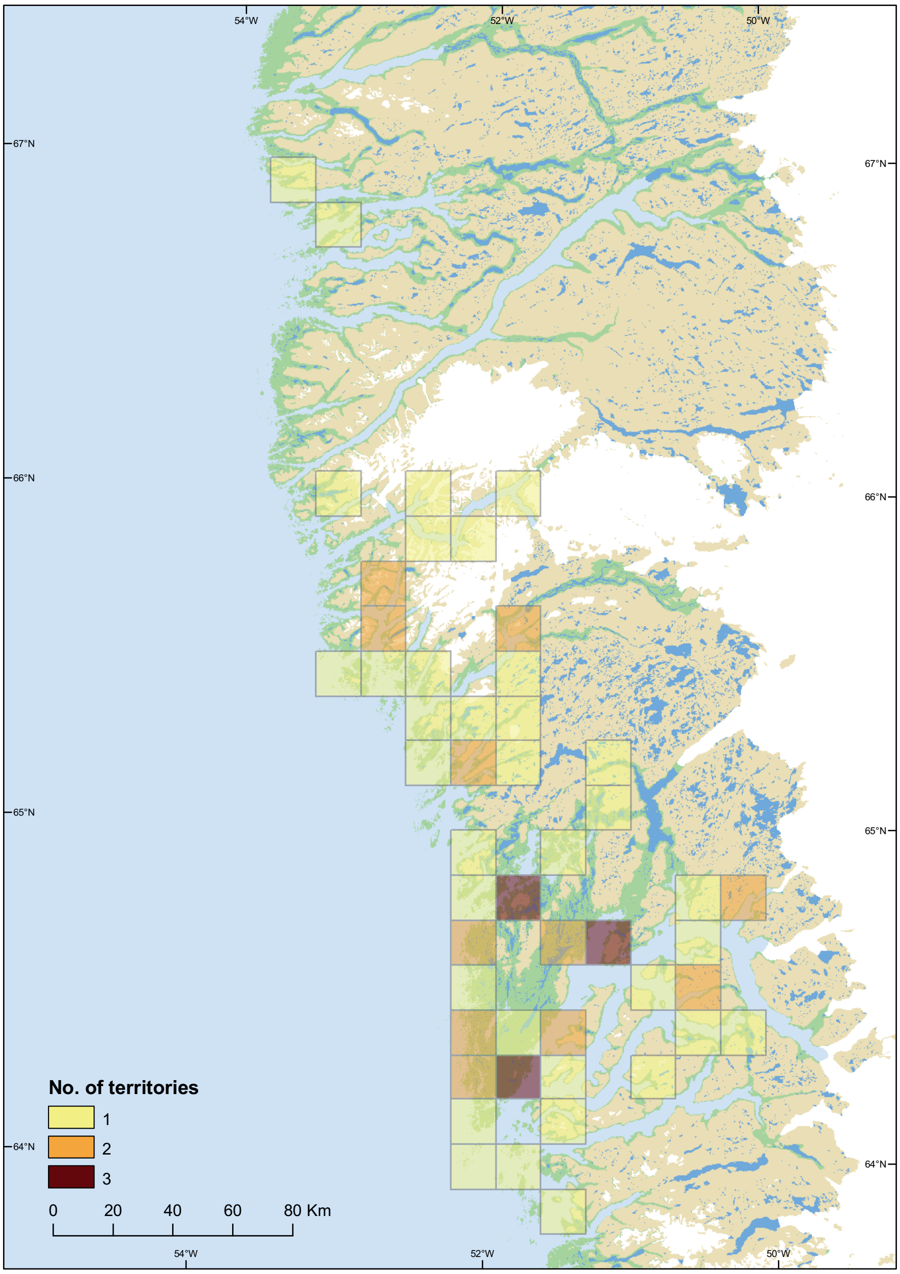



**Figure 3.7.14.** At-sea distribution of little auk in the assessment area during spring (Apr.-May), summer (Jun.-Aug.), autumn (Sep.-Dec.) and winter (Jan.-Mar.) based on available ship survey and aerial survey data collected between 1988 and 2017. Note that survey coverage and density scale varies between seasons.

**Figure 3.7.15.** Density of white-tailed sea eagle territories within a 15×15 km² grid around Nuuk and northwards (Johansen et al. 2008). A similar or even higher density of territories is found south of this map along the coasts of the southern part of the assessment area.




Colony surveys conducted in 2017 and 2019 indicate a substantial population increase in the Maniitsoq area (F. Merkel and A. Labansen, unpublished).

Razorbills are migratory and recent studies indicated that Greenland razorbills move to the waters off eastern North America for the winter (AU, unpubl.).

Razorbills' behaviour and sensitivity towards oil spills are similar to murres and black guillemots. However, the breeding population is much more dispersed than the thick-billed murres, with numerous small colonies along the coasts, so a smaller proportion of the population is likely to be affected by an oil spill.

**Atlantic puffin, *Fratercula arctica***

The breeding population of puffins in the assessment area is concentrated at the mouth of Nuup Kangerlua (Godthåbsfjord). Here approximately eight colonies hold about 1,000 birds. There are a few more small colonies within the assessment area, both north and south of Nuuk.

The puffins are migratory, but their whereabouts in winter are unknown, although one recovery of a ringed bird indicates the waters off Northeast Canada (Lyngs 2003). In the autumn high numbers of puffins have been recorded in offshore waters of the southern part of the assessment area (Fig. 3.7.13). The Norwegian SEATRACK-data indicate that these birds mainly are of Icelandic origin (see also Fayet et al. 2017).

Several colonies further north in West Greenland have decreased and the Greenland puffin population was therefore assessed as Vulnerable (VU) on the Greenland Red List (Boertmann & Bay 2018).

Puffins are highly sensitive to oil spills both on individual level and on population level (Boertmann et al. 1996, Boertmann in press) and they are most vulnerable at the colonies where high numbers can be assembled on the water.

**Little auk, *Alle alle***
This is the smallest of the auks, but the most numerous of the seabirds in the North Atlantic**.** It does not breed within the assessment area, but is a numerous autumn/winter visitor (Fig. 3.7.14). However, the species is difficult to survey due to its small size, and the knowledge on winter abundance and distribution in the assessment area is therefore inadequate. The Norwegian SEATRACK-data show that little auks form Svalbard and Bjørnøya move to the waters of the assessment area for the winter, while tracking of little auks from the Qaanaaq area, mainly move to the waters off Newfoundland (Fort et al. 2013).

Little auks are very sensitive to oil spills and large winter concentrations may suffer from high mortality if hit by oil spills.

**White-tailed eagle, *Haliaeetus albicilla***
The white-tailed eagle is a resident species along the coasts of the assessment area (Fig. 3.7.15). Pairs breed scattered in archipelagoes and fjords and the total Greenland breeding population in 1990 was estimated at 150-170 pairs (Kampp & Wille 1990). The population today is probably of the same size, but information is lacking.

Although not a seabird, white-tailed eagles take their food from the marine environment, mainly fish and birds, and may become exposed to oil spill by contact with the water and from ingesting contaminated food. An estimated 250 bald eagles (*Haliaeetus leucocephalus*), a close relative of the white-tailed eagle) were killed by the oil after the spill in Prince Williams Sound in 1989 and the population here recovered within 6 years (Bowman et al. 1997), suggesting that the recovery potential for the eagle population is good.

Due to the small population the white-tailed eagle is listed as Vulnerable (VU) on the Greenland Red List (Boertmann & Bay 2018). The population is isolated from other populations and thereby particularly sensitive to increased mortality.

## 3.8 Marine mammals

### 3.8.1 Polar bear and walrus

*Erik W. Born and Kristin L. Laidre (GINR)*

**Polar bear, *Ursus maritimus***
*Distribution:* Based on the recapture or harvest of previously tagged animals and studies of movement of adult female polar bears with satellite collars,

the Davis Strait (DS) subpopulation of polar bear occurs south of 66° N in the Labrador Sea, eastern Hudson Strait and in the sea ice covered areas of Davis Strait south of Cape Dyer on East Baffin Island and along an yet undetermined portion of Southwest Greenland (Durner et al. 2018 and references therein).

A genetic study of polar bears (Paetkau et al. 1999) indicated significant differences between bears from the Davis Strait and neighbouring Baffin Bay. The Davis Strait subpopulation of polar bears range in the 'seasonal-ice' ecoregion (Amstrup et al. 2007, 2008), with the ice-free period extending from approximately August through November. Annual ice cover in Davis Strait is highly variable. However, during 1979-2013 spring ice breakup has become earlier and fall formation has become later since 1991 (Stirling & Parkinson 2006, Laidre et al. 2015).

Satellite telemetry conducted in the period 1991-2001 showed that polar bears from the DS subpopulation range the offshore pack ice in the Davis Strait (Taylor et al. 2001). The movement of the bears instrumented with satellite-radios indicated an overall tendency to occur on the fast ice and in the shear zone between fast ice and pack ice along eastern Baffin Island. However, in December-June there is an overlap between the distribution of some polar bears from the Davis Strait subpopulation and the assessment area. There is limited overlap between the movements of bears in Davis Strait and those in Baffin Bay, the subpopulation to the north (Laidre et al. 2018a).

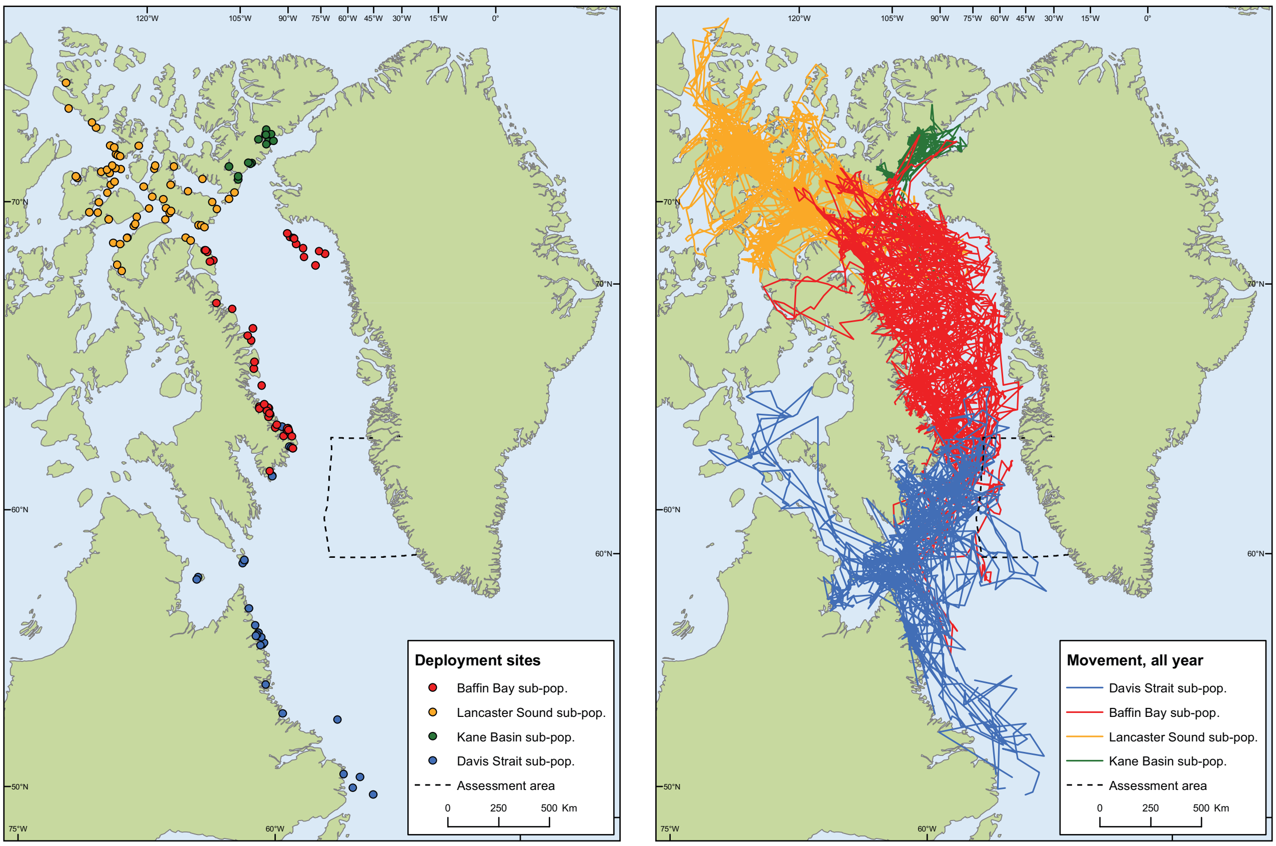



**Figure 3.8.1.** Left: Locations where adult female polar bears were instrumented with satellite transmitters (1991-1995) given by sub-population (Davis Strait, Baffin Bay, Lancaster Sound and Kane Basin). A total of 29 bears were instrumented in the Davis Strait subpopulation (blue) and their movements tracked during 1991-2001. The identification and delineation of the various sub-populations based on hierarchal cluster analyses is described in Taylor et al. (2001). Unpublished data: Nunavut Wildlife Management Division, University of Saskatchewan, Canadian Wildlife Service, Greenland Institute of Natural Resources. Right: Track lines showing the overall movement during 1991-2001 of polar bears instrumented with satellite transmitters in the Davis Strait-Baffin region and adjacent areas. A certain degree of overlap between the different sub-populations is apparent. Unpublished data: Nunavut Wildlife Management Division, University of Saskatchewan, Canadian Wildlife Service, Greenland Institute of Natural Resources.

The extent of the pack ice in the Davis Strait varies from year to year (see chapter 2). So does the position of the Davis Strait whelping patch of hooded seals, *Cystophora cristata* (Bowen et al. 1987). During the period 1974-1984, the location of this whelping patch where polar bears occur (F.O. Kapel, personal communication 1984) varied within an area confined by approx. 55° 45′W – approx. 60° W and approx. 61° 50′ N – approx. 63° 15′ N (Bowen et al. 1987: 286). It is likely that the number of polar bears occurring at the Davis Strait hooded seal whelping patch during spring also varies from year to year, depending among other factors on ice conditions in the Davis Strait and the ability of the bears to reach the whelping patch from eastern Baffin Island.

In recent years unusual occurrence of concentrations of harp seals (*Pagophilus groenlandicus)* at the eastern edge of the Davis Strait pack ice has been reported. In late January-early February large numbers of harp seals were observed in the pack ice west of the town of Sisimiut (approx. 67° N) (Rosing-Asvid 2008). Hence, variation in the distribution of prey including concentrations of harp seals may also influence the spatial distribution and number of polar bears within the assessment area.

*Number:* The most recent inventory of the Davis Strait subpopulation was completed in 2007 and estimated the population size in 2007 to be 2,158 (95% CI: 1,833-2,542) (Peacock et al. 2013, Durner et al. 2018). In 2016, the DS subpopulation was assessed to be "not reduced" and stable (Durner et al. 2018).

Amstrup et al. (2007, 2008) incorporated projections of future sea ice in four different 'ecoregions' of the Arctic, based on ten general circulation models by the International Climate Change Panel (ICCP), into two models of polar bear habitat and potential population response. One eco-region encompasses the polar bear habitat with seasonal ice ('the seasonal ice ecoregion') – including the Davis Strait – where sea ice usually is absent during the open water period. One of the models (a deterministic 'carrying capacity model') predicted a 7-10% decrease in the polar bear population in the 'seasonal ice ecoregion' approx. 45 years from now (22-32% decline approx. 100 years from now), whereas the other model (quasi-quantitative 'Bayesian network population stressor model') predicted extirpation of polar bears in this ecoregion – including the Davis Strait – by the mid-2100s.

**Walrus, *Odobenus rosmarus***

*General biology:* The following life history traits are relevant in order to evaluate the potential effects on walruses from oil-related activities. An important characteristic of walruses is that they are gregarious year round (Fay 1982, 1985), which means that impacts will concern groups rather than single individuals (Wiig et al. 1996).

Walruses are benthic feeders which forage where water depths are less than approximately 100 m (Vibe 1950, Fay 1982, Born et al. 2003); although they occasionally may dive deeper both inshore and offshore (Born et al. 2005, Acquarone et al. 2006, Lowther et al. 2015, Garde et al. 2018b). Generally, walruses have an affinity to shallow water areas with suitable benthic food and winter in areas without solid ice - i.e. where there is not 100% sea ice cover (Born et al. 1995 and references therein). In western Greenland such habitat is mainly found between approx. 66° 30′ N and approx. 70° 30′ N and between the coast and approx. 56° W (Born et al. 1994, Born et al. 1995, Dietz et al. 2014). Hence, the northern parts of the assessment area encompass walrus habitat (i.e. the Lille Hellefiskebanke and the southernmost parts of Store Hellefiskebanke).

The shallow coastal areas and banks in West Greenland harbor suitable walrus food items (MarinID 1978, Schmid & Piepenburg 1993, Blicher et al. 2011). Information from diet studies from experienced walrus hunters shows that walruses in West Greenland mainly consume bivalve molluscs, including *Mya truncata* and *Hiatella arctica* (Born et al. 1994, Born et al. 2017).(Born et al. 2017).

During the mating season (January–April; Born 2001, Born 2003 and references therein) male walruses engage in ritualised visual and acoustical display underwater (Fay et al. 1984, Sjare & Stirling 1996, Sjare et al. 2003). Recordings in April at Store Hellefiskebanke of underwater sounds of displaying adult males indicate that the walruses mate in Central West Greenland (Born et al. 1994).

*Identity of subpopulations:* Genetic analyses indicate that three subpopulations exist in the Davis Strait - Baffin Bay region (Cronin et al. 1994, Andersen et al. 1998, Andersen & Born 2000, Born et al. 2001, Andersen et al. 2009b, Andersen et al. 2009c): The (1) Eastern Hudson Bay-Hudson Strait, (2) West Greenland-Southeast Baffin Island (WG-SBI), and (3) and the northern Baffin Bay stock confined to the North Water Polynya (NAMMCO 2009, 2019). The studies indicated that (1) walruses in the West Greenland-Southeast Baffin Island and the Baffin Bay populations differ genetically with some likely limited male mediated gene flow between these populations, (2) walruses at Southeast Baffin Island and West Greenland do not differ genetically, (3) walruses from Hudson Strait have some genetic input to the WG-SBI subpopulation.

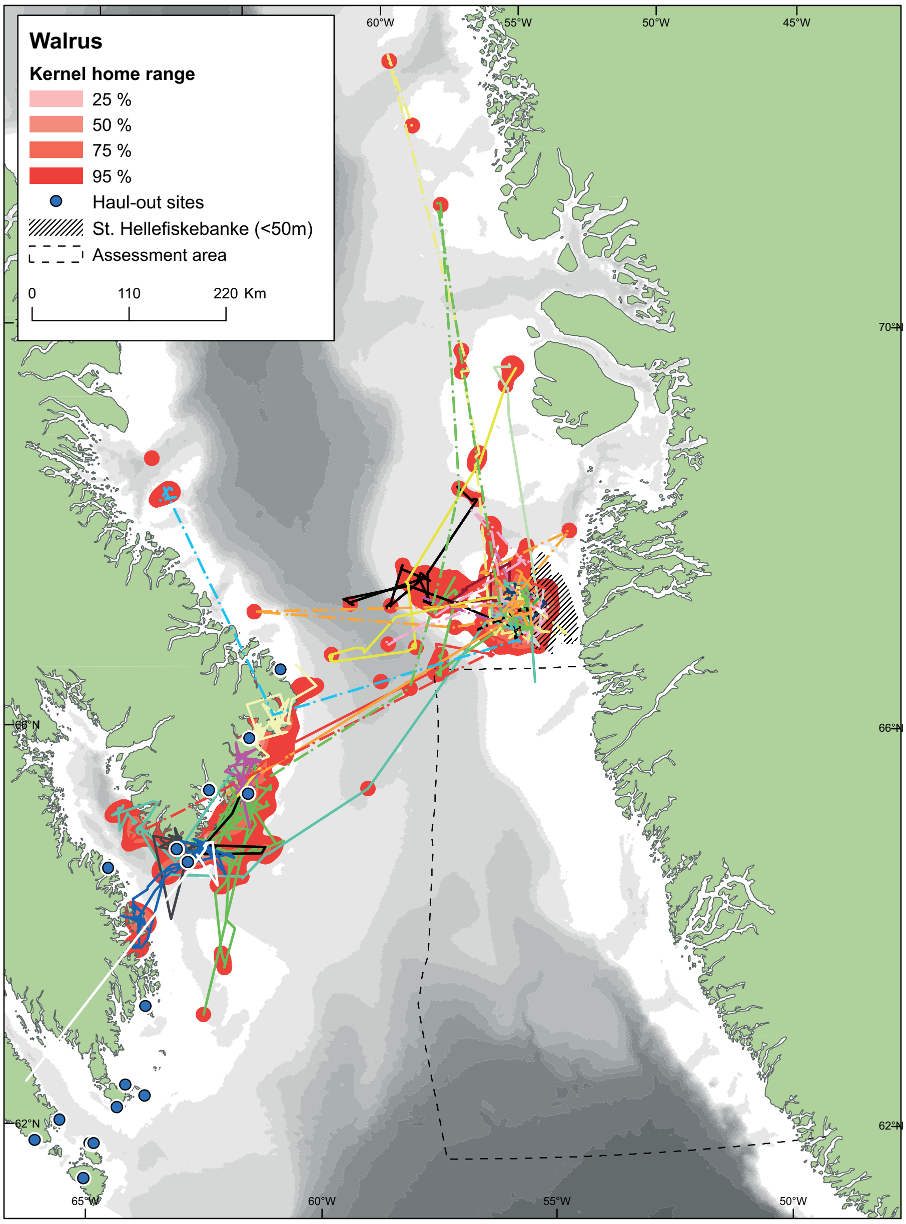
A satellite telemetry study (2005-2008) supported the findings of the genetic studies that walruses in West Greenland and at southeastern Baffin Island belong to the same subpopulation (Dietz et al. 2014), which is hunted in both Greenland and Nunavut (Andersen et al. 2014, NAMMCO 2018b).

*Distribution:* The general winter distribution of walrus in West Greenland is known from several systematic aerial surveys conducted during 1981–2012 (Born et al. 1994, Mosbech et al. 2007a, NAMMCO 2009, Heide-Jørgensen et al. 2014), as well as from interviews with walrus hunters in 2010 (Born et al. 2017). These studies showed that walruses in West Greenland are mainly concentrated in two areas during winter: (1) the shallow water banks between approx. 66° 30′ N and approx. 68° 15′ N (i.e. at Store Hellefiskebanke), and (2) the banks along the western coast of Qeqertarsuaq/Disko Island between approx. 69° 15′ N and approx. 70° 30′ N. In these areas they may occur from close to the coast west to ca. 56° W. However, they have also been observed among dense pack ice further west (Heide-Jørgensen et al. 2014, Born et al. 2017).

Although the main distribution in West Greenland is north of approx. 66° 30′ N, direct observations, satellite tracking, and information obtained from experienced walrus hunters indicate that walruses do occur inside the northern part of the assessment area – i.e. in the pack ice at the southern part of Store Hellefiskebanke (Born et al. 1994, Dietz et al. 2014, Born et al. 2017). Walruses appear in (i.e. immigrate to) the Store Hellefiskebanke area sometime in December–January and emigrate during April-May (Dietz et al. 2014, Born et al. 2017). The period between May and late fall is spent along the coast of East Baffin Island where walruses that have wintered in West Greenland mix with walruses that have wintered at Baffin Island (*Ibid.*).

Subadults and females with young generally occur closer to the coast than adult males in areas with less dense ice and shallower water (Born et al. 1994, Dietz et al. 2014, Born et al. 2017). Although larger congregations numbering one to two hundred individuals have occasionally been reported off Central

**Figure 3.8.2.** Track lines and kernel home range polygons from 31 walruses instrumented with satellite- linked transmitters at Store Hellefiskebanke during March-April 2005-2008 and at Southeast Baffin Island during August-September 2008 (Dietz et al. 2014).




West Greenland (i.e. off Attu-Nassuttoq at ca. 67° 30′ N and west of Disko island at ca. 69° 45′ N), most walruses observed during aerial surveys were either single or in pairs, and rarely groups of 3-8 walruses have been observed (Born et al. 1994, Heide-Jørgensen et al. 2014).

*Movements:* Scattered observations offshore in Davis Strait in March–July suggest that walruses migrate from the assessment area across Davis Strait from western Greenland to eastern Baffin Island during spring (Fig. 3.8.2) (Born et al. 1982, Born et al. 1994). Satellite telemetry during spring of 2005–2008 supports the notion that the majority of walruses that winter in Central West Greenland move west to summer at southeastern Baffin Island (Dietz et al. 2014).

The westward migration occurred between 7 April and 25 May, with the routes across Davis Strait being quite similar and taking place at the shallowest and the narrowest part (approx. 400 km) of the strait. All movements made by the walruses that were all instrumented on Store Hellefiskebanke occurred a little north and west of the assessment area (Dietz et al. 2014). However, as indicated walruses may also occur in the shallow waters of the northern part of the Davis Strait assessment area during late winter.

During the last decades the sea ice extent in West Greenland has decreased markedly and spring break-up now occurs earlier, e.g. 7.6 days earlier per decade over the period 1979-2010 (Dietz et al. 2014, Laidre et al. 2015). Still, satellite telemetry and aerial surveys indicate that the walruses show great fidelity to the geographic area during spring, 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 2018b).

*Abundance and trends in abundance:* 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 involved surveys about 85% of the sightings were made in the Store Hellefiskebanke area, and the remainder north of this area (*Ibid*.).

In 2010 several hunters reported that they had observed more walruses within the hunting areas and deduced that this was a sign of a population increase, which they attributed to a reduction in level of exploitation. (Born et al. 2017). An analysis of relative abundance of walrus (i.e. expressed as sightings per linear kilometer flown) during a series of aerials surveys conducted over the West Greenland wintering grounds, also indicated an increasing trend in abundance from 1981 through 2017 (NAMMCO 2018b).

Counts along eastern Baffin Island during summer (2005-2007) when the survey area is thought to also include animals from other subpopulations (i.e. West Greenland and Hudson Bay-Hudson Strait) provided an estimate of 2,100-2,500 walruses. This number was regarded as a negatively biased estimator of the population of walrus around Southeast Baffin Island and in the Hudson Bay–Davis Strait subpopulation as a whole (Stewart et al. 2014, NAMMCO 2018b). It is not clear how big a fraction of the WG-SBI subpopulation that winters in the assessment area. Nevertheless, any negative effects on the component of walruses from the WG-SBI subpopulation, which winters in West Greenland, may have an unknown impact on the subpopulation within its wider range.

*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 et al. 2017). 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 2017).

*Sensitivity*: Walruses are particularly sensible to disturbance when they are hauled out on land (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. 1994, Born et al. 1995 and references therein) and elsewhere in the distribution area of Atlantic walruses (COSEWIC 2006a, 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.

### 3.8.2 Seals

*Aqqalu Rosing-Asvid (GINR)*

Five species of seals occur in the assessment area; two species (harp and hooded seals) are migrant seals and their numbers within the assessment area fluctuate significantly with season. Ringed seals are mainly associated with areas that have sea or glacier ice, and they can maintain breathing holes in annual sea ice throughout the winter. The glacier fjords in the assessment area is likely to host some local ringed seals and others enter the area as the pack ice in Davis Strait spreads eastward during winter and spring. The Storis (pack ice from the east coast) might also reach into the assessment area from south and some influx of ringed seals is also likely to come from this front. Bearded seals are also associated with sea ice and they can maintain breathing holes. They do, however, prefer relatively light ice-conditions and many are associated with the outer edge of pack ice that during mid-winter expands into the northwestern part of the assessment area. Harbor seals spend most of their time close to the coast. The coastal part of the assessment area once had the highest occurrence of these seals in Greenland, but their numbers declined significantly during the 20$^{th}$ century due to hunting. The species is listed on the Greenland Red List as critically endangered (Boertmann & Bay 2018) and hunting on this species has been prohibited in Greenland since 2010.

**Hooded seal, *Cystophora cristata***

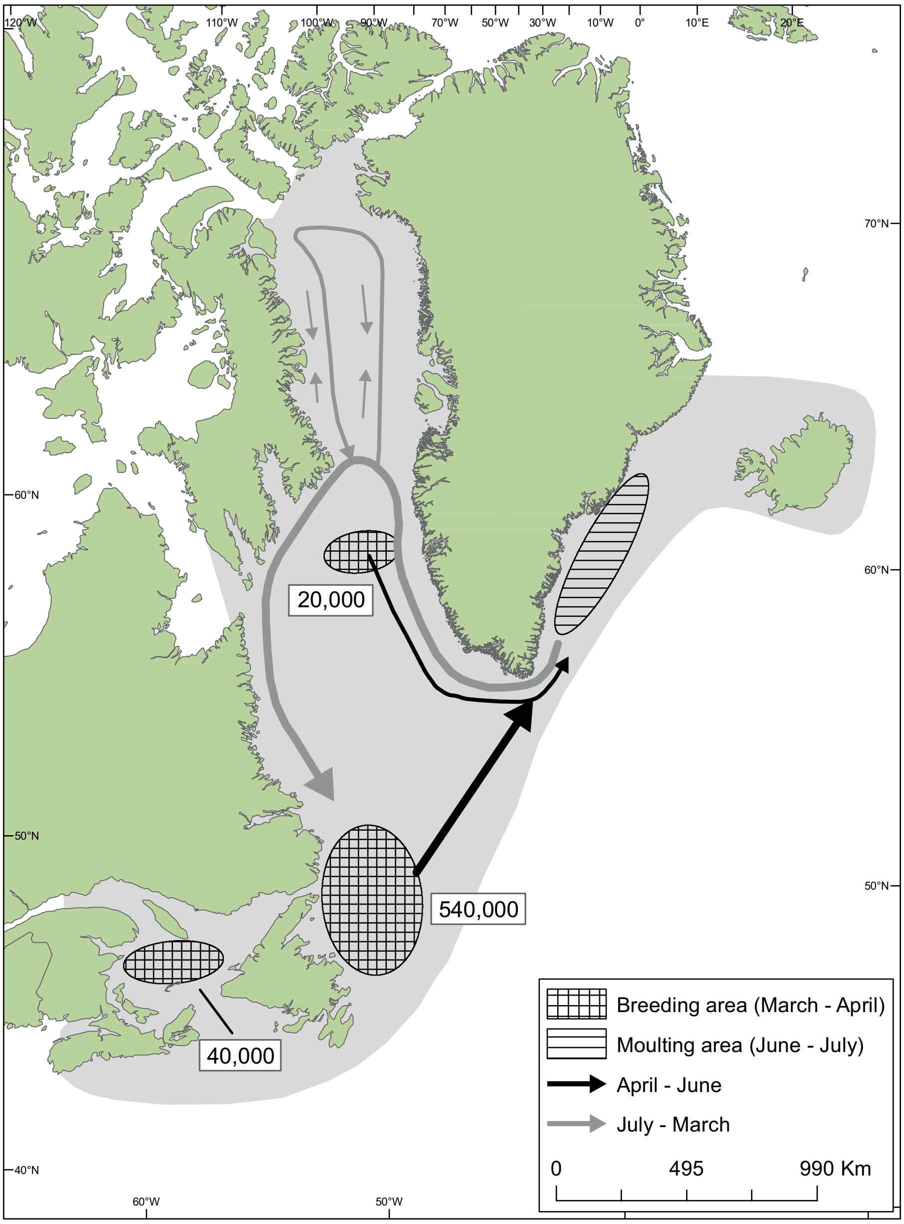
*Distribution and numbers:* Hooded seals are migratory seals (Fig. 3.8.3). The vast majority of the West Atlantic population whelp in areas around Newfoundland, but a small part of the population whelp in the Davis Strait (Stenson et al. 1996). The positions of this whelping patch as well as the number of seals that use this area for whelping change significantly from year to year. Published locations of whelping hooded seals in the Davis Strait (Sergeant 1974, 1976, 1977, ICES/NAFO 1997 , Kapel 1998) show that these seals some years whelps within the assessment area and some years just outside the area.

The hooded seals give birth in late March-early April and the lactation period is only 4 days (Perry & Stenson 1992). The female mate shortly after the lactation period and the adult seals start to disperse in April. The pups will stay a few weeks around their birthplace before they also swim away. Most hooded seals from the West Atlantic (both the seals that whelp near Newfoundland and in Davis Strait) swim to Southeast Greenland during May-June and molt on the drift ice along the east Greenland coast in June-July. In August-September many of them pass through the assessment area, when they swim back to Davis Strait and Baffin Bay where they forage during winter (Andersen et al. 2009a). They prey mainly on large fish and squids and they regularly dive to more than 500 m (maximum recorded dive depth of 1652 m) (Andersen et al. 2013). In spring they return to the whelping areas.

The total hooded seal pup production in the Northwest Atlantic (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 2006). Commercial sealing on hooded seals stopped after 2006 and no new assessment has been made since then.

In 1984 the pup production in Davis Strait was estimated to be 19,000 (14,000-23,000) (Bowen et al. 1987), but the estimate in 2005 was only 3,346 (SE = 2,237, CV = 66.8%) (ICES 2006). This change is not believed to reflect a change in overall population size, but merely a shift in distribution, as the hooded seals that whelp near Newfoundland and in Davis Strait are believed to be animals from the same population.

Figure 3.8.3. 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.




*Conservation status*: The West Atlantic hooded seals was listed as of Least Concern (LC) on the Greenland Red List, but was recently changed to Vulnerable (VU) (Boertmann & Bay 2018). This follows the international Red List and is not due to a documented population decline, but reflects an uncertainty because the last survey is old and because there are some concern about the effect of declining sea ice on the species (Kovacs 2016). The hooded seals are managed internationally through a working group under ICES /NAFO/ NAMMCO.

*Important and critical areas*: The whelping area in Davis Strait is located in or close to the assessment area. The hooded seals that whelp here are particularly sensitive to disturbance and pollution during the whelping/breeding season, which is in late March-April. It has been argued that hooded seals are especially sensitive to global warming because their birth places on the marginal ice zone are likely to become less stable and to breakup progressively earlier (Laidre et al. 2008). In the case of the Davis Strait a retreat of the ice edge is likely to move the whelping area closer to Canada and out of the assessment area.

## Harp seal, *Pagophilus groenlandica*

*Distribution and numbers:* Most of the harp seals from the West Atlantic population concentrate around the whelping areas around Newfoundland in February-April. They give birth on the drift ice in March and they molt in April. After the molt they spread out in the waters between Greenland and Canada and some seals move up along the Greenland east coast (Fig. 3.8.4).

A high number of harp seals are present in the assessment area and even more are likely to pass through the assessment area (most of them swimming northward) during summer and southward during fall when the seals gradually initiate the migration back toward the whelping areas off Newfoundland. Most adult harp seals will during summer forage in pods typically consisting of 10–20 individuals. Juvenile seals forage alone, but all ages feed mainly on capelin (*Mallotus villosus*) in the inshore part of the assessment area and on sand lance (Ammodytes spp.) on the Store Hellefiskebanke and probably also in other offshore areas (Kapel 1991 and unpublished data from the Greenland Institute of Natural Resources).

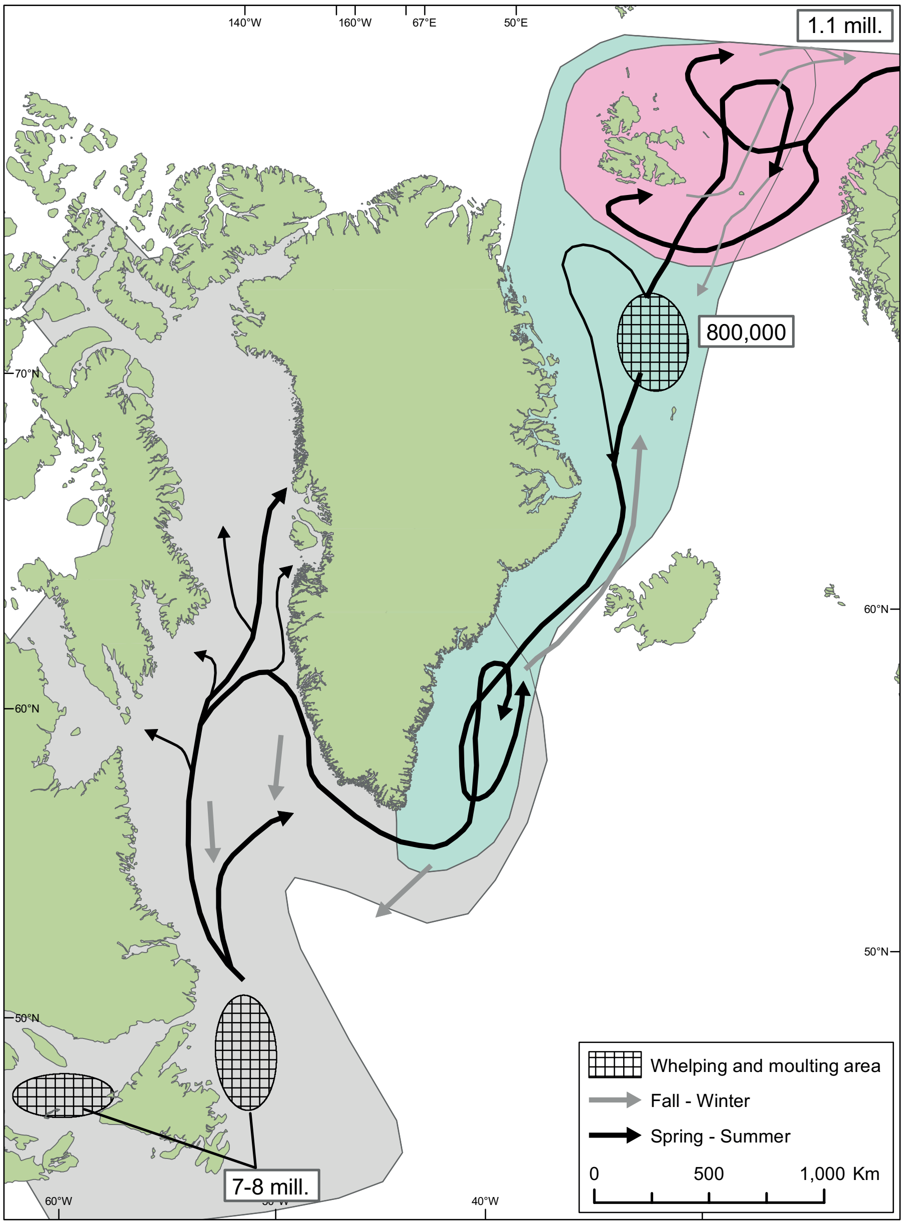



**Figure 3.8.4.** Harp seal distribution and numbers associated with known whelping areas.

The West Atlantic population that whelps around Newfoundland in early March is estimated to have increased from around 1.8 million in the early 1970's to peak about 7.8 million individuals in 2008 followed by a drop to 7.4 mill in 2012 (ICES 2014). 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 number that pass through the assessment area is probably highest during summer, but the highest concentrations might be found during winter when many of the latest migrants concentrates along the ice edge. The latest seals start their migration in February, but a few observations of single seals whelping in the assessment area have also been reported (Rosing-Asvid 2008).

*Conservation status*: The harp seal is probably the most numerous marine mammal in the northern hemisphere and the West Atlantic population is close to the highest level in historic time. It is listed as of Least Concern on the Greenland Red List (Boertmann & Bay 2018).

*Critical and important habitats*: Harp seals are found in all parts of the assessment area during most of the year and a large fraction of the population migrates through the assessment area during summer, autumn and early winter.

**Bearded seal, *Erignathus barbatus***

*Distribution and numbers:* 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 individual seals can be recognized by their 'song'. Long-term studies of bearded seal vocalization show a high degree of site fidelity among male bearded seals (Risch et al. 2007). Seasonal changes in the densities of bearded seals in some areas do, however, indicate that at least part of the population move around. These distribution changes are linked to the seasonal changes in the sea ice conditions. Bearded seals make breathing holes, but mainly in relatively thin ice. Seals that summer in areas with thick winter ice therefore either winter in reoccurring leads and polynyas or they follow the pulse of the expanding and shrinking sea ice.

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

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

The whelping period is in late April – early May often on drifting ice or near an ice edges with access to open water. The lactation period is about 24 days (Gjertz et al. 2000). A few bearded seals are likely to be born in the assessment area every year.

*Conservation status*: The bearded seal is listed as Least Concern (LC) on the Greenland Red List (Boertmann & Bay 2018) as well as on the global Red List. This is due to the uniform and widespread distribution, which is believed to be a good protection against over-exploitation.

*Critical and important habitat*: Little is known about the bearded seal habitat use in Greenland. Their wide and uniform distribution indicates that they might adapt to several habitats. During winter, the ice cover limits the availability of suitable habitats and the edge of the pack ice in the Davis Strait is therefore likely to have a significant importance to many bearded seals.

**Ringed seal, *Pusa hispida***

*Distribution and numbers:* The ringed seal habitat all parts of the Arctic that have annual sea ice. Glacier fjords with icebergs and areas with multi-year pack ice will typically also have some openings in between the ice bergs/ice floes were annual ice form during winter and these areas are also ringed seal habitat. Ringed seals give birth in March-April in lairs dug out in a snowdrift that is covering a breathing hole. Some pups are born on fjord ice in the assessment area. Ringed seals also make lairs in consolidated pack ice, e.g. in Baffin Bay (Finley et al. 1983) and such conditions might occur in the northwestern part of the assessment area. The extent of ice suitable for whelping as well as the number of ringed seals in the assessment area is, however, likely to fluctuate significantly depending on the ice and snow conditions. The pups lactate in up to seven weeks on the fast ice in Canada (Hammill et al. 1991), but pups born on the pack ice might have a shorter lactation period. The ringed seals start to shed hairs in April-May and the regrowth of new hairs is 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 and others follow the pack-ice that retreats westward 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 the juvenile seals often stray long distances (Yurkowski et al. 2016).

*Conservation status*: The ringed seals in general have a favorable conservation status, because they have 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 (Boertmann & Bay 2018).

**Figure 3.8.5.** Ringed seal lair with pup. Picture of a display in the zoological museum in Copenhagen.

Photo Aqqalu Rosing-Asvid.

*Critical and important habitats*: The relatively uniform and widespread circumpolar distribution of ringed seals implies that there are no areas that are critical for the total population. Locally, however, disruption of fast ice might have a negative influence on local nursing ringed seals in spring.

**Harbor seal, *Phoca vitulina***
*Distribution and numbers:* Harbor seals regularly haul-out on land and they rarely swim far offshore. They normally concentrate in certain areas during breeding and molting, and they might show strong site fidelity toward such haul-out sites throughout the year. Parturition will most often be in June, but the timing of parturition is a rather plastic parameter among harbor seals, and according to Reijnders et al. (2010) it has shifted 25 days earlier in the Dutch part of the Wadden Sea from 1974 to 2009. Molting is in August-early September and the breeding and molting area might be at the same or different locations.

Up until the 1950s harbor seals were relatively common in the assessment area, but hunting has driven them to near extinction (Rosing-Asvid 2010a). In the recent decade only two remnant concentrations of harbor seals have been registered in the assessment area by the Greenland Institute of Natural Resources. One is on the sandbanks next to the air strip in the Kangerlussuaq airport (67˚00´N; 50˚45´W), in the northern part of the assessment area. In 2018 two females gave birth and nursed their pups there. In 2019 two adult seals showed up again, but only one of them gave birth this year. The second breeding area is on Sioraq (Frederikshåb Isblink) (62°38N, 50°43W) in the southern part of the assessment area. Sightings in June 2020 indicate that this area is home for at least 30-40 harbor seals. In addition, there are observations indicating that other small populations might exist, but their breeding and molting sites are not known.

*Conservation status*: Harbour seals are listed as Critically Endangered (CL) on the Greenland Red List (Boertmann & Bay 2018).

*Critical and important habitats*: Small remnant and endangered populations are known to live in and near Kangerlussuaq around (67˚00´N; 50˚45´W), and in and near Sioraq (62°38N, 50°43W).

### 3.8.3 Whales, dolphins and porpoises (order Cetacea)

*Nynne Hjort Nielsen, Tenna Kragh Boye, Malene Simon, Fernando Ugarte (GINR) & Georgina E. Scholes (AU)*

The order Cetacea, which includes whales, dolphins and porpoises, is divided into two sub-orders: Mysticeti (baleen whales) and Odontoceti (toothed whales). As their English name clearly indicates, the main difference between baleen whales and toothed whales is that the former use baleen plates hanging from the roof of their mouths to catch their prey, while the later have 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. Most relevant for evaluating the impact of human activities, 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 echolocation clicks used for communication and to gain detailed information about objects ahead of the animal by listening to the reflected echoes (Mellinger et al. 2007). An overview of the frequencies used by the cetaceans present in the assessment area is shown in Tab. 3.8.1.

For the reasons explained above, hearing and sound production are vital for cetaceans. They can be affected by human made noise, including the sounds produced by hydrocarbon exploration and exploitation activities. Potential effects on cetaceans from anthropogenic sounds include behavioural changes (e.g. avoidance of the area or disruption of feeding), physical damage (mainly to auditory organs) and masking (obscuring of sounds of interest to the animal by interfering sounds). The sensitivity of cetaceans to anthropogenic sounds from hydrocarbon exploration and development activities as well as oil spill is discussed in detail in Chapter 6.

Recent knowledge about the distribution and abundance of cetaceans in the assessment area comes from aerial surveys carried out by GINR in March - April 2006 and 2012 and in August - September 2007 and 2015, covering the northern part (winter) and eastern part (summer) of the assessment area (Heide-Jørgensen et al. 2016, Hansen et al. 2019). Information is also available from passive acoustic monitoring (PAM) moored across the Davis Strait, recording continuously from October 2006 to September 2008 (Simon et al. 2010). Additional information about the seasonality, distribution and biology of cetaceans comes from a variety of sources, including scientific studies, catch statistics and observations from marine mammal observers on board seismic surveys.

**Table 3.8.1.** 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 Hz.

| Species | Latin | Sound type | Min freq. (Hz) | Max freq. (Hz) | References |
|---|---|---|---|---|---|
| ***Odontocetes*** | | | | | |
| Harbour porpoise | *Phocoena phocoena* | Click | 120,000 | 150,000 | (Villadsgaard et al. 2007) |
| White beaked dolphin | *Lagenorhynchus albirostris* | Click | 75,000 | 250,000 | (Rasmussen & Miller 2002) |
| | | Whistle | 3,000 | 35,000 | |
| Long-finned pilot whale | *Globicephala melas* | Click | 4,100 | 95,000 | (Eskesen et al. 2011) |
| | | Whistle | 260 | 20,000 | (Rendell & Gordon 1999) |
| Narwhal | *Monodon monoceros* | Click | 24,000 | 95,000 | (Miller et al. 1995) |
| | | Whistle | 300 | 18,000 | (Ford & Fisher 1978) |
| Beluga | *Delphinapterus leucas* | Click | 46,600 | 112,600 | (Au et al. 1985) |
| | | Whistle | 1,400 | 14,000 | (Belikov & Bel'kovich 2006, 2007) |
| Killer whale | *Orcinus orca* | Click | 30,000 | 100,000 | (Simon et al. 2007) |
| | | Whistle/call | 1,500 | 18,000 | (Ford 1989, Thomsen et al. 2001) |
| N. bottlenose whale | *Hyperoodon ampullatus* | Click | 2,000 | 26,000 | (Hooker & Whitehead 2002) |
| Sperm whale | *Physeter macrocephalus* | Click | 5,000 | 24,000 | (Madsen et al. 2002) |
| ***Mysticetes*** | | | | | |
| Minke whale | *Balaenoptera acutorostrata* | Call / song | 80 | 800 | (Mellinger et al. 2000) |
| Sei whale | *Balaenoptera borealis* | Call / song | 30 | 400 | (Rankin & Barlow 2007) |
| Humpback whale | *Megaptera novaeangliae* | Call / song | 35 | 24,000 | (Payne & Payne 1985) |
| Fin whale | *Balaenoptera physalus* | Call / song | 15 | 30 | (Watkins et al. 1987) |
| Blue whale | *Balaenoptera musculus* | Call / song | 14 | 20 | (Cummings & Thompson 1971) |
| Bowhead whale | *Balaena mysticetus* | Call / song | 100 | 5,000 | (Ljungblad et al. 1982) |

With the exception of blue whales, sei whales and sperm whales, which are protected by law, and bottlenose whale, whose blubber has a laxative effect, all cetaceans are hunted in Greenland and are considered as an important resource for both economic and cultural reasons (see Chapter 5.3.4).

### 3.8.4 Baleen whales (*Mysticeti*)

The six species of baleen whales occurring in the assessment area belong to two families: rorquals (Balaenopteridae, five species) and right whales (Balaenidae, one species). Among the rorquals, minke whales (*Balaenoptera acutorostrata*), fin whales (*Balaenoptera physalus*) and humpback whales (*Megaptera novaeangliae*) are seasonal inhabitants and relatively abundant. Sei whales (*Balaenoptera borealis*) are less abundant than both minke-, fin- and humpback whales, and blue whales (*Balaenoptera musculus*) are rare, but seasonally present. The bowhead whale (*Balaena mysticetus*) migrates seasonally through the assessment area and is one of the two species of the right whale family that inhabit the North Atlantic. The critically endangered northern right whale (*Eubalaena glacialis*) may have used the assessment area in the past, but its current distribution is most likely limited to few individuals in transit through South Greenland to and from poorly known offshore areas of the North Atlantic (Cooke 2018e).

The waters off West Greenland are very productive and serve as an important foraging area to the seasonal residential baleen whales. They target dense patches of prey and the distribution of the whales is correlated with certain prey items, such as capelin (*Mallotus villosus*), krill (*Meganyctiphanes norvegica and Thysanoessa sp.*) and sandeels (*Ammodytes sp.)* (Heide-Jørgensen & Laidre 2007, Laidre et al. 2010, Simon 2010).

The climate driven changes in Arctic play a major role in the ecosystem and affect all levels of the food-web (see review by Wassmann et al. 2011). Recently, Hansen et al. (2019) have documented a shift, or fluctuation, in the main distribution of minke, fin and humpback whales from West to East Greenland. Ice-associated marine mammals, such as the bowhead whale are expected to move northwards due to warming waters, consequently losing their sea ice habitat (Chambault et al. 2018). Therefore, changes in the climate and ecosystem are likely to have an effect on the distribution of baleen whales in the assessment area.

In the following text we will focus on the biology and occurrence of the different species of baleen whales within the assessment area.

**Fin whale, *Balaenoptera physalus***
*General biology:* The North Atlantic fin whale reach an average length of 19–20 m and an average weight of 45–75 tonnes. In Greenland, fin whales target prey such as sandeels, offshore patches of krill and coastal aggregations of capelin (Kapel 1979) and there is a strong correlation between offshore krill abundance and high density of fin whales (Laidre et al. 2010).

*Distribution and movements:* Fin whales seasonally visit West Greenland waters (from Cape Farewell to north of Disko Island) during summer and migrate south to unknown breeding grounds during winter. However, passive acoustic monitoring shows that fin whales are present in Davis Strait until late December and the increased fin whale song suggest that mating starts in October-November while the whales are still in the assessment area (Simon et al. 2010). The southward migration of the fin whales coincides with the formation of sea ice, suggesting that ice coverage is an important limiting factor for the northern distribution of fin whales during winter (Simon et al. 2010). Aerial surveys indicate that the highest abundance of fin whales in West Greenland is within the assessment area (Hansen et al. 2019).

*Abundance and conservation status:* An estimated 2,200 fin whales visit West Greenland (Hansen et al. 2019) and fin whales are placed in the category of *least concern* on the Greenland Red List due to signs of increasing abundance in the North Atlantic (Boertmann & Bay 2018). However, on a global scale the species is considered *Vulnerable* by the IUCN Red List of Threatened Species, as a result of a major decline in abundance of fin whales due to whaling in the 20$^{th}$ century (Cooke 2018d).

*Critical and important areas:* The majority of the fin whale population in West Greenland are found in the assessment area, which constitute an important foraging ground (Laidre et al. 2010, Hansen et al. 2019).

**Minke whale, *Balaenoptera acutorostrata***
*General biology:* The minke whale is the smallest (about 7 m and 8 tonnes) and most abundant baleen whale in Greenland waters. They are the most icthyophagous of the baleen whales and feed mainly on sandeel and capelin (Kapel 1979).

*Distribution and movements:* Minke whales migrate between low latitude breeding grounds and high latitude feeding grounds arriving in Greenland during spring. The assessment area covers the highest densities of minke whales in West Greenland and they are found both offshore and inshore in bays and fjords (Laidre et al. 2010, Hansen et al. 2019).

*Abundance and conservation status:* The population in West Greenland is currently estimated around 5.000 animals (Hansen et al. 2019); however, large variations in relative minke whale abundance across years suggest that the fraction of minke whales using the West Greenland banks as a summer feeding ground may vary from year to year (Heide-Jørgensen & Laidre 2008). There is molecular evidence that minke whales in the assessment area belong to a distinct population that summers in what is recognises by the International Whaling Commission (IWC) as the West Greenland management area (Andersen et al. 2003, Born et al. 2007). Furthermore, minke whale catch data show distinct sexual segregation in the West Greenland subpopulation where mostly females are found within the assessment area and in Northwest Greenland while males tend to migrate to Southwest Greenland (Laidre et al. 2009)

Both IUCN (2008) and the Greenland Red List (Boertmann 2007) places minke whales in the *Least Concern* category (Boertmann & Bay 2018, Cooke 2018a).

*Critical and important areas:* Like fin whales, the majority of the minke whale population in West Greenland utilize the assessment area for restoring their blubber layer.

**Humpback whale, *Megaptera novaeangliae***
*General biology:* Humpback whales are about 13 m long and weigh 28 tonnes. In Greenland, humpback whales feed mainly on capelin, sandeel and krill. They travel along the coast into fjords and bays to benefit from shallow aggregations of capelin (Heide-Jørgensen & Laidre 2007). Yet, it seems like the majority of humpback whales stay offshore to take advantage of large prey

patches on the banks with a high- density humpback whale area within the assessment area (Laidre et al. 2010).

*Distribution and movements:* Humpback whales migrate between their low-latitude breeding grounds in the Caribbean and the high-latitude feeding ground in Greenland. They arrive in the assessment area in spring (May) and stay until late autumn (October). However, a minority of individuals over-winter in Greenlandic waters (Simon 2010).

Although individual humpback whales show site fidelity toward specific foraging sites, returning year after year to the same area within few kilometres (Boye et al. 2010), they travel between different foraging sites within the same season (Heide-Jørgensen & Laidre 2007).

Whale watching is increasing in Greenland and within the assessment area particular around Nuuk. Here, humpback whales visit the fjord system to spend the summer foraging and local tourist operators offers daily whale watching tours (Boye et al. 2010). These tours constitute a significant proportion (estimated 20 % and increasing, pers. comm. Visit Greenland) of the tourist-based income in Nuuk.

*Abundance:* In 1981, Whitehead et al. (1983) estimated the population size of West Greenland humpback whales to constitute 85-200 animals, but after protection from commercial whaling in 1966, the many years of protection resulted in an annual increase of humpback whale abundance of 9,4 % to around 4,200 whales in West Greenland in 2007 (Heide-Jørgensen et al. 2012b). In 2015, however, the abundance of humpback whales was decreased to an estimated 993, which is believed to be due to a general eastern shift in the distribution of baleen whales in West Greenland (Hansen et al. 2019).

*Conservation status:* The humpback whale is listed as *Least Concern* on both the IUCN Red List and the Greenland Red List (Boertmann & Bay 2018, Cooke 2018f). As with fin and minke whales, there can be large fluctuations in the numbers of humpback whales in West Greenland, as exemplified in 2015, when only about 900 humpback whales were estimated to be summering in West Greenland (Hansen et al. 2019).

*Critical and important areas:* Humpback whales are more dynamically dispersed in West Greenland compared to fin- and minke whales. Thus, on a population level, they are most likely not heavily dependent on the assessment area. However, on the individual level humpback whales show site fidelity and may depend more heavily on certain areas. From a human perspective, the humpback whales around Nuuk constitute a significant economic value by means of whale watching, but appears to rely on a few individuals that are repeatedly sighted (Boye et al. 2014).

**Sei whale, *Balaenoptera borealis***
*General biology:* Sei whales are on average 14 m long and weigh 20–25 tonnes. They feed almost exclusively on krill (Kapel 1979) and the overall distribution of sei whales is correlated with high densities of krill deeper than 150 m (Laidre et al. 2010). Small schooling fish and squid also form an important part of their diet in some areas. (Laidre et al. 2010)

*Distribution and movements:* Sei whales are believed to make seasonal migrations between low-latitude wintering grounds and high-latitude feeding grounds. There is very little information on sei whales in West Greenland, but sound signals were recorded in the Davis Strait in August-September, 2006-07 (Simon et al. 2010), and few observations, all near the continental slope, have been made from ship and aerial surveys in summer (Heide-Jørgensen et al. 2008, Hansen et al. 2019).

*Abundance and conservation status:* The abundance of sei whales in West Greenland was estimated from a ship survey in 2005 to around 1,600 individuals. As with fin- and minke whales, their main distribution was found within the assessment area (Heide-Jørgensen et al. 2008). Sei whales are considered *Endangered* on both the IUCN Red List and on the Greenland Red List (Boertmann & Bay 2018, Cooke 2018b).

*Critical and important areas:* Knowledge on distribution and important foraging areas in West Greenland are not known.

**Blue whale, *Balaenoptera musculus***

*General biology:* Blue whales are the largest animals ever to have existed on earth and reach an average length in the Northern Hemisphere of 25 m and weigh up to 120 tonnes. Their main prey is krill, but also capelin and sandeel are part of their diet (Kapel 1979).

*Distribution and movements:* Blue whales are globally distributed from the low latitudes to polar waters, where dense pack ice and the ice edge limit their northern and southern distributions (Norris 1977). As with other rorquals, it is assumed that blue whales travel between foraging areas at high latitudes in the summer and low-latitude breeding areas during winter (Heide-Jørgensen et al. 2001).

Observations of blue whales in West Greenland are rare and their presence in the assessment area is poorly known. Yet several sightings have been reported within the assessment area between 62°-66°N and individuals have been documented to travel between foraging areas in Gulf of St. Lawrence to West Greenland, which suggests a shared population of blue whales between West Greenland and Eastern Canada (Sears & Larsen 2002). Passive acoustic monitoring in 2006-2007 revealed blue whale calls in August-September in the Davis Strait (Simon et al. 2010).

*Abundance and conservation status:* Although numbers of blue whales seem to be increasing, blue whales are considered as *Endangered* on the IUCN Red List because most populations, including those in the North Atlantic, were decimated by whaling in the 20$^{th}$ century (Cooke 2018c). The number of blue whales occurring in West Greenland is unknown and therefore the species is classified as *Vulnerable* on the Greenland Red List (Boertmann 2007, Boertmann & Bay 2018). In the northwestern Atlantic, blue whales are only common in the Gulf of St. Lawrence, where about 400 animals have been photo-identified (Ramp et al. 2006).

*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. However, in recent observations suggest that Disko Bay, north of the assessment area, may be an important area for blue whales during summer.

**Bowhead whale, *Balaena mysticetus***

*General biology:* Bowhead whales are long-lived and may be more than 200 years old (George et al. 1999). They reach a length of 14-18 m and a weight 60-100 tonnes. In West Greenland, bowhead whales feed on the high densities of Arctic copepods in Disko Bay (Fig. 3.8.6) (Heide-Jørgensen et al. 2006, Laidre et al. 2007, Heide-Jørgensen et al. 2010a). The whales migrating to West Greenland constitute 79 % females and besides for feeding the whales may use the area as a mating ground (Heide-Jørgensen et al. 2010a, Rekdal et al. 2015).

*Distribution and movements:* The bowhead whales belonging to the Baffin Bay stock spend most of the year in the Canadian high Arctic around Baffin Island (Heide-Jørgensen et al. 2010a) and in winter (January-February), part of the population migrates to West Greenland to forage in Disko Bay. The Disko Bay and the waters to the southwest of Disko are used extensively for foraging by mature whales of both sexes and it is especially important for mature females that – aside from feeding – probably also are mating in the bay (Stafford et al. 2008, Heide-Jørgensen et al. 2012a). An unknown number of individuals pass through the assessment area during their migration. This is supported by satellite telemetric data from 83 bowhead whales (Chambault et al. 2018) and passive acoustic monitoring in Davis Strait with recordings of bowhead whale song from January to June and a clear peak in March-May (Simon et al. 2010).

*Abundance and conservation status:* Extensive commercial whaling of bowhead whales reduced the stock to a level where whaling was no longer profitable at the end of the 19th century (Ross 1993) and sightings were rare in West Green-

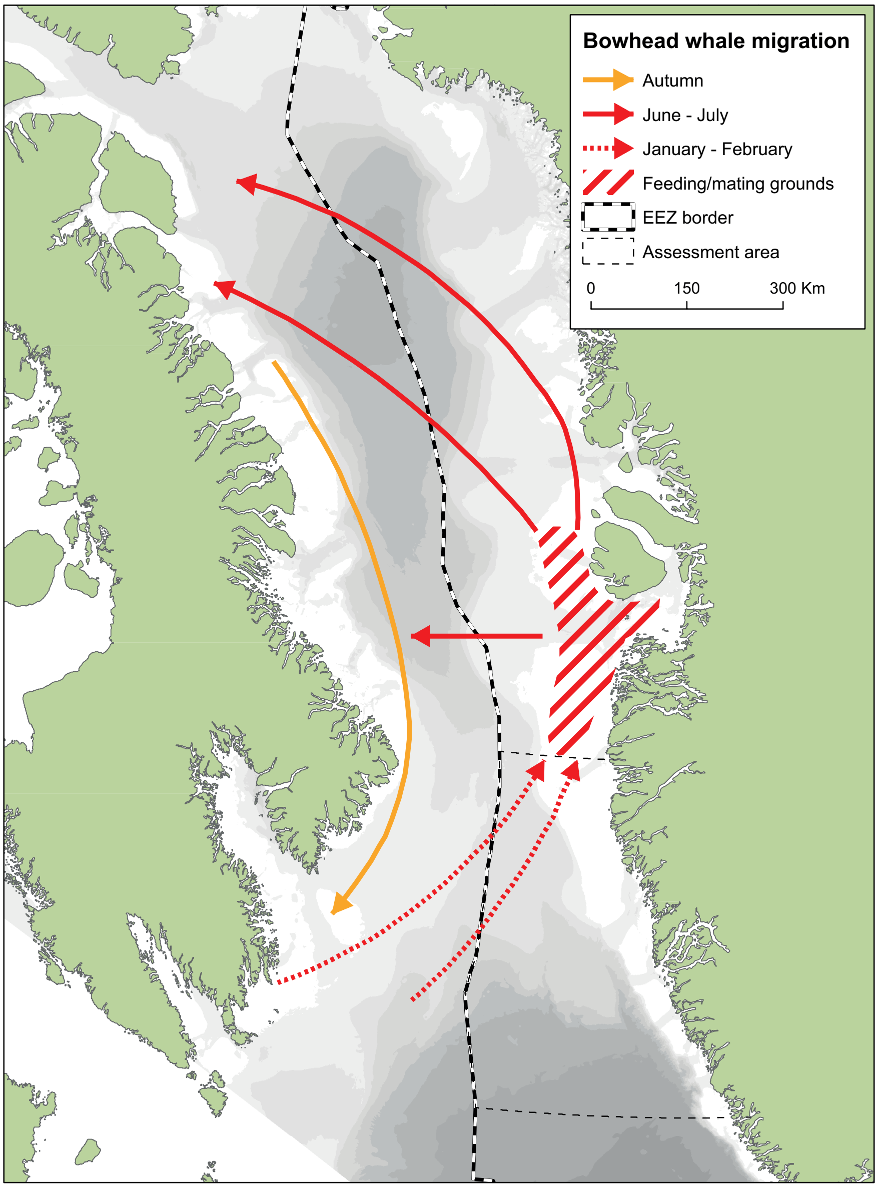



**Figure 3.8.6.** Migration routes for bowhead whales in the Davis Strait and Baffin Bay. In January-February the whales migrate through the assessment area on their way to feeding/mating grounds just north of the assessment area (hatched area). Some whales have displayed alternative routes, e.g. crossing Davis Strait directly west of Disko Bay followed by movement to the south and into the Hudson Strait. However, all whales return to Disko Bay through the assessment area.

land. However, the stock is now recovering, and the whales have returned to the Disko Bay feeding/mating area. The most recent population estimate of bowhead whales in Disko Bay is around 1,500 (Heide-Jørgensen et al. 2007, Rekdal et al. 2015) and the bowhead whale is now listed as *Least Concern* on the IUCN Red List and as *Nearly Threatened* on the Greenlandic Red List (Boertmann & Bay 2018, Cooke & Reeves 2018).

*Critical and important areas:* The migration corridors between Disko Bay and northern Baffin Island (May and June) and between southern Baffin Island and Disko Bay (February) pass the upper western part of the assessment area. However, the most important areas are north of the assessment area.

### 3.8.5 Toothed whales (*Odontoceti*)

Eight species of toothed whales occur in the assessment area: long-finned pilot whale (*Globicephala melas)*, white-beaked dolphin (*Lagenorhynchus albirostris)* harbour porpoises (*Phocoena phocoena*), narwhal (*Monodon monoceros*) beluga whale (*Delphinapterus leucas*), killer whale (*Orcinus orca*), sperm whale (*Physeter macrocephalus*) and northern bottlenose whale (*Hyperoodon ampullatus*). Changes in prey distribution or ice coverage, e.g. due to climatic changes, are likely to alter the distribution of marine mammals, including toothed whales. The distribution of e.g. the beluga whale depends largely on the distribution of ice coverage; the whales staying close to the edge of the pack ice and moving further north, or west, or further offshore if any loosening in the pack ice occurs (Heide-Jørgensen et al. 2010b, Heide-Jørgensen et al. 2017).

**Sperm whale, *Physeter macrocephalus***
*General biology:* Sperm whales are the largest of the toothed whales and reach lengths of 18 m and weights of 50 tonnes. Sperm whales prey on a variety of deep-sea fish and cephalopods. Stomach samples from 221 sperm whales caught between Iceland and Greenland showed that benthic or pelagic fish (especially the lumpsucker, *Cyclopterus lumpus*) constituted the majority of the diet but also oceanic cephalopods were important prey (Martin & Clarke 1986). Stomach content of sperm whales caught in West Greenland contained exclusively fish (Kapel 1979).

*Distribution and movements:* Although they are found in all oceans, the species display sexual segregation where females and calves reside in tropical and subtropical waters year round, while males inhabit high latitude feeding grounds with occasional visits to their low latitude breeding grounds (Best 1979).

*Abundance and conservation status:* The abundance of sperm whales in Greenland is not known, but sperm whales have been encountered in West Greenland and within the assessment area during aerial surveys (e.g. Hansen et al. 2019). Sperm whales are found mainly in deep waters along the continental slope, and have been observed every summer for the past decade by local hunters in Maniitsoq (in the assessment area, north of Nuuk). But they can also be seen in deep fjords and are observed in the fjord system of Nuuk, within the assessment area, during days or weeks at a time during most years (GINR, unpubl. data). Echolocation clicks of sperm whales have also been recorded close to the West Greenlandic continental shelf in the Davis Strait (GINR, unpubl. data). Male sperm whales have been found to feed both at shallow depths of around 100 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). Sperm whales are expected to use the assessment area during ice-free periods in suitable habitat, such as deep-sea waters close to continental slopes and underwater canyons with abundance of cephalopod or fish prey.

The IWC considers the North Atlantic sperm whales as belonging to a single population (Donovan 1991), which is further supported by genetic analyses (Lyrholm & Gyllensten 1998). On a global scale, sperm whales are categorised as *Vulnerable* on both the IUCN Red List and on the Greenland Red List (Boertmann & Bay 2018, Taylor et al. 2019).

*Critical and important areas:* Knowledge on distribution and important foraging areas of sperm whales in West Greenland is poor. However, the shelf breaks and the deep offshore waters may constitute important habitats for this species.

**Long-finned pilot whale, *Globicephala melas***

*General biology:* The long-finned pilot whale (hereafter called pilot whale) is medium-sized and reaches a length of just over 6 meters and a weight of 2.5 tonnes. It is often found in large groups counting tens of individuals (Hansen & Heide-Jørgensen 2013). It occurs in temperate and sub-polar zones but catch statistics show that it is occasionally found as far North as Upernavik. In the USA, pilot whales have seasonal movements that appear to be dictated by their main prey, the long-finned squid (*Loligo pealei*) (Payne & Heinemann 1993, Gannon et al. 1997), but they can diversify their diet according to prey availability and will take medium-sized fish when available (Gannon et al. 1997).

*Distribution and movements:* Recent aerial surveys showed that pilot whales preferred deep offshore waters and the largest abundance was found within the northernmost part of the assessment area in and south of Lille Hellefiskebanke (Hansen et al. 2019).

*Abundance and conservation status:* An estimated 9,000 pilot whales inhabit West Greenland, including the assessment area (Hansen et al. 2019). These whales probably belong to a large North Atlantic population, however, Bloch and Lastein (1993) genetic comparison of pilot whales from the US East Coast, West Greenland, the Faeroe Islands and the UK showed that West Greenland pilot whales are distinct from other populations and suggests that population isolation probably occurs by sea surface temperature rather than distance (Fullard et al. 2000).

Abundance in the Central and Eastern North Atlantic has been estimated to 780,000 animals (Buckland et al. 1993), while relative abundance in Newfoundland was estimated at 13,200 individuals in 1980 (Hay 1982). Hence pilot whales are abundant and considered as *Least Concern* both on the Greenland Red List and on the IUCN Red List (IUCN 2008, Boertmann & Bay 2018).

*Critical and important areas:* The main distribution of pilot whales seems to lie in the northern part of the assessment area, which most likely serve as an important foraging area.

**White-beaked dolphin, *Lagenorhynchus albirostris***

*General biology:* White-beaked dolphins are endemic to the North Atlantic Ocean where they inhabit cold temperate and sub-Arctic areas (Reeves et al. 1999). Adults are on average 240-280 cm long and weigh 200-300 kg and they feed on a variety of small schooling fishes such as herring (*Clupea harengus*), cod and whiting (Gadidae sp), along with squid and crustaceans (Jefferson et al. 2008). Their diet within Greenlandic waters is not known, but cod, capelin and sandeel may constitute prey items. In West Greenland, white-beaked dolphins are found in groups of up to 20 individuals (Hansen et al. 2019), but have been found to occur in larger groups of hundreds of individuals (Rasmussen 1999, Jefferson et al. 2008). They occur both in offshore waters and on continental shelves.

*Distribution and movements:* From aerial surveys conducted in West and East Greenland, white-beaked dolphins are present from ca. 70° N and southwards, and with highest densities in the southern part and south of the assessment area (Hansen et al. 2013, Hansen et al. 2019).

*Abundance and conservation status:* The estimated abundance of white-beaked dolphins is 15,260 animals in West Greenland (Hansen 2010, Hansen et al. 2019). White-beaked dolphins are considered as *Least Concern* at both the Greenland Red List and IUCN Red List (Boertmann & Bay 2018, Kiszka & Braulik 2018)

*Critical and important areas:* As white-beaked dolphins are mainly found south of the assessment area it appears that they are not heavily dependent on this area.

**Killer whale, *Orcinus orca***

*General biology:* Killer whales are found in all oceans, at various depths and do not seem to have any latitudinal restrictions on their home range, other than sea ice. However, abundance is higher in colder waters near the shore (Jefferson et al. 2008). Killer whales feed on prey varying from small schooling fish to large marine mammals and their high dietary specialisations divides them into *ecotypes*. Examples of prey choice are herring in Norway (Christensen 1982), sharks in New Zealand (Visser 2005), sea lions and elephant seals in Patagonia (Lopez & Lopez 1985) and either minke whales, fish or seals and penguins in Antarctic (Pitman & Ensor 2003). Mating between different ecotypes rarely occurs (Pilot et al. 2009). Killer whales live in natal pods where mating occur outside the pod during interaction with other groups (Pilot et al. 2009). Groups most often contain between 3-30 individuals, but temporal aggregations may count more than 100 animals (review in Baird 2000).

*Distribution and movements:* Studies on killer whales in Greenland are almost non-existent and their distribution, abundance and genetics are poorly understood (see review by Jourdain et al. 2019).

*Abundance and conservation status:* Sightings are sparse along the West Greenland coast (Teilmann & Dietz 1998) and during a large aerial survey in 2015, killer whales where only observed in South and East Greenland, and with no sightings in the assessment area (Hansen et al. 2019). These scarce observations are in agreement with the official catch statistics of killer whales in Greenland, however, catches of killer whales in East Greenland have increased in the past decade (APNN, unpub. data, Jourdain et al. 2019).

It is not known whether the killer whales found in Greenland constitute their own population or are part of a larger population within the Atlantic Ocean. The notion of a population in the Northeast Atlantic with a range including West Greenland and East Canada is supported by satellite tracking of a single individual from August to November 2009 that moved from the Canadian High Arctic (Lancaster Sound), via Baffin Bay and the Davis Strait, to waters west of the Azores (Petersen et al. 2009). Due to the scarce knowledge in Greenland, killer whales are listed as *Data Deficient* on the Greenland Red List (Boertmann & Bay 2018). Despite the extensive studies on killer whales in other areas of the world they are likewise listed as *Data Deficient* on the IUCN Red List due to ambiguities regarding taxonomy (Reeves et al. 2017).

*Critical and important areas:* As killer whales are rarely seen in the assessment area, this appears not to be an important area for this species.

**Harbour porpoises, *Phocoena phocoena***
*General biology:* Harbour porpoises are the smallest cetaceans found in Greenland and reach a length of 1.7 m and a weight of up to 80 kg. It is amongst the most abundant whale species in the North Atlantic and also in West Greenland where it occurs from the southernmost tip to the Avanersuaq district in Northwest Greenland (Teilmann & Dietz 1998).

*Distribution and movements:* The main distribution of harbour porpoises in West Greenland lies between Sisimiut and Paamiut (Teilmann & Dietz 1998, Nielsen et al. 2018), which corresponds to the range of the entire assessment area from 62°-67°N. During summer, harbour porpoises in West Greenland mainly inhabit coastal and continental shelf areas, but they occasionally utilize the fjords (Hansen 2010, Hansen et al. 2013, Hansen et al. 2019). 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 app. 66° N, catch statistics and tracking data confirm their presence year-round in West Greenland (APNN, unpubl. data, Nielsen et al. 2018).

Because harbour porpoises have a high metabolism, they need to locate suitable prey items on a regularly basis (Rojano-Donate et al. 2018). Their main prey consists of several fish species and squid, and in West Greenland capelin (*Mallotus villosus*) is the predominant part of their diet (Lockyer et al. 2003, Heide-Jørgensen et al. 2011).

*Abundance and conservation status:* The abundance of harbour porpoises in West Greenland has been estimated to approximately 83,300 animals (Hansen 2010, Hansen et al. 2019). 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). Harbour porpoises are listed as *Least Concern* on both the Greenland Red List and the global IUCN Red List (Hammond et al. 2008, Boertmann & Bay 2018).

*Critical and important areas:* The assessment area constitutes an important foraging ground for harbour porpoises in West Greenland, however, they also use a much larger area north and south of the assessment area and are probably not critically dependent on the assessment area.

**Beluga whale, *Delphinapterus leucas***
*General biology:* Beluga whales reach a length up to 5 metres and a weight of 1,500 kg and although they are born grey, they turn white with age. They prey mainly on fish, especially polar cod but also squid and shrimp constitute a part of their diet (Heide-Jørgensen & Teilmann 1994). Beluga whales most often travel in groups of two to ten whales, but larger groups are not uncommon, especially during their annual migration.

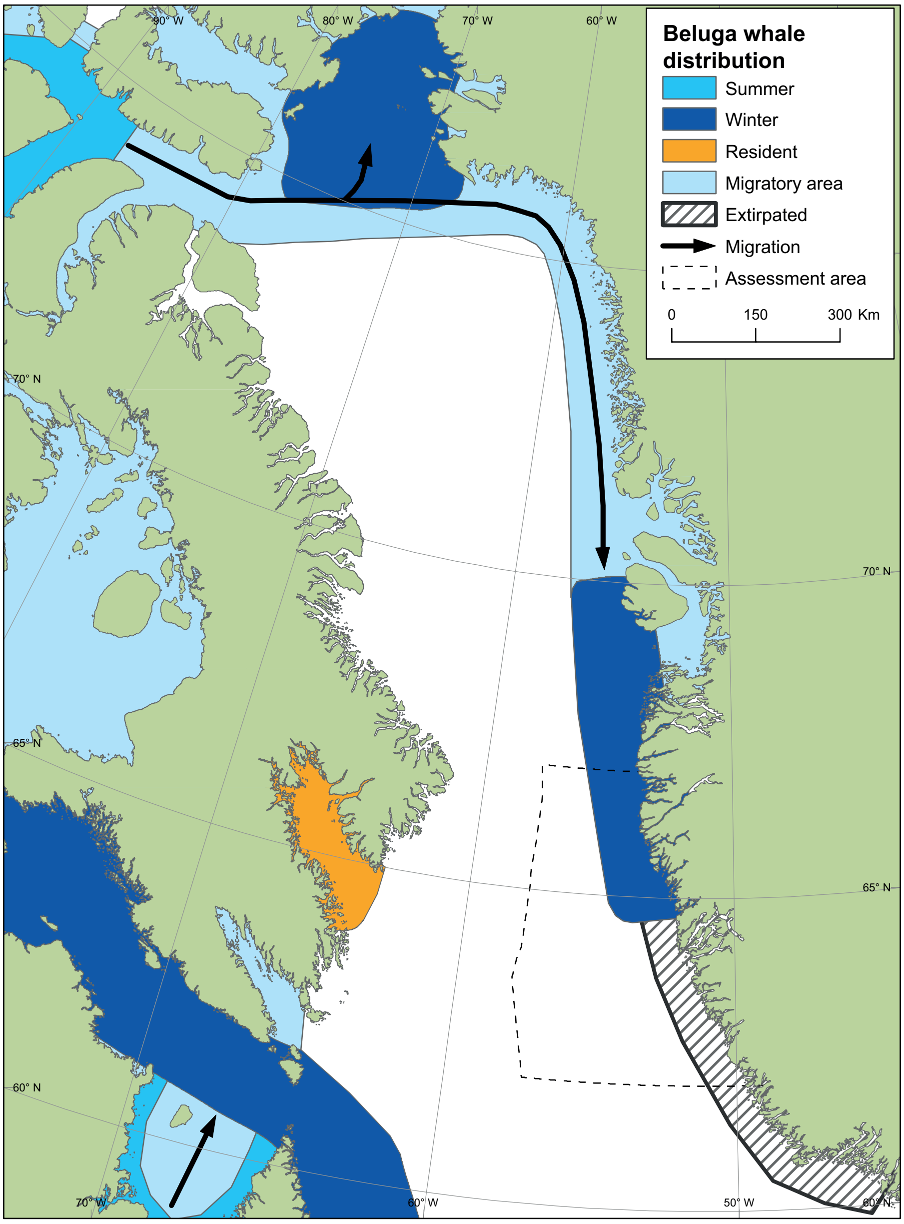



**Figure 3.8.7.** Map of known wintering grounds for beluga whales in West Greenland and eastern Nunavut. Summering grounds are in Arctic Canada. Belugas can be found along the whole northwest coast of Greenland during migration between winter and summer grounds. Map modified from Heide-Jørgensen et al. (2017) and NAMMCO (2018a).

*Distribution and movements:* Beluga whales only occur in the Arctic and Sub-Arctic region, where they live among the pack ice close to the ice edge, or in leads and polynyas during winter and migrate to shallow bays and estuaries during summer (NAMMCO 2008). The beluga whales found in West Greenland during winter spend the summer in the Canadian High Arctic archipelago and tagging with satellite transmitters indicates that only a fraction of the whales travel to West Greenland while the majority most likely reside in the North Water Polynya (Heide-Jørgensen et al. 2003). The whales that do travel to West Greenland migrate along the coast of north-western Greenland and arrive at more southern feeding areas south of Disko in December, where they remain scattered on the shallow banks until spring (Heide-Jørgensen et al. 2010b). Although beluga whales occur within the northern part of the assessment area, their main distribution is not within this area. Instead, Store Hellefiskebanke just north of the assessment area supports the highest densities of beluga whales, where only ice coverage seem to be the limiting factor of this species' movements further north or offshore (Heide-Jørgensen et al. 2010b). Beluga whales are expected to acquire major part of their annual food intake in their winter quarters (Fig. 3.8.7).

*Abundance and conservation status:* The wintering whales in West Greenland are part of a larger population that spend the summer in the Canadian High Arctic

(NAMMCO 2008). The latest abundance estimate of the West Greenland aggregation was calculated in 2012 to constitute around 9,000 individuals and it is considered substantially depleted (NAMMCO 2008, Heide-Jørgensen et al. 2010b, NAMMCO/JCNB 2015). However, the abundance of belugas has increased due to reduction of catches in compliance of catch quotas, and because the ice edge habitat used by belugas has moved further away from human settlements (Heide-Jørgensen et al. 2016). Because of the population recovery, beluga whales in West Greenland have gone from *Critically Endangered* (Boertmann 2007) on the Greenland Red List to *Vulnerable (Boertmann & Bay 2018)*. On a global scale, the beluga is categorised as *Lest Concern* (Lowry et al. 2017).

*Critical and important areas:* Belugas are found in the upper northern part of the assessment area, but the main distribution is further north.

**Narwhal, *Monodon monoceros***

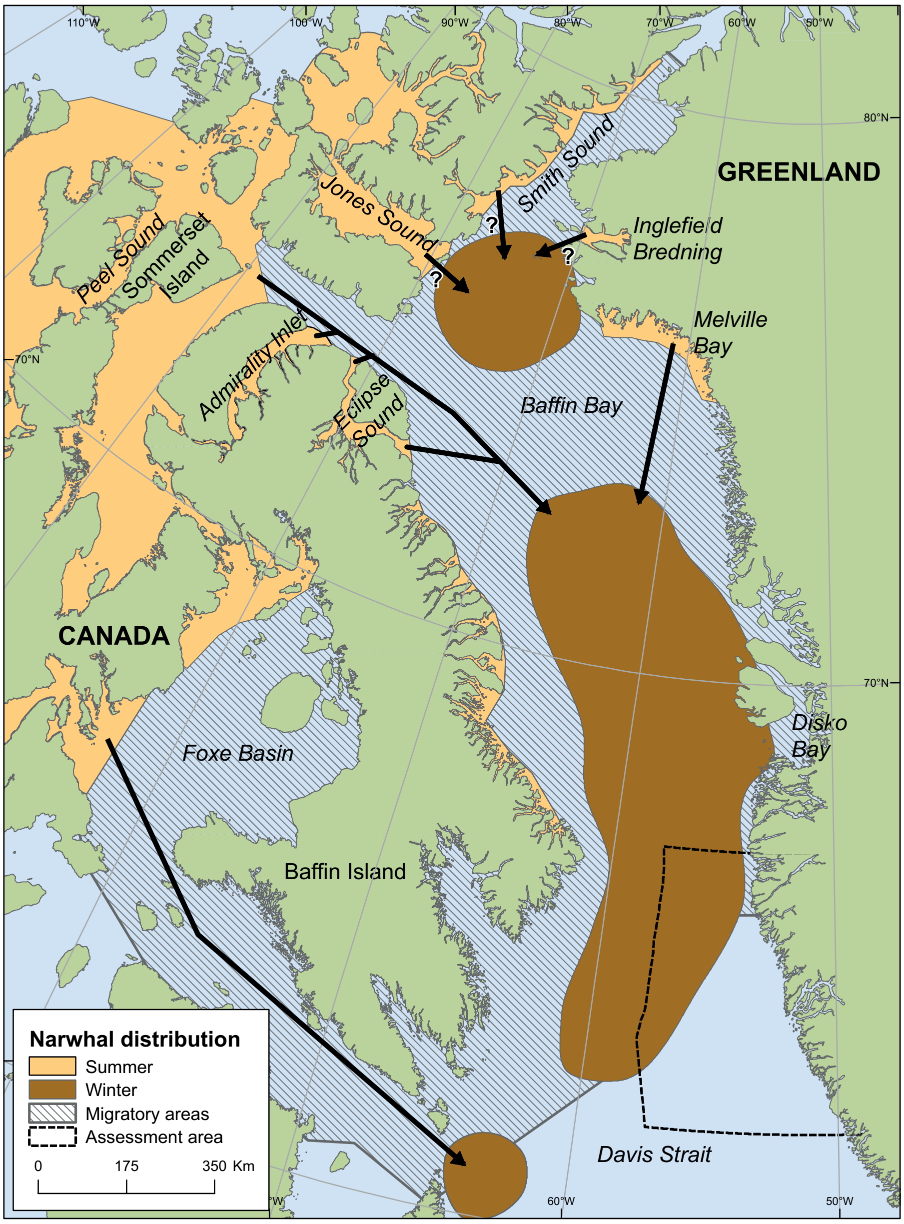
*General biology:* Narwhals are Arctic cetaceans, that spend almost half of the year in heavy pack ice and darkness (Laidre & Heide-Jørgensen 2011). They are a medium-sized toothed whale that, along with the beluga, are the only members of the family Monodontidae. Adult male narwhals reach lengths of up to 560 cm and weights of 1645 kg, the females being ca. 2/3 of the male weight (Garde et al. 2015). They feed primarily on Greenland halibut but also on other species of Arctic fish and squid (Laidre & Heide-Jørgensen 2005). Intense benthic feeding behaviour has been documented for narwhals on their winter feeding grounds and suggests that a major portion of the annual energy intake is obtained on these winter feeding grounds (Laidre et al. 2004, Laidre & Heide-Jørgensen 2005). Hence, the wintering grounds are critically important habitat for narwhals (Laidre et al. 2008).

*Distribution and movements:* In Greenland and Canada, narwhals undertake seasonal migrations between coastal summer grounds and offshore wintering grounds (Dietz & Heide-Jørgensen 1995, Laidre & Heide-Jørgensen 2005, Dietz et al. 2008, Heide-Jørgensen et al. 2015). Narwhals display a high degree of site fidelity to summering and wintering grounds and individuals tagged with satellite transmitters migrated between summering grounds in Arctic Canada or Melville Bay and wintering grounds in central Baffin Bay and western Davis Strait (op cit.).

A recent study has documented the narwhals physiological escape response to different levels of disturbance from net entanglement and handling (Williams et al. 2017). Short handling times (<60 min) resulted in "normal" flight behaviour upon release including linear increased heart rate with stroke frequency (fluke locomotion). However, long handling times (100-165 min) were followed by an elevated stroke frequency without the increased heart rate resulting in a high metabolic cost. This type of cognitive control of the heart rate has been documented in pinnipeds and cetaceans, and a key benefit under normal conditions is oxygen conservation when submerged (Ridgway et al. 1975, Elmegaard et al. 2016, Williams et al. 2017). Narwhals use this behaviour to avoid threats such as killer whales by relying on slow movements and sinking to depths beneath the cover of ice or moving to shallows unreachable by pursuing predators. Thus, when exposed to novel anthropogenic disturbances, narwhal physiology seems to counteract the otherwise obvious choice of adjusted heart rate and strike frequency, potentially resulting in fatal outcome.

Seismic survey activity in Baffin Bay in 2008 have been causally linked to three large ice entrapments of narwhals in Canada and North Greenland (Heide-Jørgensen et al. 2013). The authors were concerned that the offshore seismic

Figure 3.8.8. Main summer and winter grounds of narwhals in West Greenland and the Eastern Canadian Arctic. Narwhals can be found along the whole northwest coast of Greenland during migration between winter and summer grounds. Map modified from Hobbs et al. (In press)




activity caused the narwhals to delay their offshore winter migration thus becoming lethally entrapped by rapidly forming fast ice.

*Abundance and conservation status:* The northern part of the assessment area may overlap with the southern part of narwhal wintering grounds. There are about 18,000 narwhals wintering in a relatively small area in the offshore pack ice (Laidre & Heide-Jørgensen 2011). These narwhals can be found at extremely high densities (average 77 narwhals $km^2$ open water in 2008) in leads in dense pack ice (Laidre & Heide-Jørgensen 2011). There were approximately 18,500 narwhals in the wintering ground in West Greenland in 2012 (Heide-Jørgensen et al. 2010c, NAMMCO/JCNB 2015). As mentioned above, the narwhals wintering in or close to the assessment area come from a number of summering grounds in Arctic Canada and Northwest Greenland, including Melville Bay. It is estimated that up to 120,000 narwhals winter in Baffin Bay, including animals from the, listed by NAMMCO, vulnerable stock in Melville Bay (NAMMCO 2018a).

Due to intense hunting in the past, the stocks of narwhals in West Greenland have been under great pressure and narwhals are considered as *Near Threat-*

*ened* on the Greenland Red List (Boertmann & Bay 2018). Catches from the Melville Bay stock are still considered unsustainable (GINR 2019). On a global scale, narwhals are abundant and are placed in the category *Least Concern* on the IUCN Red List (Lowry et al. 2017).

*Critical and important areas:* Narwhals are found in the upper northern part of the assessment area, but the main distribution is further north.

**Northern bottlenose whale, *Hyperoodon ampullatus***
*General biology:* This species is found only in the North Atlantic, where they inhabit deep waters off the continental shelf and submarine canyons (Jefferson et al. 2008). These 7-9 m long whales dive as deep as 1,400 meters (Hooker & Baird 1999). They forage primarily on squid (e.g. Lick & Piatkowski 1998), but their diet includes other invertebrates and fish. They live in groups where some individuals may form long-term associations (Gowans et al. 2001). Bottlenose whales are present in Greenland during summer (Mosbech et al. 2007a) and are common in the assessment area.

*Distribution and movements:* The species has been poorly studied in Greenland and abundance, distribution and seasonality patterns along the west coast of Greenland are unknown. To our knowledge, the only place where bottlenose whales have been studied in detail is off Nova Scotia, Canada, where they show high site fidelity, relatively small home range and little genetic exchange with other areas (Hooker et al. 2002, Whitehead & Wimmer 2005, Dalebout et al. 2006). All these factors make bottlenose whales vulnerable to the effect of human activities.

*Abundance and conservation status:* No abundance estimate exist for bottlenose whales in Greenland and due to the scarce knowledge on bottlenose whales in Greenland and globally, 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* on both the Greenland Red List and the IUCN Red List (Taylor et al. 2008, Boertmann & Bay 2018).

*Critical and important areas:* As bottlenose whales are poorly studied in Greenland it is not possible to point out critical and important habitats for this species within the Davis Strait assessment area. However, the shelf breaks and the deep offshore waters are probably important habitats for this species.

# 4 Protected areas and threatened species

*David Boertmann & Daniel Clausen(AU)*

## 4.1 International nature protection conventions

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). The purpose of the executive order is to ensure the conservation status for nature and wildlife within the Ramsar areas and were incorporated in the national conservation legislation in 2016 (Link). A single Ramsar site is situated within the assessment area, the fjord Ikkattok and adjacent archipelagos near Paamiut (Egevang & Boertmann 2001) – see Fig. 4.1.1 and this Link.

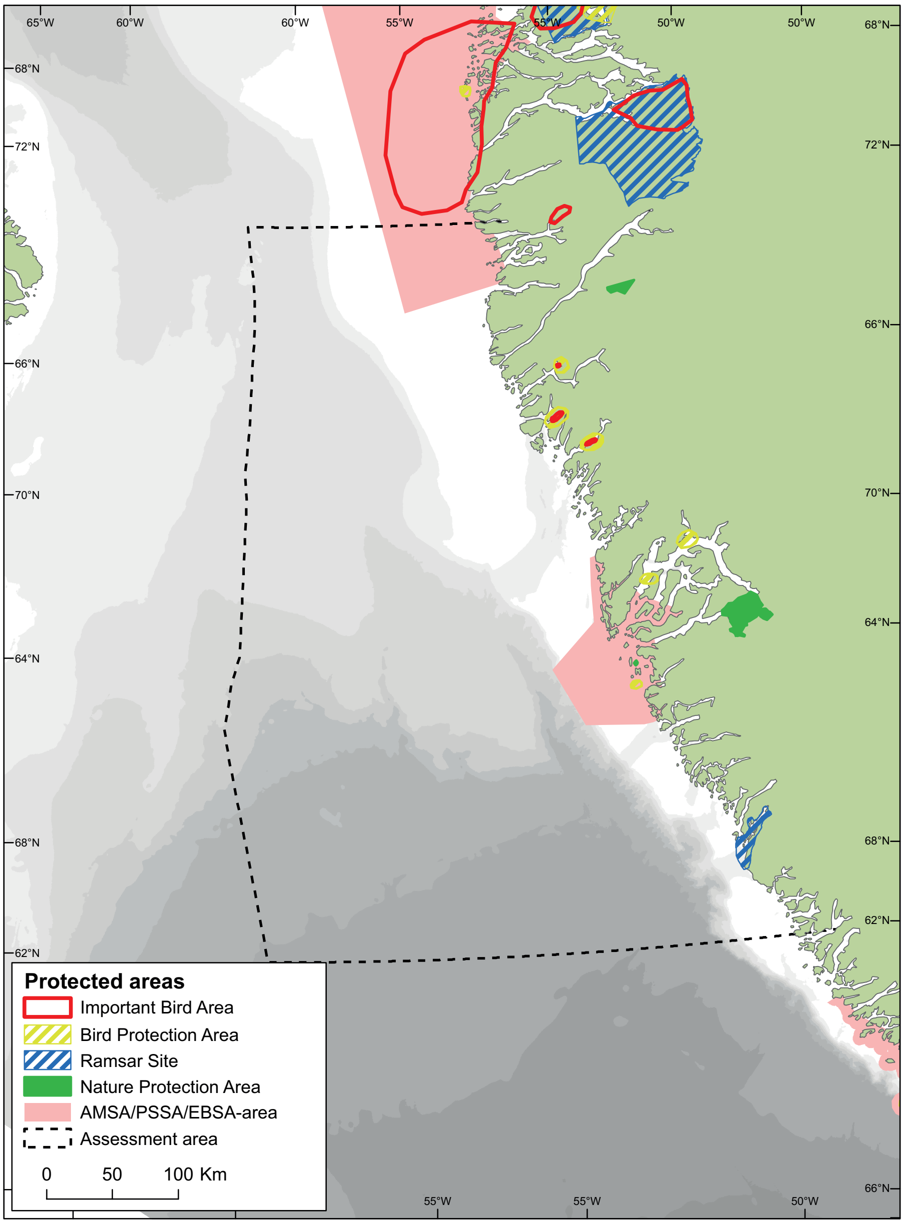



**Figure 4.1.1.** Areas within or near the assessment area protected according to national legislation or international conventions.

**Table 4.3.1.** Species evaluated as threatened or near threatened on the national red list of Greenland (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) |
| Sei whale | Endangered (EN) |
| Blue whale | Vulnerable (VU) |
| Beluga whale | Vulnerable (VU) |
| Narwhal | Near threatened (NT) |
| Sperm whale | Vulnerable (VU) |
| Great northern diver | Near threatened (NT) |
| Light-bellied brent goose | Vulnerable (VU) |
| Greenland white-fronted goose | Endangered (EN) |
| Gyr falcon | Vulnerable (VU) |
| White-tailed eagle | Vulnerable (VU) |
| Sabines gull | Near threatened (NT) |
| Black-legged kittiwake | Vulnerable (VU) |
| Ivory gull | Vulnerable (VU) |
| Arctic tern | Near threatened (NT) |
| Thick-billed murre | Vulnerable (VU) |
| Common murre | Endangered (EN) |
| Atlantic puffin | Vulnerable (VU) |
| Atlantic salmon* | Vulnerable (VU) |

* Local stock spawning in a single river in Nuuk fjord system.

## 4.2 National nature protection legislation

Only three areas protected under Greenland nature protection legislation are located within the assessment area. However, two of these are inland sites and will not be affected by offshore oil activities. The third site is the island of Akilia near Nuuk (Order no. 19 of November 1, 1998), which is close to the outer coast and protected due to geological interest (Fig. 4.1.1).

Seven sites within the assessment area are protected as Bird Protection Areas under the executive order about protection of birds (The Government of Greenland's Executive Order No. 17 of October 28, 2019 on the protection and capture of birds). But this order also states that in general all seabird breeding colonies are protected from disturbing activities (see maps showing seabird breeding colonies within the assessment area in Chapter 3.7). According to the Mineral Extraction Law, a number of areas are designated as 'areas important to wildlife' and here mineral (and hydrocarbon) exploration activities are regulated in order to protect wildlife. There are several of these areas important to wildlife within the assessment area and they also include the most important seabird breeding colonies. The areas important to wildlife can be found via this Link under Marine Mammals Protection Areas, Terrestrial Important Areas and Bird Important Areas.

**Table 4.3.2.** Species of national responsibility and endemic subspecies occurring in the assessment area.

| National responsibility species |
|---|
| Narwhal |
| Walrus |
| Polar bear |
| Light-bellied brent goose |
| Greenland white-fronted goose (endemic subspecies) |
| Mallard (endemic subspecies) |
| Common eider |
| Iceland Gull (endemic subspecies) |
| Black guillemot |
| Little auk |
| **Species with isolated population in Greenland (endemics not included)** |
| Great cormorant |
| Red-breasted merganser |
| Harlequin duck |
| White-tailed eagle |
| Harbour seal |
| Atlantic salmon (local spawning stock) |

## 4.3 Threatened species

Greenland has evaluated flora and fauna according to risk of extinction (Boertmann & Bay 2018), following the IUCN redlist system (Link). Among the fish, bird and marine mammal species occurring in the assessment area there are several that are in the categories of threatened species (Tab. 4.3.1).

National responsibility species are species of which the Greenland population constitute a significant part (20%) of the global population, and their global survival is dependent on a favourable conservation status in Greenland. Endemic species or subspecies are also of national responsibility as the total global population is found within Greenland. Those occurring in the assessment area are listed in Tab. 4.3.2.

The International Union of Nature Conservation (IUCN 2020) lists the species which are globally threatened. See Tab. 4.3.3 for the species occurring within the assessment area.

## 4.4 Other international 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 (Fig. 4.1.1). These areas are designated using a large set of criteria, for example, that at least 1% of a bird population should occur in the area. For further information, see the IBA website (Link). Some of the IBAs are included in or protected by the national regulations, for example as seabird breeding sanctuaries, but many are without protection or activity regulations.

As a follow up to the Arctic Marine Shipping Assessment (AMSA), conducted by the Arctic Council working group Protection of The Arctic Marine Environment (PAME 2009), Arctic Council decided to identify areas of heightened

**Table 4.3.3.** Species occurring in the assessment area and listed as globally threatened or near threatened (IUCN 2020).

| Species | Redlist category |
|---|---|
| Long-tailed duck | Vulnerable (VU) |
| Common eider | Near Threatened (NT) |
| Ivory gull | Near Threatened (NT) |
| Razorbill | Near Threatened (NT) |
| Atlantic puffin | Vulnerable (VU) |
| Polar bear | Vulnerable (VU) |
| Walrus | Vulnerable (VU) |
| Hooded seal | Vulnerable (VU) |
| Fin whale | Endangered (EN) |
| Sei whale | Endangered (EN) |
| Blue whale | Endangered (EN) |
| Sperm whale | Vulnerable (EN) |
| Narwhal | Near Threatened (NT) |
| Beluga whale | Near Threatened (NT) |
| Sperm whale | Vulnerable (EN) |

ecological and cultural significance in the Circumpolar Arctic. It was decided to use the International Marine Organization (IMO) criteria to identify Particular Sensitive Sea Areas (PSSA) in this work. According to the AMSA, the identification can be used by the states, taking into account the special characteristics of the Arctic marine environment, and explore the need for internationally designated areas for the purpose of environmental protection related to impacts of increased shipping due to the climate changes. Two AMSA-areas are within the Davis Strait assessment area, see Fig. 4.1.1 (AMAP/CAFF/SDWG 2013).

# 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 hydrocarbon exploration and exploitation is important, mainly as a baseline for monitoring the potential contamination of the environment from these activities.

There exists relatively 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, and will be included in the following overview as proxy for the expected general level of contamination stress in the assessment area.

Table 5.1.1. 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 wolfish | 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 |
| Maine mammals | | | | | |
| Ringed seal (1 year old) | Muscle | 0.029 | 0.068 | | |
| Ringed seal (1 year old) | Liver | 0.366 | 0.229 | | |

**Table 5.1.2.** Mean concentrations (µg/g wet weight) of Cd, Hg and Se in biota sampled in Qeqertarsuaq, Disko Island, found in the AMAP monitoring programme (unpublished data).

| 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 |

### 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 e.g. 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 Webster et al. (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 a 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 (1997). 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).

Tab. 5.1.1 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 Tab. 5.1.2.

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 (Tab. 5.1.2) no large differences are notable. In a study covering the period from 1994 to 2018 a significant increase 6.6% annually was found in sculpin from Qeqertarsuaq, while no trend was found in ringed seals from the same area (F. Rigét, unpublished).

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 has levels of 2.33 and 6.28 mg/kg wet weight, respectively (Tab. 5.1.2). During the period from 1994 to 2018 no temporal trend was found of Cd concentrations in sculpins and ringed seals from Qeqertarsuaq (F. 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 (Tab. 5.1.1). 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.

### 5.1.2 Persistent organic pollutants (POPs)

Persistent organic pollutants (POPs) have a long lifetime in the environment, and therefore have the potential to be transported over long distances. Most of the total quantity of POPs found in the Arctic environment is derived from the industrialised southern regions (AMAP 2010a). POPs 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 hydrocarbon exploration and exploitation constitute a risk of local contamination of POPs. POPs 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 POPs 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 POPs and the POPs Protocol to the Convention on Long-range Trans-boundary Air Pollution. Many of these POPs show declining concentrations in Arctic biota (Rigét et al. 2019), e.g. dichlorodi-phenyl-trichloroethane (DDTs), drins (aldrin, endrin and dieldrin), polychlorinated biphenyls (PCBs) and chlordanes. North of the assessment area, in Qeqertarsuaq, declining levels of these compounds have been observed in ringed seals (Rigét et al. 2013). In human blood from the Arctic including from people living in the Disko area most POPs 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 high enough that certain species, including many top predators, may be at risks for biological effects from these compounds (AMAP 2018b). POPs are also found in human maternal blood indicating foetus exposure and possible influencing foetus development (Long et al. 2015).

Levels of POPs concentrations (ng/g lipid weight) in biota from Qeqertarsuaq are summarized in Tab. 5.1.3.

The levels of POPs are generally decreasing in the order ∑PCB > ∑DDTs > ∑CHLs > Toxaphene > HCB > ∑HCHs, as also seen in marine biota from Disko (Tab. 5.1.3). In general, the levels of POPs found in biota from West Greenland are lower than in biota from East Greenland (Rigét et al. 2015).

Polybrominated diphenyl ethers (PBDEs) is a group of POPs, 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 PBDEs in both animals and humans are

**Table 5.1.3.** Recent mean concentrations (ng/g lipid weight) of POPs in biota from Disko. Data from the AMAP monitoring programme.

| POPs mean conc. | 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 | F. Rigét, unpublished |
| $\sum_{10}$PCB | 1994 | Glaucous gull liver | 469 | Cleemann et al. (2000a) |
| $\sum_{10}$PCB | 1994 | Icelandic gull liver | 37.9 | Cleemann et al. (2000a) |
| $\sum_{10}$PCB | 2016 | Ringed seal blubber | 131 | Rigét, unpublished |
| ∑DDTs | 1994 | Blue mussel soft tissue | 0.24 | Cleemann et al. (2000b) |
| ∑DDTs | 2001 | Black guillemot egg | 435[1] | Rigét, unpublished |
| ∑DDTs | 1994 | Glaucous gull liver | 396 | Cleemann et al. (2000a) |
| ∑DDTs | 1994 | Icelandic gull liver | 35.8 | Cleemann et al. (2000a) |
| ∑DDTs | 2016 | Ringed seal blubber | 176 | Rigét, unpublished |
| HCB | 1994 | Blue mussel soft tissue | 0.027 | Cleemann et al. (2000b) |
| HCB | 2001 | Black guillemot egg | 228 | Rigét, unpublished |
| HCB | 1994 | Glaucous gull liver | 32 | Cleemann et al. (2000a) |
| HCB | 1994 | Icelandic gull liver | 11 | Cleemann et al. (2000a) |
| HCB | 2016 | Ringed seal blubber | 11.3 | Rigét, unpublished |
| ∑HCH | 1994 | Blue mussel soft tissue | 0.39 | Cleemann et al. (2000b) |
| ∑HCHs | 2001 | Black guillemot egg | 54.9 | Rigét, unpublished |
| ∑HCHs | 1994 | Glaucous gull liver | 3.2 | Cleemann et al. (2000a) |
| ∑HCHs | 1994 | Icelandic gull liver | 1.4 | Cleemann et al. (2000a) |
| ∑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

much lower than the above mentioned POPs, 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 (Tab. 5.1.3). This temporal pattern is different from several other trend patterns found in Arctic biota, where the levels have increased until the mid-2000ies, after which concentrations have either decreased or stabilized (Rigét et al. 2019).

Perfluorinated alkylated substances (PFASs) are another group of compounds which is very persistent in the environment. In biota and humans, PFASs bind to blood proteins and, therefore, bioaccumulate mainly in liver, kidneys and bile secretions in contrast to most other POPs which are lipophilic.

Perfluorooctane sulphonate (PFOS) is usually found in much higher concentrations compared to other fluorinated compounds in Arctic wildlife. The largest producer of PFOS, the 3M US company, announced in 2000 it would phase out its production. PFOS was banned in the EU in June 2008, and in 2009 PFOS was included in the Stockholm Convention on POPs. 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). Just north of the assessment area, in Qeqertarsuaq, this has been observed in ringed seals where 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. 2013). However, in blood from Greenlanders from Nuuk, West Greenland PFOS have increased in the period from 1998 to 2005 (Long et al. 2015).

### 5.1.3 Persistent 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, as in the case of Sisimiut within the assessment area (Villumsen & Ottosen 2006) and around 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 2017a). 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 (PAHs), which originate from two main sources: combustion (pyrogenic) and crude oil (petrogenic). PAHs represent the most toxic fraction of oil, they have serious long-term environmental effects and are released to the environment through oil spills and discharge of produced water (see also Chapter 6). Sixteen PAHs are included on the lists of priority chemical contaminants by the World Health Organization and the U.S. Environmental Protection Agency (EPA), and PAHs are ranked as high priority substances in the European Water Framework Directive (Directive 2000/60/EC) (European Commission 2001).

Levels of petroleum hydrocarbons (incl. PAHs) are generally low in the Arctic marine environment and often close to background concentrations, except in areas with anthropogenic impact such as harbours. Presently, the majority of petroleum hydrocarbons in the Arctic originate from natural sources such as seeps (Skjoldal et al. 2007).

Total petroleum hydrocarbons (TPH) and PAH levels were measured at 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

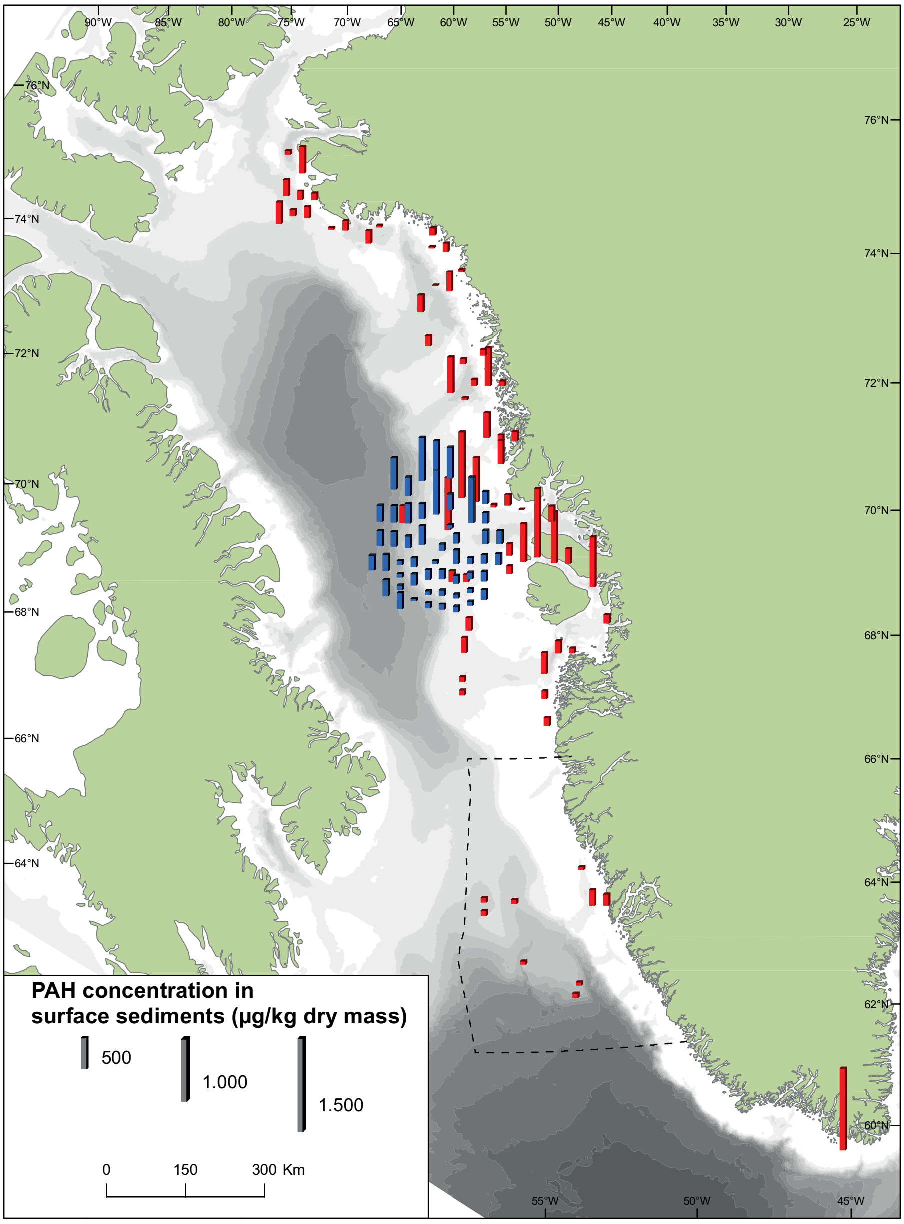



**Figure 5.1.1.** Polycyclic aromatic hydrocarbon (PAH) concentrations (µg $kg^{-1}$ dry mass) in surface sediments (usually in the 0-1 cm) in western Greenland. Coloured bars indicate PAH concentrations and sampling carried out by different companies/institutions. Red bars indicate sampling by Aarhus University (Denmark) and blue bars by Capricorn (Cairn, Edinburgh). Note: Data includes 23 PAH compounds which are listed by the United States Environmental Protection Agency (EPA) as priority pollutants.

(Fig. 5.1.1) could probably be attributed to the Marrat oil seep, which has been studied some years ago (Mosbech et al. 2007a). In general, PAH levels seem to be low in sediments within the assessment area (Fig. 5.1.1)

### 5.1.5 Biological effects of contaminants in the Arctic

**POPs and mercury**

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The research and monitoring activities described in the previous section clearly indicate the presence of different kinds of contaminants (e.g. POPs and among those organohalogenated substances (OHCs) 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 POPs (OHCs) 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. 2018a) 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 OHCs, 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 PCBs on killer whale populations around the world including several Arctic subpopulations. It was 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 provided 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).

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 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 (Sonne et al. 2009, Dietz et al. 2015, Dietz et al. 2018a). 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 (Fig. 5.1.2, 5.1.3). Several hot spots were detected among 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. 2018b).

However, it was also concluded that there remain numerous knowledge gaps on the biological effects of exposure in Arctic biota. These knowledge gaps in-

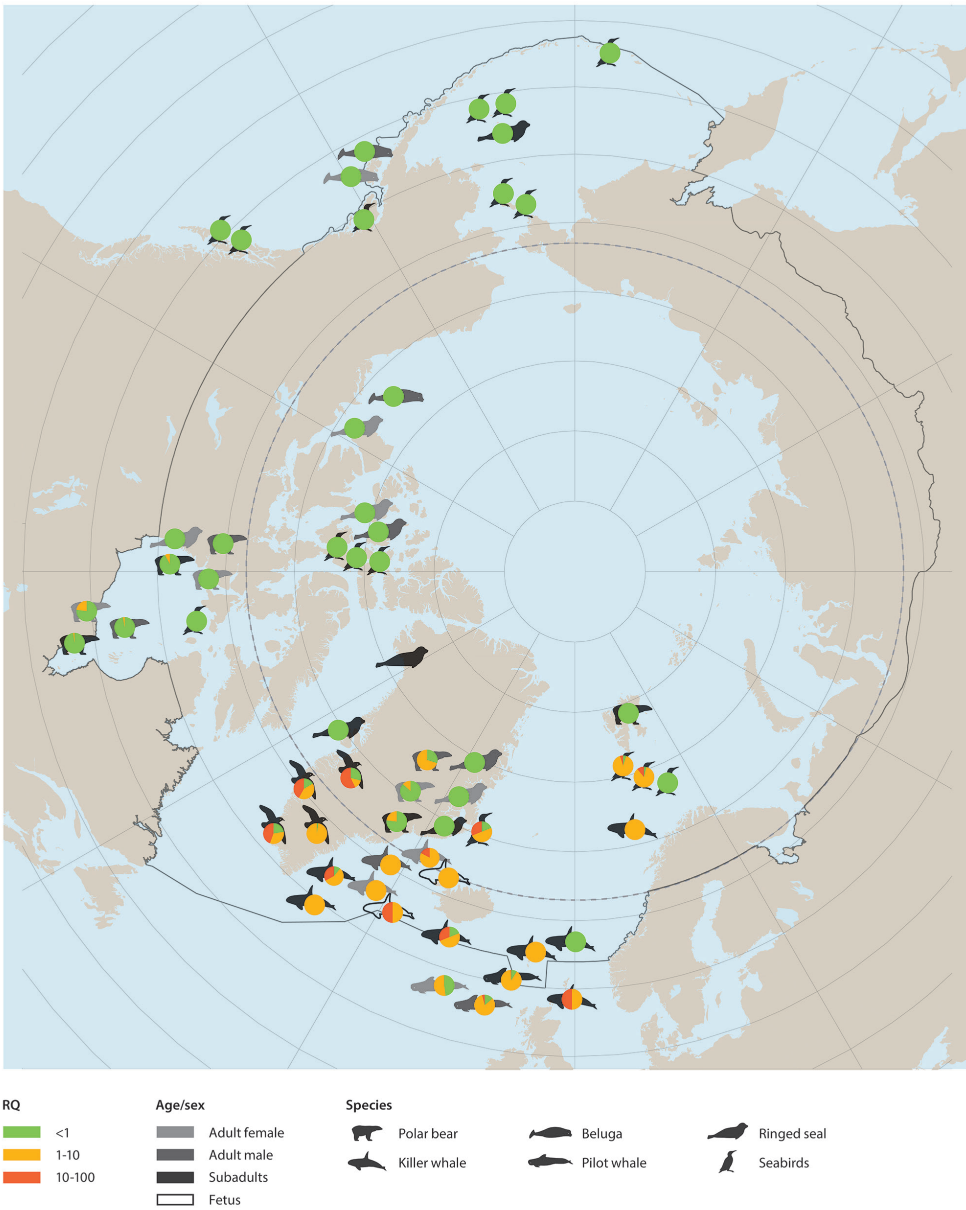



**Figure 5.1.2.** Risk quotients (RQs) for PCB-mediated effects on the immune and hormone systems based on post-2000 data of Arctic key species and their ΣPCB loads using a conservatively determined critical body residue of 10 µg/g lw PCBs (Dietz et al. 2019).

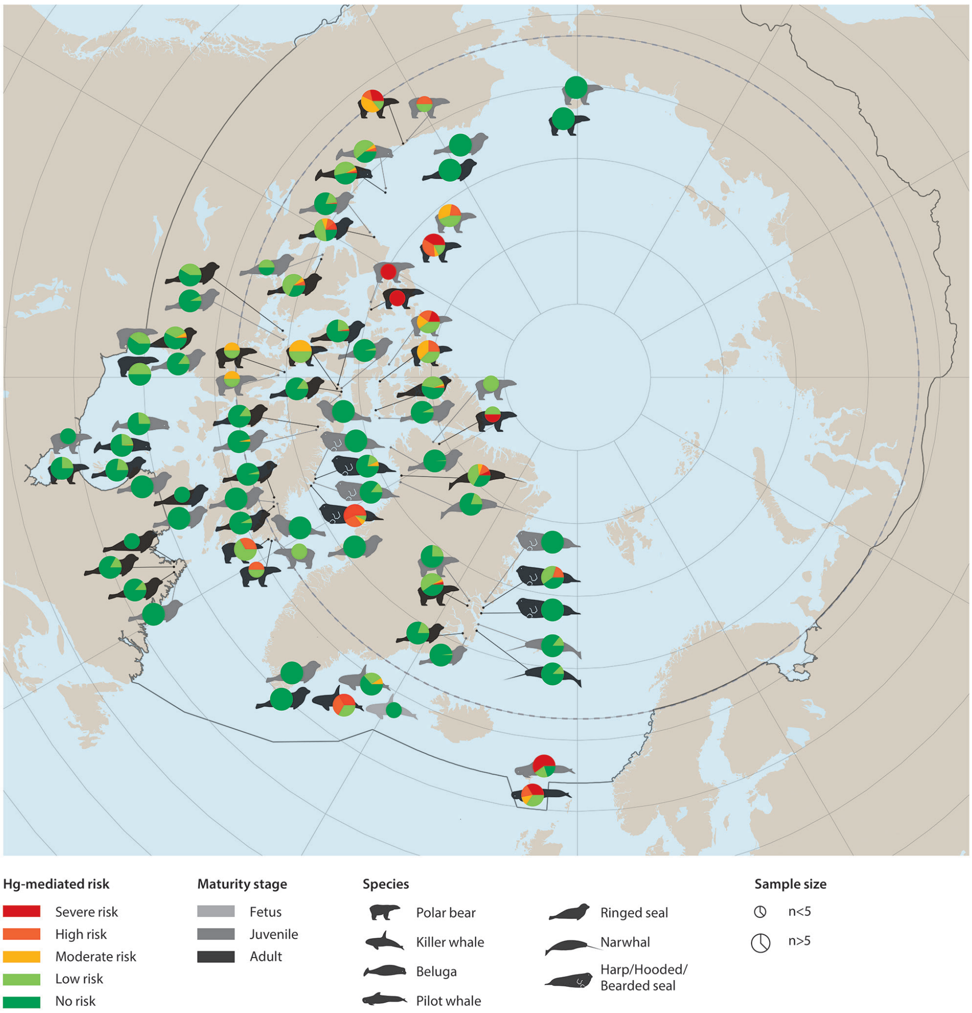



**Figure 5.1.3.** Geographical overview of the proportion of individuals of specific Arctic marine mammal populations that are at risk of Hg-mediated health effects; based on post-2000 monitoring data grouped according to maturity where possible (Dietz et al. 2019).

clude 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 assessments would benefit from significant efforts to integrate human health and 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 PAHs are more or less easily metabolised by invertebrates and generally efficiently metabolised by vertebrates such as fish (reviewed by Hylland 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 2006).

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 (Neff 2002, Hylland 2006).

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 (Mosbech 2002, Chapman & Riddle 2003, Chapman & Riddle 2005, Olsen et al. 2011). There is a particular need for toxicity data on early life stages, as they are most vulnerable (Short et al. 2003, Khan & Payne 2005, Frantzen et al. 2012). To some extent this data gap for PAH's and other toxic oil components has been addressed in recent years: polar cod (Nahrgang et al. 2016), capelin (Beirão et al. 2018, Beirão et al. 2019, Tairova et al. 2019), Calanus (Agersted et al. 2018, Toxværd et al. 2018a, Toxværd et al. 2018b, Skottene et al. 2019).

## 5.2 Plastic in the assessment area

*Jannie F. 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 et al. 2015, Halsband & Herzke 2019). It is assessed that on a global scale 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 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, Laist 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 macroplastics (>25mm). 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 et al. 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 plastic in the Greenland Sea, Fram Strait and Barents Sea (Bergmann et al. 2016, Cózar et al. 2017), on the seabed in Fram Strait (Parga Martínez et al. 2020), in seabirds, especially fulmars (see review by (PAME 2019, Baak et al. 2020) and whales (Panti et al. 2019). There is anecdotal evidence that also Polar bears ingest plastic.

Microplastic 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 in amphipods (Gammarus setosus, Iannilli et al. 2019), blue mussels (Sundet et al. 2016, Bråte et al. 2020), snow crabs (Sundet 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 dumpsites 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 source, because no efficient cleaning technology is installed. Other local sources are shipping and fisheries. 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 (Provencher et al. 2014, Strand et al. 2018). 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 Bürmeister, Helle Torp Christensen, Teunis Jansen, Adriana Nogueira, Anja Retzel, Rasmus Nygaard, Søren Post, Karl Zinglersen (GINR) & Georgina Scholes (AU)*

Commercial fisheries represent the most important export industry in Greenland, underlined by the fact that fishery products accounted for more than 90% of the total Greenlandic export revenue (4058 mill DKK) in 2018 (Statistics of Greenland 2018). The four most important species on a national scale are deep-sea shrimp (export revenue in 2018: 1,678 million DKK), Greenland halibut (1093 million DKK), Atlantic cod (350 million) and snow crab (85 million DKK) (Statistics of Greenland 2018). Greenland halibut, shrimp, snow crab and cod are also the main commercially exploited species within the assessment area. Lumpsuckers, wolffish, redfish and salmon are exploited in the more coastal regions of the area.

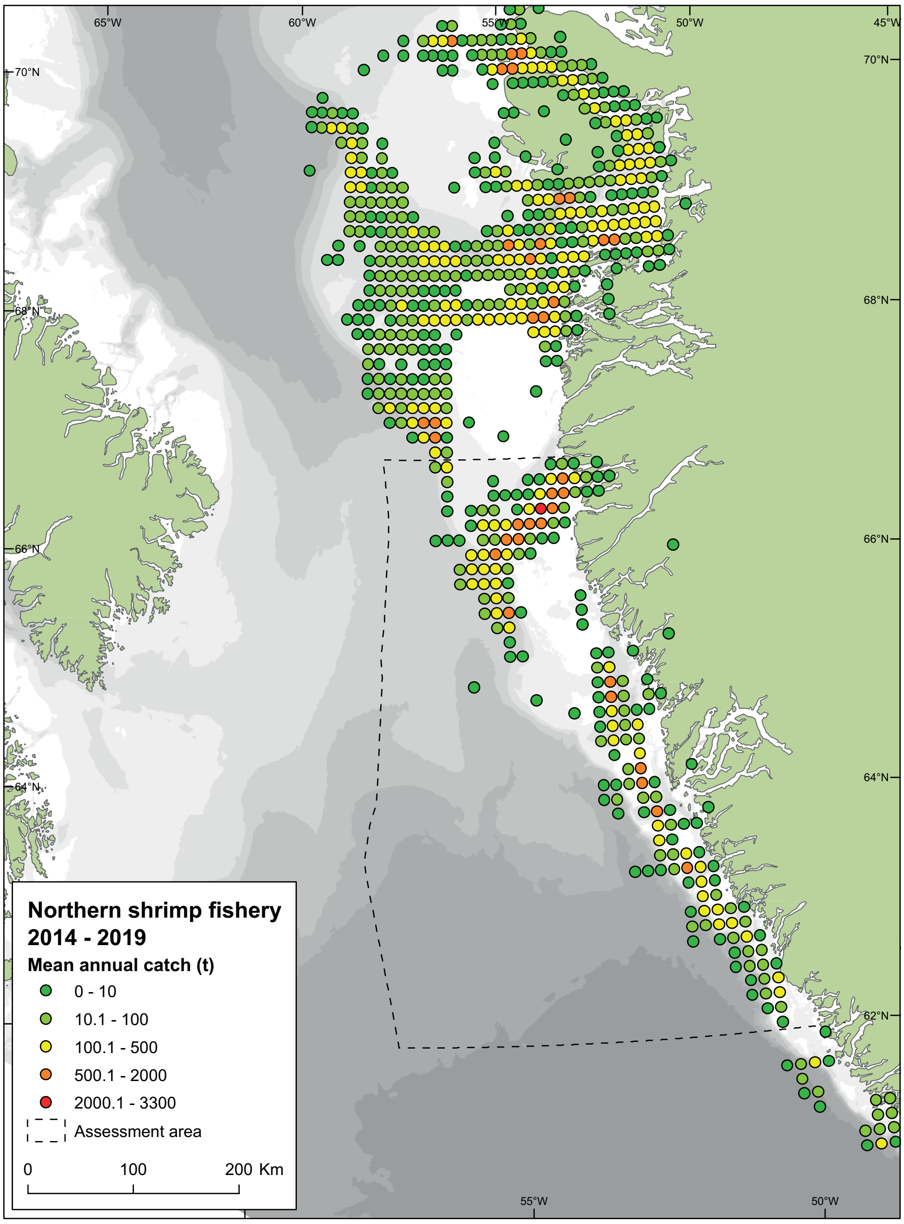
**Shrimp, *Pandalus borealis***

Northern shrimp is caught on the bank slopes and in Disko Bay. The fishery for shrimp began in inshore areas in 1935 as a small-scale fishery and it developed slowly to become a 150,000 tonnes fishery. The major part of the catch is taken by large modern trawlers, which process the catches onboard. The fishery extends from 59° 30'N to 76°N in West Greenland waters. The annual catch in 2018 was approximately 95,000 tonnes (Burmeister & Rigét 2019a) (Fig. 5.3.1). The assessment area holds very important grounds for the northern shrimp fisheries and between 50% and 70% of the annual catch was taken here from 1990 to the mid2010s. Over the past five years the average proportion of the annual catch taken from the assessment area has been considerably lower, ca. 20% of the total catches. The majority (more than 80%) of the catches and fishing effort has been conducted north of 66°N.

**Snow crab, *Chionoecetes opilio***

Snow crabs are important for communities in the assessment area. Fishing is permitted between 60°N and 74°N on the west coast of Greenland. The commercial fishery for snow crab started in 1996. Landings peaked in 2001 at approximately 15,000 tonnes, and the snow crab was at that time the third most important species in terms of total export income for Greenland. The assessment area is the most important snow crab fishing area and crabs are harvested both inshore and offshore, with only a few fjords left unexploited. The fishery is mainly situated along the inner and outer edges of the offshore banks from 62°N to 67°N, but also Holsteinsborg Dyb and Godthaabs Dyb are important fishing sites. Total catches in the assessment area peaked at approximately 9,500 tonnes in 2001 (Fig. 5.3.2). In the succeeding years catch declined substantially to approximately 1,500 tonnes in 2009 (Burmeister 2010). However, over the past five years annual catches of approx. 2,000 tonnes have been taken in the assessment area (Burmeister 2019).

**Figure 5.3.1.** Distribution and size of northern shrimp catches within and near the assessment area. Catch size calculated as the annual average for 2014-2019.

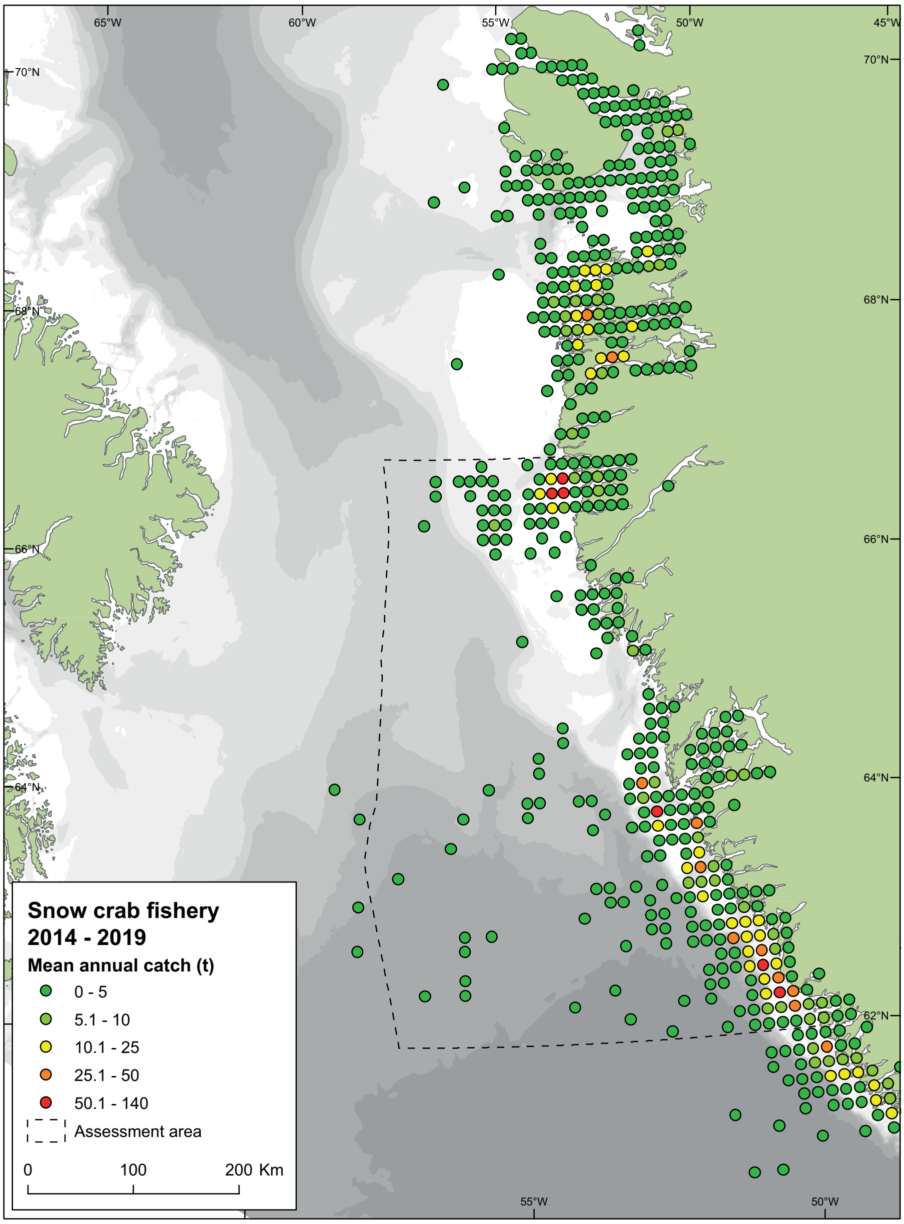



**Greenland Halibut, *Reinhardtius hippoglossoides***

During the period 2003-2009 annual catches of Greenland halibut in the Davis Strait were about 10,000-12,000 tonnes. Since 2010, catches have been increasing, reaching a high of about 17,000 tonnes in 2018 (NAFO 2019). Half of the catch is from Greenland waters (Fig. 5.1.3) and constitutes a significant proportion of the total Greenlandic catch of Greenland halibut. Most catches are taken within the assessment area. The other half of the catch is taken in Canadian waters close to the Greenland border. In recent years most of the catches in Greenland waters use bottom trawl apart from a very small fishery which uses longlines (2 boats, about 20 tonnes). The fishery has been distributed in the same way throughout the period (Fig. 5.3.3).

*Greenland halibut inshore exploitation:* Greenland halibut in the inshore areas of West Greenland are considered to be recruited from the offshore stocks of Greenland halibut in the Davis Strait (Riget & Boje 1988). In northern Greenland (north of 67°N) a large inshore fishery with total catches up till 25,000 tonnes (Nygaard et al. 2010). In the assessment area inshore fishery is mainly conducted in Nuup Kangerlua (the Nuuk fjord system). Since 2010 annual landings of Greenland halibut from Nuup Kangerlua has been around 1000

Figure 5.3.2. Distribution and size of snow crab catches within and near the assessment area. Catch size calculated as the annual average for 2014-2019.




t/yr. The landings of Greenland halibut in the other inshore areas south of Sisimiut has also increased during the most recent decade.

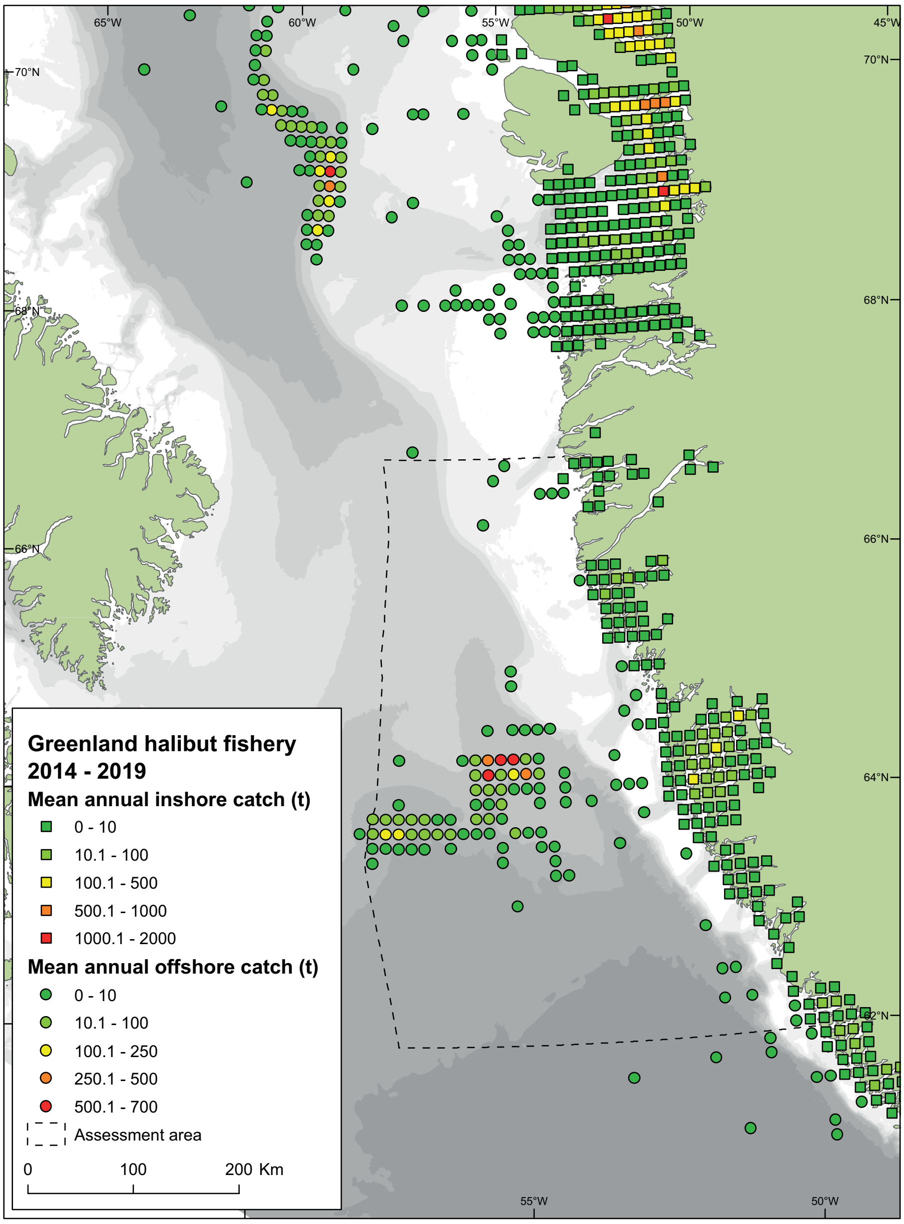
**Atlantic cod, *Gadus morhua***

In the assessment area cod fishery has been very important historically. The West Greenland commercial cod fishery started in 1911 in local fjords (Horsted 2000). In the 1920s the offshore fishery developed and total landings increased over the next few decades and then peaked in the 1960s with annual catches of some 350,000-500,000 tonnes. Spawning stock and water temperatures then decreased and in the late 1960s the stock collapsed (Buch et al. 1994). Except for a temporary improvement for cod during 1988-90 the stock remained at a very low level until early in 2000. Since the beginning of this millennium the Atlantic cod stock has improved and large spawning cod have been documented in East Greenland in 2007 (ICES 2010). In 2016 and 2017 total catches peaked with 50,000 tonnes but decreased thereafter (Fig. 5.3.4).

**Lumpsucker, *Cyclopterus lumpus***

Lumpsucker is caught commercially along the entire west coast of Greenland (Fig. 5.3.5). The fishery is mainly conducted using gillnets and takes place

Figure 5.3.3. Distribution and size of the Greenland halibut catches within and near the assessment area. Catch size calculated as the annual average for 2014-2019. Note that different scales apply to inshore and offshore catches.

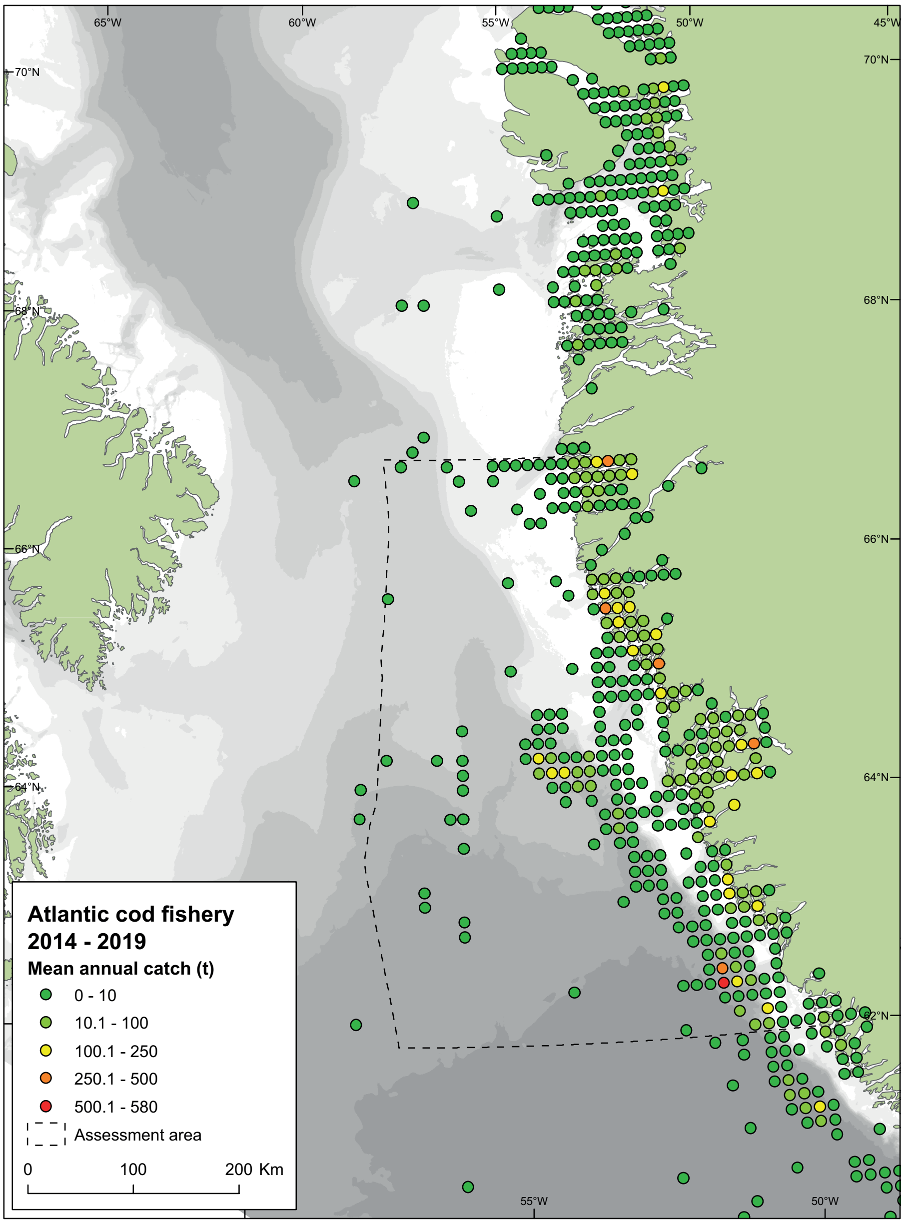



in spring and early summer when the fish move into shallow coastal waters to spawn (Kennedy et al. 2019). The roe is the commercial product and the total landings and individual landings in different areas varies considerably between years. Catches peaked in 2013, where roe landings exceeded 2,000 tonnes, but have since fluctuated around 1,000 tonnes (GINR, unpubl. data).

**Capelin, *Mallotus villosus***

Capelin is not fished commercially, but caught for local consumption. There have, however, been several trial fisheries targeting roe-bearing females, latest in 2007, but these have been unsuccessful in finding exploitable resources of capelin. In September 2005, an acoustic survey showed considerable concentrations of capelin in several Greenland fjords, including two in the assessment area (Bergstrøm & Vilhjálmsson 2006). Especially the Nuup Kangerlua (64°N) had high concentrations of capelin, whereas only small capelin concentrations were found outside the fjords along the Greenland west coast. However, yearly trawl surveys conducted by the Greenland Institute of Natural Resources along the coast show that some capelin migrate to the shelf area, where they presumably spend time from autumn to winter (Friis-Rødel &

**Figure 5.3.4.** Distribution and size of the Atlantic cod catches within and near the assessment area. Catch size calculated as the annual average for 2014-2019.




Kanneworff 2002). No other reliable capelin biomass estimates exist and the current stock status is unknown.

**Salmon, *Salmo salar***

The fishery for Atlantic salmon in Greenland waters began in 1960-62 and peaked in the early 1970s at a catch level of more than 2,000 tonnes a year (Jensen 1990). The fishery was quota regulated from 1972, but due to declining stocks NASCO agreed in 1998 that no commercial fishery for salmon should be allowed. Since then, the export of salmon from Greenland has been banned and the fishery has been limited to the amount that can be sold and consumed within Greenland. The coastal fishery constitutes a significant income for a few fishermen in each community. In 2019 reported landings amounted to 30 tonnes. Approximately half of the total catch of salmon in Greenland is caught in the assessment area.

**Redfish, *Sebastes mentella* and *Sebastes norvegicus***

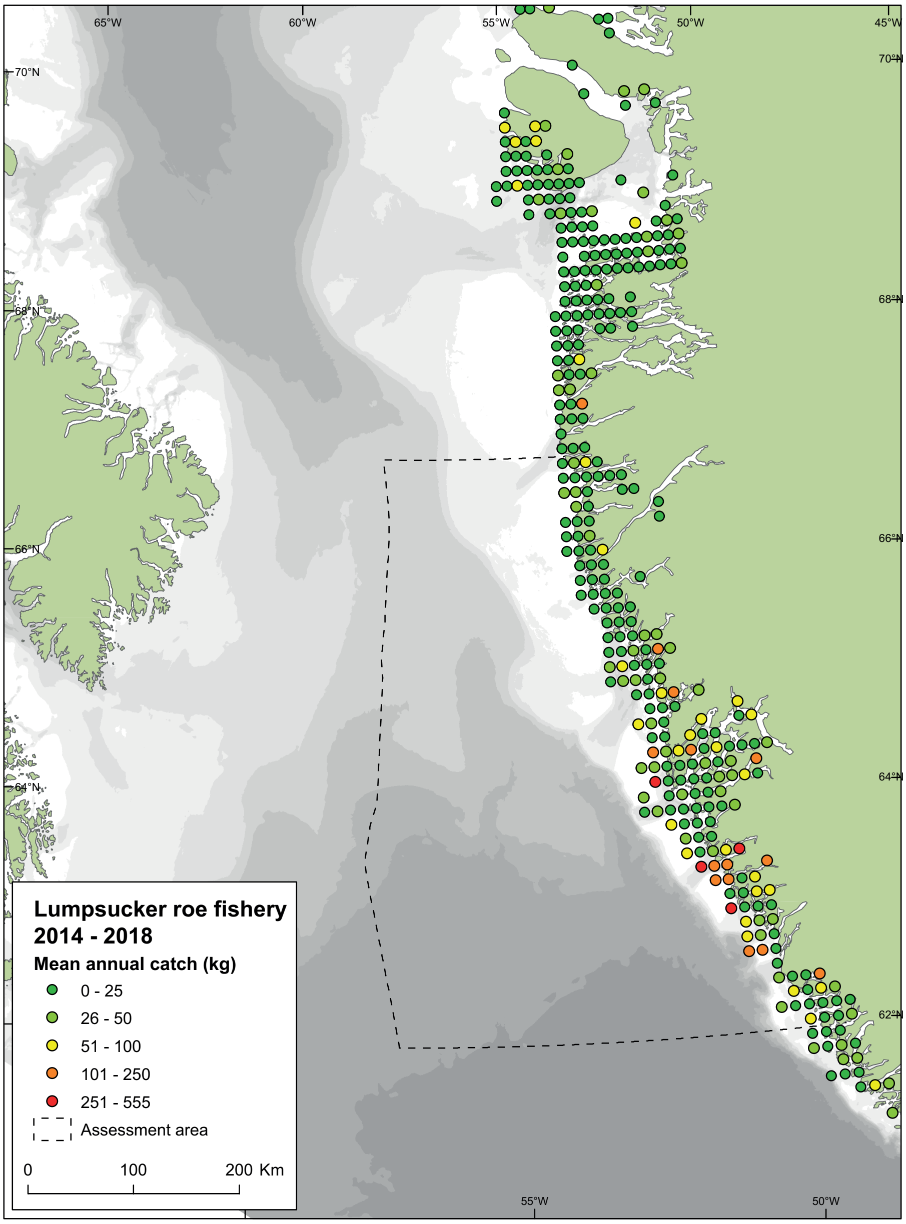



**Figure 5.3.5.** Distribution and size of the lumpsucker catches within and near the assessment area. Catch size calculated as the annual average for 2014-2019.

Official landings of redfish at West Greenland increased during the 1950s from a level of more than 10.000 tons and peaked in 1962 at more than 60.000 tons. During the recent three decades official landings, excluding potential bycatches in other fisheries, have been at a very low level and the stocks in West Greenland are considered depleted. Current advice is "no directed fishery". A small catch takes place inshore in the West Greenland fjords, but no specific catch statistics is available for the assessment area.

**Wolffish, *Anarhichas minor*, *Anarhichas lupus* and *Anarhichas denticulatus***
Catch statistics are currently not divided into species, but reported as wolffish sp. The commercial fishery for wolffish in West Greenland were around 3,000 to 5,000 t/yr. from the 1950s to the mid-1980s. With the failing cod fishery off West Greenland, trawlers started targeting Atlantic wolffish on the banks off West Greenland and from 1974-1976 reported landings from trawlers were around 3,000 tons per year. After 1980, catches of wolfish gradually decreased. In recent years, wolffish is mainly caught inshore, partly as bycatch in the longline or gillnet fishery for Greenland halibut and cod. Catches increased until 2014 to about 1000 t/yr. within the main areas from Disko Bay to the Maniitsoq area.

**Iceland scallop, *Chlamys islandica***

Iceland scallop is caught in shallow waters in the assessment area where currents are strong. Only one fishing boat is active in the fishery. Annual catches have been varying with an average below 625 tonnes over the past five years.

### 5.3.2 Subsistence and recreational fisheries and hunting

*Flemming Merkel & AnnDorte Bürmeister (GINR)*

Hunting and fishing are an integrated part of Greenlandic culture. Subsistence hunting is still of economic importance and recreational hunting and fishing activities make a significant contribution to private households. In Southwest and South Greenland, a large part of the subsistence fishing and hunting of marine mammals and seabirds has gradually developed into recreational activities.

Small-scale fishing and hunting are important activities in the assessment area, both in the larger towns, but especially in the smaller settlements where there are fewer options for alternative employment (Merkel et al. 2018). The income generated from commercial hunting, i.e., the local sale of meat and skin, is an important source of livelihood and as a supplementary food supply for hunters and their relatives (Rasmussen 2005). Hunting is considered to be a fundamental element of Greenlandic culture, and products such as skin, bones, antlers and teeth source material used in clothing, jewellery and art (Merkel et al. 2018).

A proportion of the catch presented above (Chapter 5.3.1) on commercial fisheries includes subsistence and recreational fisheries. Data on subsistence and recreational fisheries in Greenland are not separated. It is however assumed that the majority of Greenlanders participate and benefit from subsistence and recreational fisheries.

Many fish species are utilised on a subsistence basis, the most important are spotted wolfish, Greenland halibut, redfish, Atlantic cod, polar cod, Greenland cod, Arctic char, salmon and Greenland shark.

### 5.3.3 Bird hunting

*Flemming Merkel (GINR)*

Birds have historically played an important role as a supplement to hunting marine mammals, caribou and to fishing *(Merkel et al. 2018)*. The most important hunted bird species are thick-billed murre, common eider, king eider, little auk *and* black guillemot (Fig. 5.3.6 and 5.3.7).

Catches have been reported annually to Piniarneq, the official Greenlandic hunting statistics since 1993, and represent the major source of information on bird hunting. The data are generally not quality assured, but the reported numbers of birds are assumed to represent comparable indices of hunting over time. Since 1996, the reported catch of all species in the assessment area has been significantly reduced (Fig. 5.3.6 and 5.3.7). Within the assessment area, the number of reported common eider was reduced to from 33,000 to 11,000 from 2000 to 2002, when the hunting season was shortened by approximately two months, and has now stabilised around 10,000 birds annually. For the thick-billed murre the catches have decreased gradually over the past 20 years (Fig. 5.3.6).

**Figure 5.3.6.** Annual number of murres and common eiders hunted in West Greenland from Paamiut to Sisimiut (the assessment area) in the period 1996-2017. Data from Piniarneq/LULI, 9 December, 2019, Ministry of Fisheries, Hunting and Agriculture, Government of Greenland.

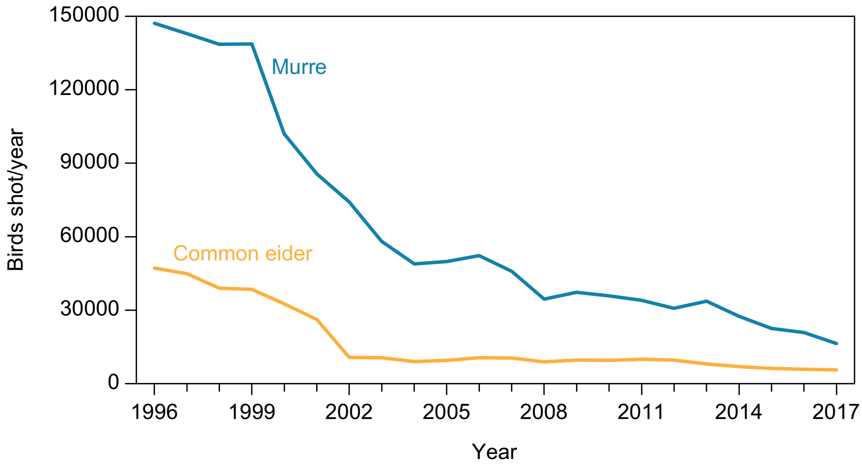
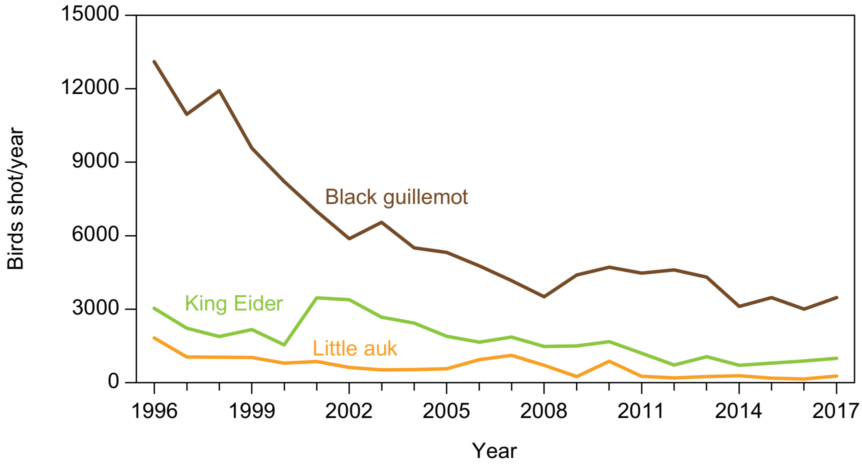



**Figure 5.3.7.** Annual number of king eider, black guillemot and little auk hunted in West Greenland from Paamiut to Sisimiut (the assessment area) in the period 1996-2017. Data from Piniarneq/LULI, 9 December, 2019, Ministry of Fisheries, Hunting and Agriculture, Government of Greenland.




Specific hunting seasons are established by the Department of Fisheries, Hunting and Agriculture and vary between species and region. For most species, the main hunting season in the assessment area is from 15 October to 1 March (15 March for common eider), but significantly shorter for the murres (1 November to 15 December). Daily quotas for the hunted species are 10 - 40 birds for commercial licences and 5 - 10 for recreational licences (Anon 2009).

### 5.3.4 Hunting of marine mammals

*Nynne Hjort Nielsen, Tenna Kragh Boye, Fernando Ugarte, Erik W. Born, Aqqalu Rosing-Asvid, Malene Simon, Karl Zinglersen (GINR) & Georgina E. Scholes (AU)*

**Seals**

Seals are important for both part-time and full-time hunters in the assessment area. Some skins are purchased and prepared for the international market by the tannery in Southwest Greenland, and the meat is eaten locally (Rosing-Asvid 2010b).

Harp seals are caught in large numbers (Fig. 5.3.8), especially young seals during summer (Fig. 5.3.9). In winter and early spring most of the West Atlantic harp seals congregate near the whelping areas around Newfoundland. However, a small fraction of the harp seals will stay in West Greenland throughout the year.

**Figure 5.3.8.** Catch statistics for seals in the assessment area, 1993-2016 (Data from Piniarneq/LULI, 20/3 2020, Ministry of Fisheries Hunting and Agriculture, Government of Greenland)

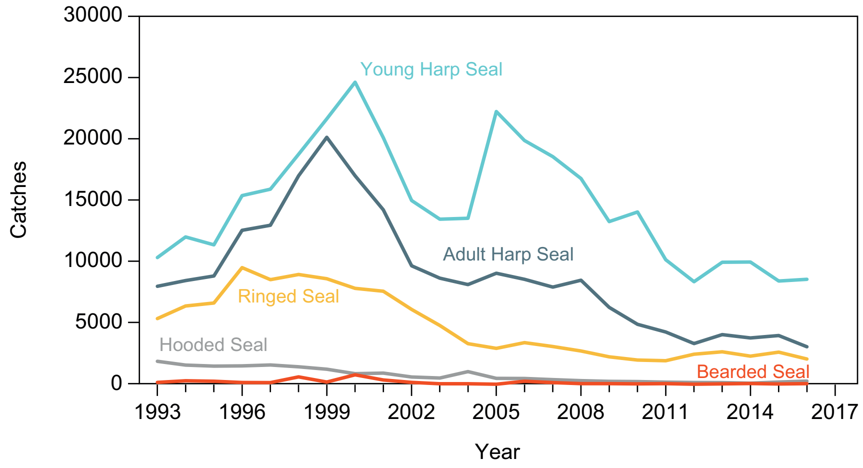
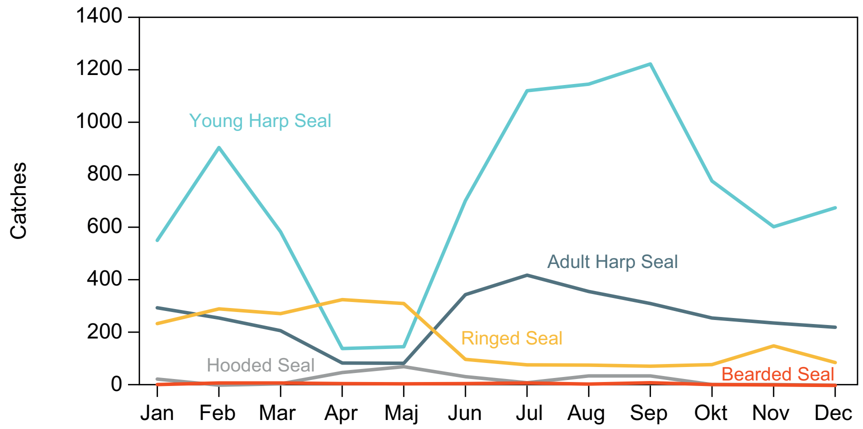



**Figure 5.3.9.** The seasonal distribution of the seal catches in the assessment area in 2016 (Data from Piniarneq/LULI, 20/03 2020, Ministry of Fisheries Hunting and Agriculture, Government of Greenland).




Hooded seal can also be caught throughout the year, but catches are highest during spring, just prior to and after whelping, when some of the hooded seals concentrate in the small whelping area close to the assessment area. The hunt also increases a little in the fall when post-moult seals migrate through the assessment area towards their main foraging areas in Davis Strait and Baffin Bay.

Catches of ringed seals and bearded seals increase during winter and spring when the Davis Strait pack ice approaches the coast.

**Catches (2012-2016)**

*Harp seal*: Average 14,927; range: 12,735 – 15,903

*Ringed seal:* Average 2,444; range: 2,091 – 2,680

*Hooded seals:* Average 193; range: 123 - 285

*Bearded seal:* Average 66; range: 35 – 95

*Harbour seal:* Protected against hunting

**Walrus**

Walruses are caught by Greenlandic subsistence hunters within the northern parts of the assessment area. Between 1 March and 30 April (both days included) it is allowed to hunt walruses from the West Greenland - Baffin Island (WG-SBI) subpopulation between 66° N (i.e. the tip of the south coast at the entrance to Kangerlussuaq/Søndre Strømfjord) and 70° 30′ N (i.e. northern tip of Qeqertarsuatsiaq/Hareøen) (Anon 2006, Wiig et al. 2014).

Since 2006 there have been quotas in Greenland for how many walruses can be killed annually (Anon 2006, 2019). During 2015-2019 the quota in West Greenland was 69 per year, but this was increased to 74 for 2020 (Anon 2019). For the 2020 hunting season the regional quota in the region of most relevance to the Davis Strait assessment area (i.e. Maniitsoq-Sisimiut) is 31 (Anon 2019).

The catch of walrus is reported by the hunters using two reporting systems "Piniarneq" and "Særmeldingskemaer" (i.e species-specific special reporting forms). For a description of these two systems cf. e.g. Born et al. (2017). Information provided by the hunters in the "Særmeldingskemaer" during 2007-2018 (data from 2018 only partial) about site of individual catches showed that hunters living in the municipalities of Maniitsoq, Sisimiut, Kangaatsiaq and Aasiaat take walruses at Store Hellefiskebanke (i.e. a little north of the assessment area), as well as farther north along western Disko Island (Garde et al. 2018a). The total removal of walruses from the WG-SBI subpopulation in 2017, 2018 and 2019 was 69, 91 and 99, respectively. These figures include estimates of struck-but-lost and removals from the shared WG-SBI subpopulation at Baffin Island, Canada. The catch reported in West Greenland alone in those two years were 35 and 61 walruses, respectively (GINR 2019).

During 1993-2012 the catches reported in the catch reporting system Piniarneq decreased significantly at Store Hellefiskebanke and along western Disko Island (Born et al. 2017). During an interview survey carried out in 2010, 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 (Ibid.).

According to the Særmeldingskemaer, the number of walruses caught at the Store Hellefiskebanke varied between 17 and 38 per year during 2007-2017 – i.e. after the quotas took effect. NAMMCO (2018b) and Garde et al. (2018a) stated that the catch reported in the Særmeldingskemaer for Store Hellefiskebanke has increased since 2007. However, inferred from data in Garde et al. (2018a: Tab. 11) the catch of walruses at Store Hellefiskebanke has not shown any statistically significant trend over the 2007-2017 or 2007-2018 period (simple regression analyses, results not shown; $R2 \leq 0.117$ or less, $P \geq 0.276$ or higher; this report).

Despite that the majority of walruses occur on the more northern parts of Store Hellefiskebanke, it cannot be excluded that exploration and exploitation activities south of there (i.e. in the assessment area) may negatively influence the walruses and therefore walrus hunting activity there.

**Polar bear**

Total annual quotas for the harvest from the DS population in Canada is 46 for Nunavut and 6 for Nunatsiavut (Newfoundland and Labrador). There is no quota in Nunavik (Quebec). In January of 2006, Greenland established a quota system. An annual quota of 2 bears was established for the Davis Strait population (Obbard et al. 2010). During 2017-2019, the average catch from the Davis Strait population in Canada was 58 polar bears per year, while in the Davis Strait area of Greenland it was one polar bear per year (GINR 2020).

It is not known if the polar bears caught in the Davis Strait area of Greenland belong to the Davis Strait population shared with Canada, or are vagrants moving north from South Greenland, originally from the East Greenland population.

**Baleen whales**

Minke whales, fin whales, bowhead whales and humpback whales are hunted in West Greenland and annual quotas are set every 7 years by the IWC (The International Whaling Commission) (Tab. 5.3.1). The Government of Greenland then divides the quota among the different municipalities. The latest IWC report gives quotas for aboriginal subsistence whaling in Greenland, for the years 2019-2025 (IWC 2018) (Tab. 5.3.1).

Fin whales, bowhead whales and humpback whales can only be hunted using harpoon cannons with explosive penthrite grenades (Anon 2010). Due to a lack of boats equipped with harpoon cannons in the northernmost parts of West Greenland, fin whales and humpback whales are normally taken in Disko Bay or further south. Bowhead whales are hunted only in Disko Bay. Most Minke whales are also taken with harpoon cannons, but a proportion of the quota is allocated to settlements with no harpoon vessels and allows for a 'collective hunt' from dinghies using high-calibre rifles.

Fin whales have been regularly hunted in West Greenland since the 1920s and minke whales since the 1940s. The quota for fin whales is 19 whales per year with the possibility of transferring up to 50 % of the unused quotas from one year to the next (IWC 2018). During 2016-2018, there was an average of 8 fin whales caught each year in West Greenland (Link).

The quota for minke whales for West Greenland is 164 whales per year (IWC 2010, 2018) of which 50 are allocated to 'collective hunt' from dinghies. In 2020, the quotas for minke whales was allocated to 15 towns and settlements, of which four are within the assessment area (APNN 2019c). In 2016 – 2018, an average of 132 minke whales were taken yearly in West Greenland (Link). In 2019, the total catch of minke whales reported in zones within the assessment area was 58 individuals (APNN 2019b). Most minke whale catches within the assessment area are females due to a sexual segregation in their summering feeding grounds, resulting in generally more females than males in West Greenland (Laidre et al. 2009).

Apart from a period between 1987 and 2009, humpback whales have been hunted in Greenland for centuries (Fabricius 1780). Ten humpback whales per year are allocated to hunters in West Greenland, of which an average of 4 were

**Table 5.3.1.** 2019-2025 quotas for the four species of baleen whales and the 2019 quotas for two species of toothed whales caught in West Greenland waters (APNN 2011, 2019a). Quotas for narwhal and beluga are described in Chapter 5.3.4. Catches of fin whales and humpback whales correspond to all West Greenland.

| Species | West Greenland quota | Quota in the assessment area | Catch in the assessment area in 2019 |
|---|---|---|---|
| Minke whale (*Balaenoptera acutorostrata*) | 164 | Open (12 for collective hunt) | 58 |
| Fin whale (*Balaenoptera physalus*) | 19 | Open | 8 |
| Humpback whale (*Megaptera novaeangliae*) | 10 | 6 | 4 |
| Bowhead whale (*Balaena mysticetus*) | 2 | 2 | 0 |
| Narwhal (*Monodon monoceros*) | 424 | 6 | up to 3[1] |
| Beluga whale (*Delphinapterus leucas*) | 340 | 41 | up to 24[1] |

[1]Including animals taken by hunters from Sisimiut, which could have been hunting north of the assessment area.

taken each year between 2016 and 2018 (Link). Of the quota of 10 humpback whales for 2020, three whales were given to the municipality of Qeqqata and three to Sermersooq, both within or close to the assessment area. Two humpback whales were given to the municipality of Qaasuisup, north from the assessment area and one to Kujalleq, south of the assessment area.

In 1927 the bowhead whale was protected from hunting. The population has now recovered to the extent that a quota of two animals per year has been approved by the IWC. Bowhead whales are caught in Disko Bay, north of the assessment area. Only 8 whales were caught in Greenland between 2009 and 2020, the last one in 2015.

**Toothed whales**

Eight species of toothed whales are hunted in Greenland and quotas have been implemented for two of these (narwhal and beluga). The Government of Greenland set the annual quotas, taking into consideration both the scientific advice from NAMMCO (the North Atlantic Marine Mammal Commission) and traditional ecological knowledge from local hunters.

Catches of narwhals and belugas are amongst the most important for the communities of Northwest Greenland (Heide-Jørgensen 1994). Sisimiut and Maniitsoq, in the northern part of the assessment area, are the southernmost places where narwhals and belugas are regularly caught. Large catches over several decades caused an apparent decline in the population sizes of the two species. In 2004, quotas were introduced by the Government of Greenland. The quotas for 2020 are 340 belugas and 410 narwhals (Tab. 5.3.1) (APNN 2019a). For Sisimiut and Maniitsoq, a total of 6 narwhals and 50 belugas were allowed to be harvested in 2020. Narwhal and beluga are the only toothed whales whose hunt is regulated by quotas in Greenland (Anon 2011).

Harbour porpoise, pilot whales, white-beaked dolphins , killer whales and perhaps bottlenose whales and white-sided dolphins are also hunted. The latter has the same common name in Greenlandic as white-beaked dolphins, which complicate registration of actual catches of these two species, however, the white-sided dolphin have a more southern distribution than white-beaked dolphin, thus the majority of the catches of these two species in the assessment area is most likely white-beaked dolphins.

Catches of these six species is unregulated, but from 1993 the catches of harbour porpoises were included in a national reporting system. Pilot whales and killer whales were included in the reporting system in 1996, and dolphins and bottlenose whales were added in 2003. The data is entered into a large database administrated by the Ministry of Fisheries, Hunting and Agriculture (APNN). The data presented below comes from this database. A validation of killer whale data from 1996 to 2007 showed that there are human mistakes in the reporting.

In the period from 1993-2018 an average of 2,239 harbour porpoises were taken annually. Of the 58,205 catches reported from 1993-2018 in West Greenland, 48,534 harbour porpoises (i.e. 83 %) were taken within, or close to the assessment area (i.e. between Paamiut and Sisimiut) (Fig. 5.3.10a).

Due to their unpredictable occurrence, pilot whales, white-beaked/white-sided dolphins and killer whales are caught opportunistically. From 1996-2018, a yearly average of 226 pilot whales were reported caught in West Greenland, with annual catches varying from 5 to 433 pilot whales. In the Davis Strait assessment area, average catches during this period (1996- 2018) were 46 pilot

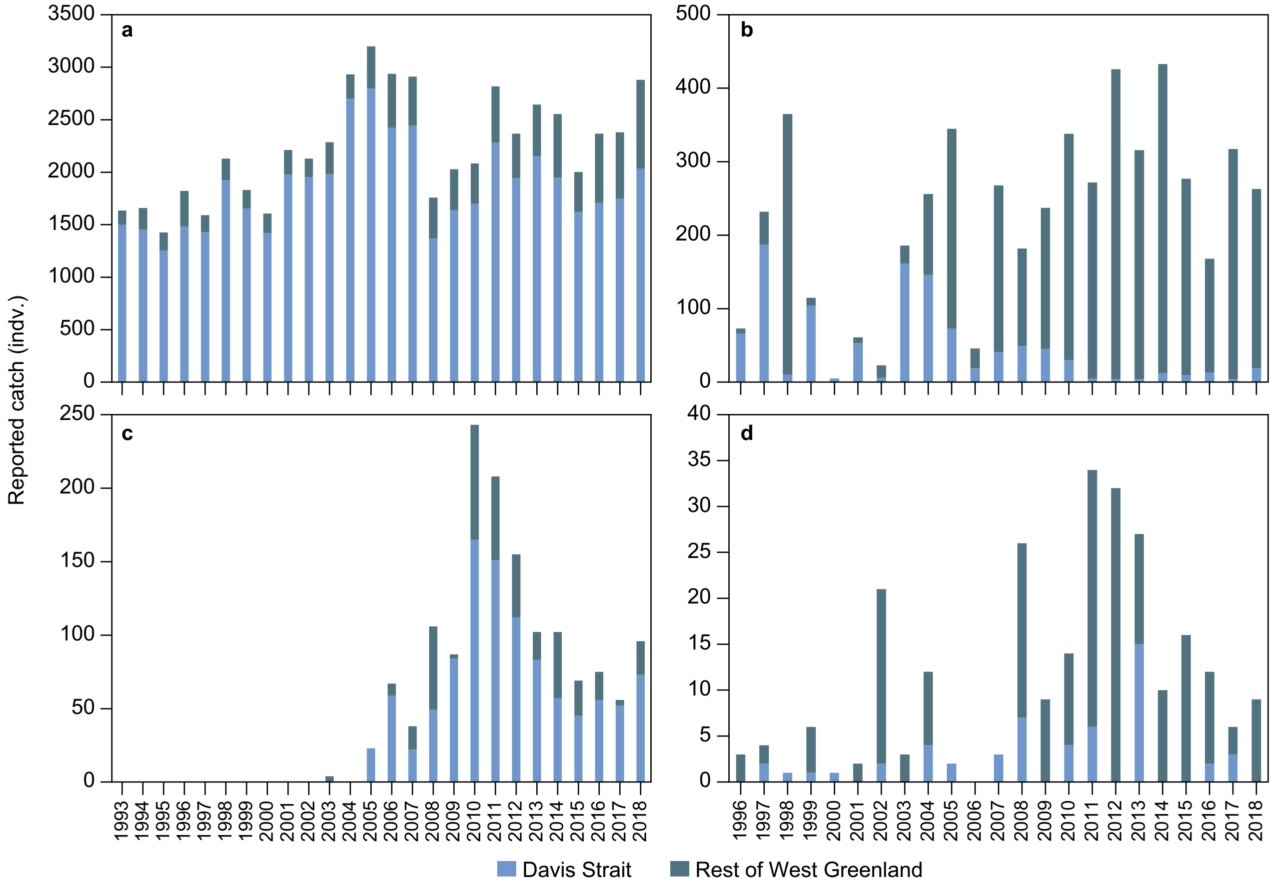



**Figure 5.3.10.** The total catch in West Greenland of a) harbour porpoise, b) pilot whale, c) white beaked/white sided dolphin and d) killer whale. The grey bars show the catch for Davis Strait and the blue bars the remaining West Greenland (data from APNN). Note that the catches for killer whales have not been validated after 2007 and represents an overestimation.

whales a year, or 20% of the total catch in West Greenland and varied from 5 to 161 pilot whales per year (Fig. 5.3.10b).

On average, 95 white-beaked/white-sided dolphins have been caught annually in the period from 2003-2018 (Fig. 5.3.10c). Out of 1,431 dolphins reported caught in West Greenland from 2003-2018, 1,031 (i.e. 77 %) were caught in the assessment area.

Killer whales are hunted partly for human subsistence and partly to feed sledge dogs. They may also be hunted by some because they are considered as competitors for seal and whale hunters. From 1996-2018 a total of 253 killer whales have been reported caught in West Greenland and the annual average catch for the entire period was 12, ranging between 0 and 34 killer whales per year (Fig. 5.3.10d). The killer whales have been caught irregularly along the entire West coast from Upernavik in the north to Nanortalik in the south, with 33% of the catches (i.e. 53 animals) taken within the assessment area.

Bottlenose whales are not eaten in Greenland because their blubber causes diarrhea in humans as well as dogs. Nevertheless, a few catches have been reported. It is possible that these reports are mostly mistakes, but until they have been validated, we can mention that between 2006-2018 a total of 113 catches were reported of which 54 (48%) were taken in the assessment area.

### 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 in the assessment area and nationally. The most important asset for the tourist industry is the unspoiled, authentic, and pristine nature and the picturesque 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 2008 were approximately 84,000 guests and approximately 236,000 "bed nights" and in 2019 these figures were 105,000 and 266,000, respectively (Statistics of Greenland 2020). In the Sermersooq municipality, which includes the capital Nuuk and covers a large part of the assessment area the number of "bed nights" were 50,000 in 2008 and 61,000 in 2019 (Fig. 5.3.11).

In addition, cruise ships bring an increasing number of tourists to Greenland. The National Strategy of Tourism 2008-2010 planned a 10% increase per year in the number of cruise tourists (Department of Industry 2007), and the development of this activity in the four towns of the assessment area is shown in Fig. 5.3.12. 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.

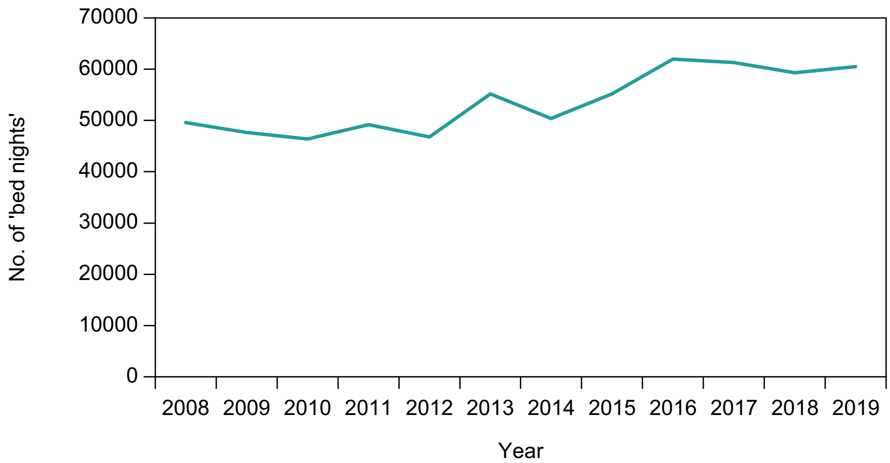
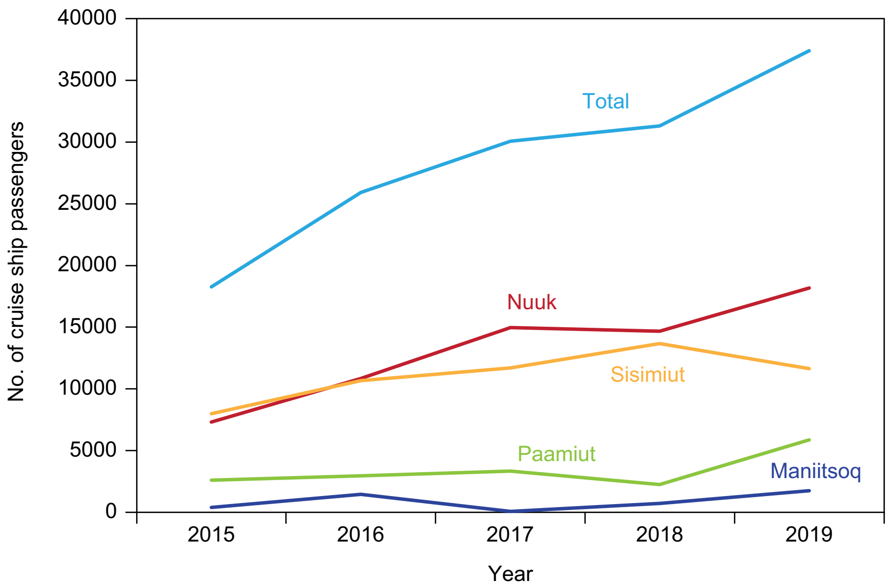



**Figure 5.3.11.** Development 2008-2019 in number of "bed nights" in Sermersooq Municipality. Data from Greenland Statistics.




**Fiure. 5.3.12.** Development in number of cruise ship passengers visiting towns in the assessment area. Data from Greenland Statistics.

**Tourist activities**

Tourist activities are mainly based in the towns of the assessment area, where there are accommodation facilities and tourist operators. Activities takes place throughout the year and includes dog sledding, northern lights watching, skiing, kayaking, visits to archeological and UNESCO World Heritage sites, bird cliffs, whale habitats (see also Chapter 3.8.4 about humpback whales), glaciers, small settlements, hiking areas etc. See also www.greenland.com.

## 5.4 Impacts of Climate Change in the Davis Strait and Disko West region

*Anders Mosbech & Eva Friis Møller (AU)*
*With contributions from Kristin Laidre, Erik Born, Tenna Boye & 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 multidecadal 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 (Meredith et al. 2019), NOAA report cards (Link), (AMAP 2017b, 2018a, 2019) and (CAFF 2017).

The AMAP (2019) *Arctic Climate Change Update* 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 maximum 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. 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 (Fig. 5.4.1). 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 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 (Fig. 5.4.2). 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 (Fig. 5.4.2). 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 (Fig. 5.4.3).

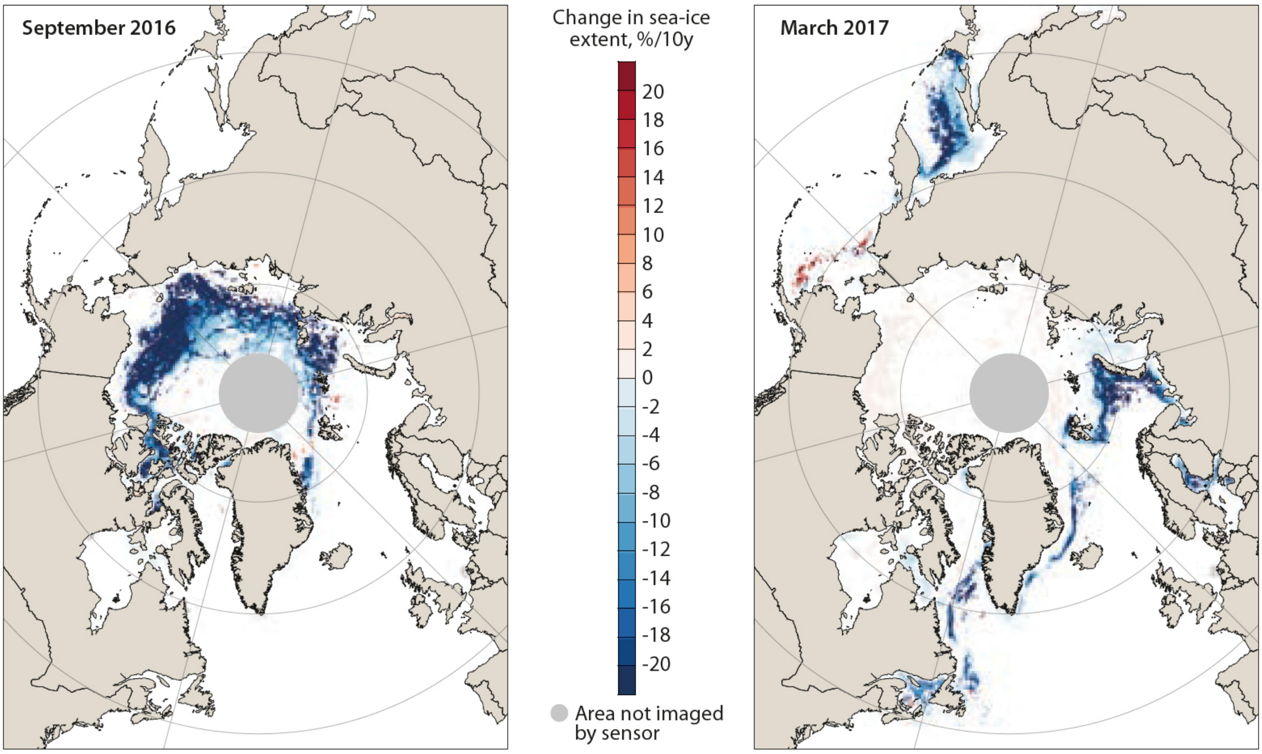



**Figure 5.4.1.** Linear trends in sea-ice extent (relative to the 1981-2010 average) for September 2016 and March 2017. Data source: NASA Team algorithm and the NSIDC Sea Ice Index (Fetterer et al. 2016).

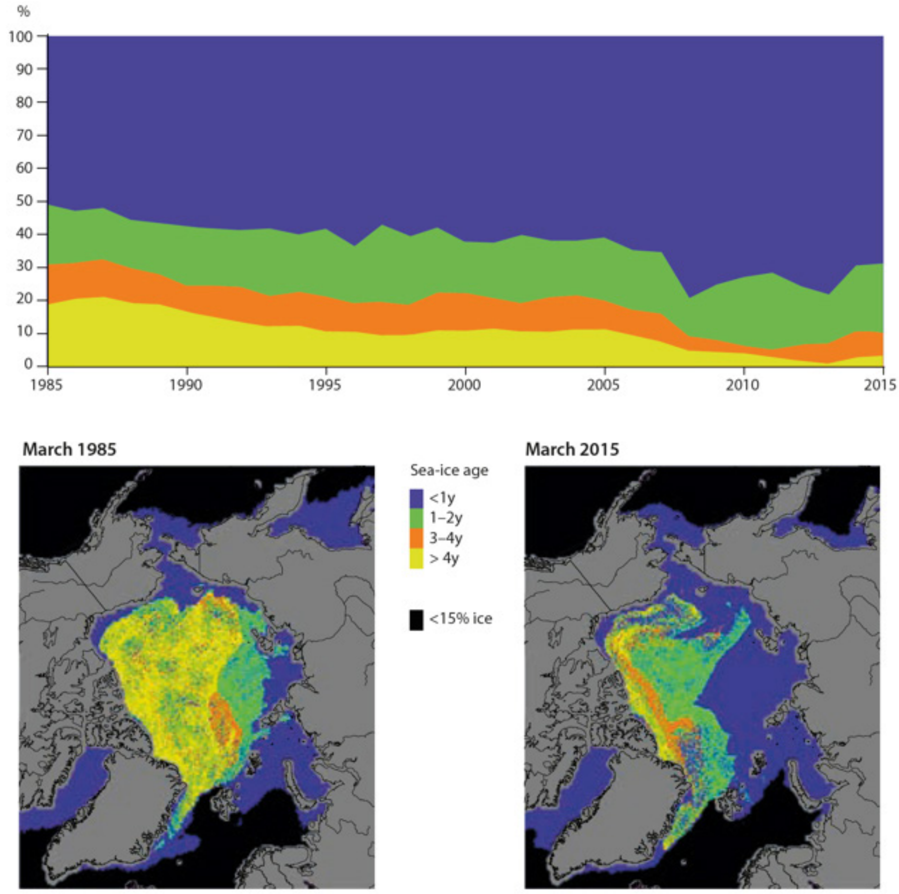
The reductions in sea ice are caused by a combination of atmospheric warming and the influx of warmer waters from the south. The coverage, extent, and thickness of multi-year sea ice reflect climate conditions over years to decades, making the loss an indicator of Arctic and global climate change. The 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 blooms (one in spring and one in autumn) have increased in regions with the greatest loss of sea ice. Autumn blooms are common also in high latitude systems, although often not detectable in remote sensing due to deeper chlorophyll max. Prolonged inshore summer blooms are often related to subglacial discharge. 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 Observed 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 todays. If emissions continue to increase, future changes in the Arctic would be even more substantial and long-lasting. The following

Figure 5.4.2. A time series of sea-ice age in March from 1985 to the present and maps of sea ice age in March 1985 and March 2015 (from Perovich et al. 2015, Barber et al. 2017).

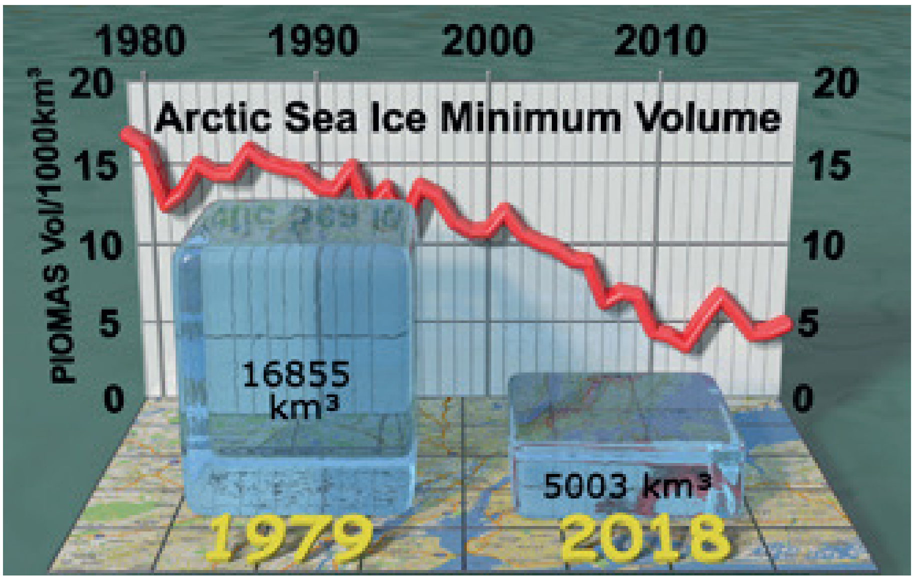



description is based on updated climate projections in the most recent AMAP assessments (AMAP 2017b, 2018a, 2019), using scenarios that depict plausible changes in future greenhouse gas emissions and concentrations over time.

### 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

Figure 5.4.3. Arctic sea ice minimum volumes, 1979–2018. Visualization by Andy Lee Robinson using data from Pan-Arctic Ice Ocean Modeling and Assimilation System, University of Washington, Polar Science Center. Animated version available at https://youtu.be/GZzEUJ86PCg.



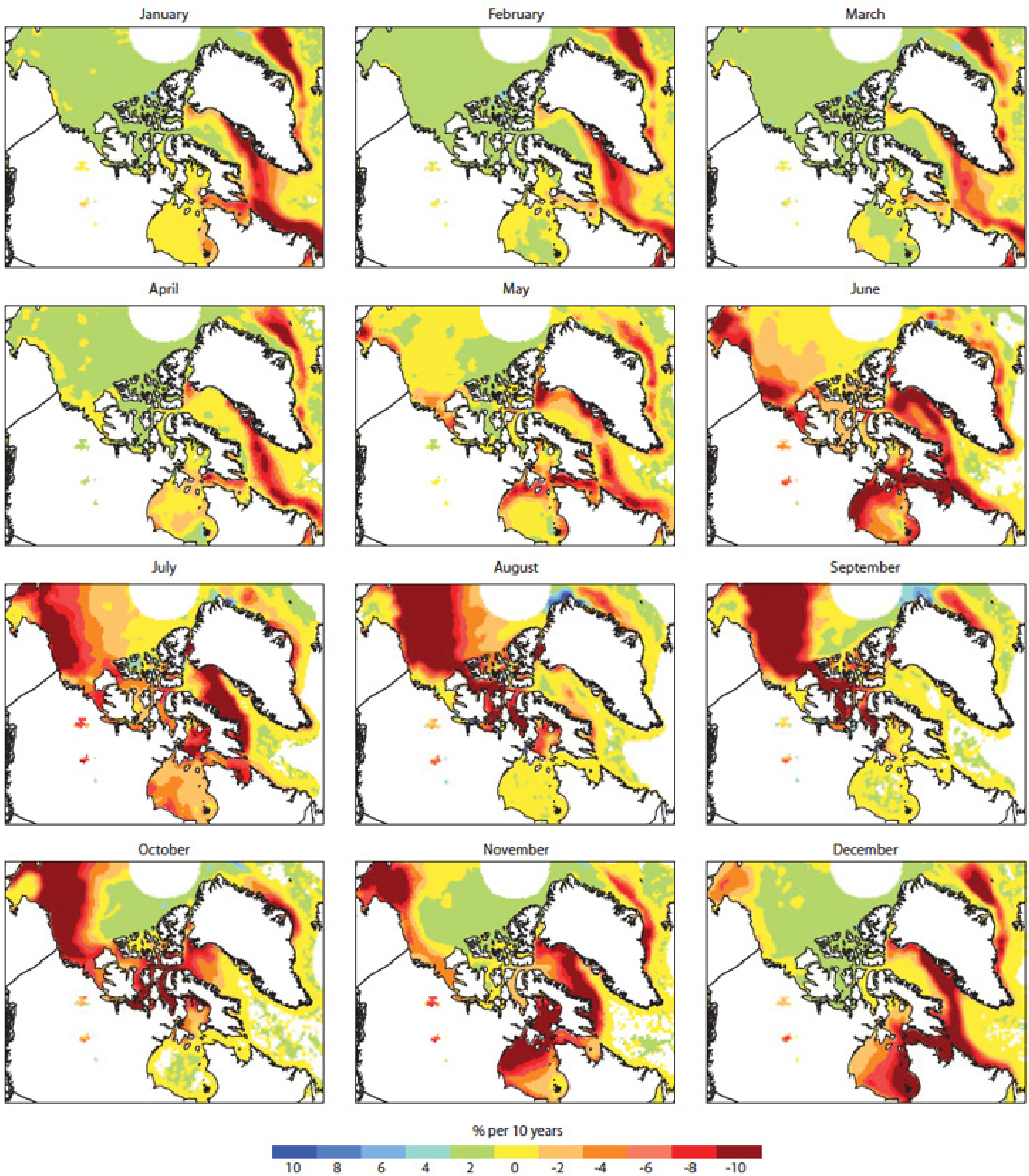



**Figure 5.4.4.** A Trends in monthly average ice concentration (%) over the Canadian Arctic and adjacent waters, 1979–2012, expressed as percent change per decade and based on the passive microwave satellite data (figure from Langen et al. (2018) using data from Cavalieri and Parkinson (2012)).

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 Fig. 5.4.4 and 5.4.5.

**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 (Fig. 5.4.6). The strongest warming is projected to occur during the

Projektions in ice:

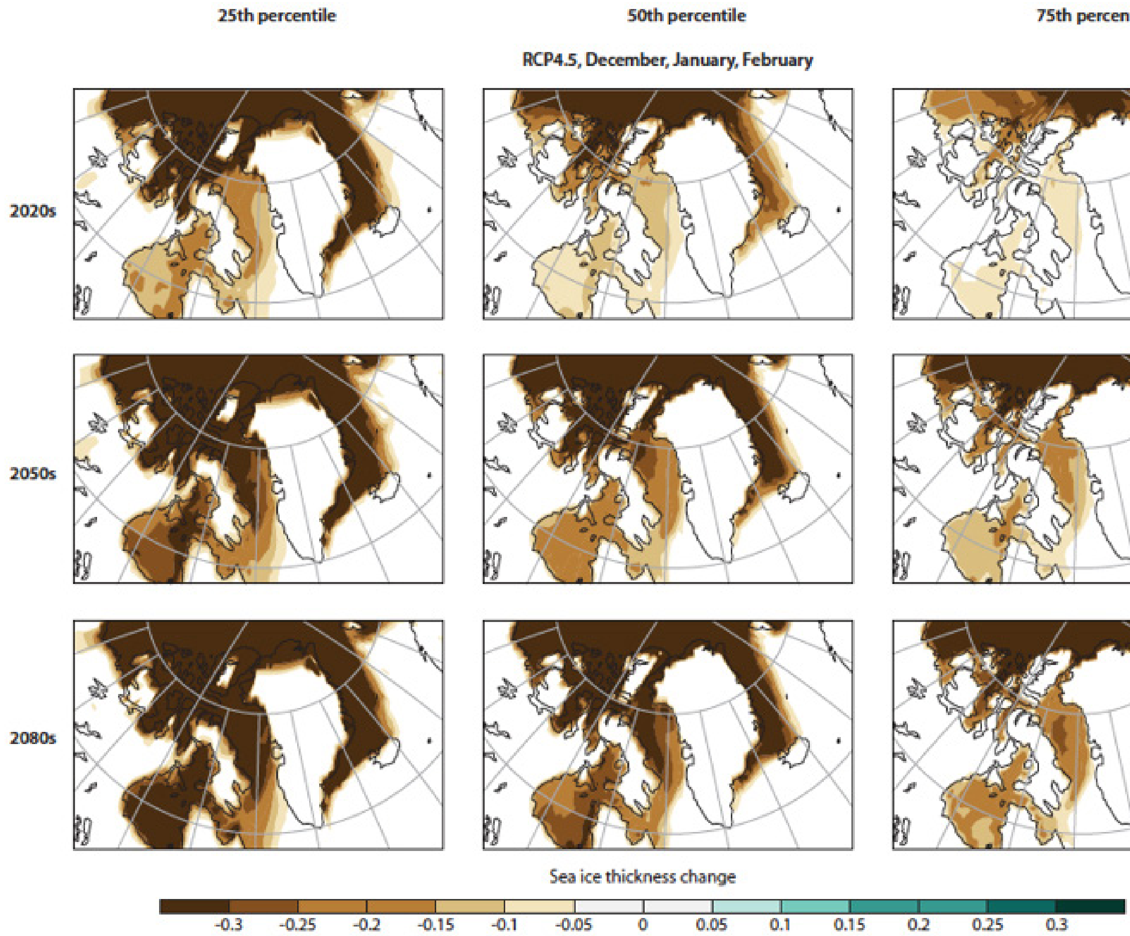



**Figure 5.4.5.** Projected change in winter (DJF) sea ice thickness (change in meters relative to the 1986–2005 average) for the RCP4.5 scenario, according to a 29-member CMIP5 multi-model simulation. Results are shown for three periods in the future: 2016–2035 (labeled 2020s), 2046–2065 (labeled 2050s), and 2081–2100 (labeled 2080s). The figures illustrate the 25th, 50th, and 75th percentile changes projected by the CMIP5 models (from Langen et al. 2018).

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 Baffin Bay - Davis Strait 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, Mankoff et al. 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 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 2017b, Lewis et al. 2020, and see below).

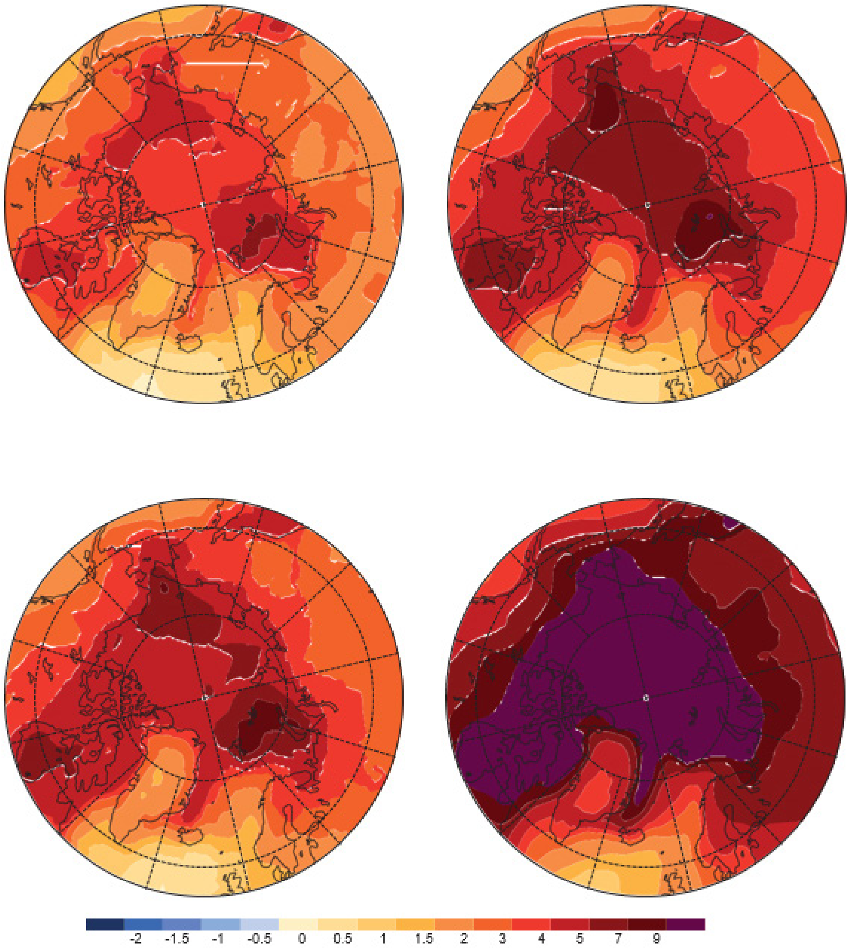



**Figure 5.4.6.** Projected changes in near-surface temperature (50th percentile), relative to 1986–2005, for December–February under the IPCC 'intermediate' RCP4.5 scenario (left panels) and the 'worst case' RCP8.5 scenario (right panels). Upper panels are for the decade of the 2050s, lower panels are for the 2080s (graphic courtesy of G. Flato, Environment and Climate Change Canada).

**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 undersaturation (IPCC 2019). Water with $pCO_2$ 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 (*Ibid*).

**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 Tab. 5.4.1 for a summary of responses of Arctic marine organisms to climate change and also CAFF (2017).

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).

**Table 5.4.1.** 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 |

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 (Harding et al. 2009, Frandsen et al. 2014, 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.

**Benthic fauna**

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, Włodarska-Kowalczuk et al. 2005, Pawłowska et al. 2011, Węsławski et al. 2011, Versteegh et al. 2012).

**Fish**

The important fish stocks in the region exhibit significant different trends, see Chapter 3.6 and 5.3.1. The Greenland halibut stock has increased in the Davis Strait, while the northern shrimp stock has declined in the Davis Strait assessment area, but increased in the Disko West assessment area. The Atlantic cod stock appears to be slowly rebuilding in both areas. 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. Hovgaard & Wieland 2008). Thus, it can be expected that the shrimp population will continue to decline in the Davis Strait 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 1980'ies and the early 1990'ies (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 may change on all trophic levels, and food resources could be lost for some species. Therefore, some species may have to work harder to maintain their energy balance, potentially causing 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 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 favored 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 southwest 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 indicates 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 region in recent decades (Boertmann 2008b), 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 (Descamps et al. 2013, Merkel et al. 2014).

**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.

The impacts of less sea ice have been demonstrated for the Baffin Bay polar bear subpopulation. 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. 2018a). 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. 2018a). This has translated to reduced geographic ranges, more time on land, reduced emigration, poorer body condition and reduced reproduction (Laidre et al. 2018a, Laidre et al. 2018b, Laidre et al. 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). 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, beluga 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.

### 5.4.3 Climate research facility

Both at Nuuk and at Qeqertarsuaq there are land-based 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 programme (GEM; see https://g-e-m.dk/). The marine subprogramme of GEM aim to establish long-term data series of key parameters in order to understand how the distribution and composition of marine plants and animals and the marine carbon cycle is affected by climatic changes.

The Greenland Institute of Natural Resources (GINR) has been operating and maintaining inshore and offshore fishery surveys for decades along West Greenland and Southeast Greenland. In recent years, these surveys have become more multidisciplinary covering more benthic and pelagic ecosystems components. In 2021, the institute will implement a new offshore research vessel designed for multidisciplinary survey and research cruises. Dedicated inshore and offshore research cruises focused on the marine ecosystems processes and the effects of climate change has been conducted during the recent decades in and adjacent to the assessment area. The Greenland Climate Research Centre, a department at GINR, is operating an autonomous mooring network, with plans for further expansions of the network in coming years. The institute has also strengthened its collaboration with University of Washington (USA) and Department of Fisheries and Oceans (Canada), which has been operating autonomous mooring platforms and gliders, and maintaining ship-based sampling, across Southern Baffin Bay, Davis Strait and Northern Labrador Sea for more than a decade.

### 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 & 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 and tourism. and can be direct (such as the mortality from hunting) or indirect such as disturbance (Christensen et al. 2018, Dawson 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, a by-product from the production process (see Chapter 6.2.4). 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 another 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 populations of thick-billed murre have been declining, mainly due to unsustainable harvest (Merkel et al. 2014, Merkel et al. 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 petroleum 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 (Christensen et al. 2018, Dawson 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. 2017), 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 (Christensen et al. 2018, Dawson 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

## 6.1 Phases of oil and gas activities

*David Boertmann (AU) & David Blockley (GINR)*

Hydrocarbon (oil/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. Environmentally 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. However, 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 hydrocarbons 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 hydrocarbons deposits to be commercially viable, there need to be a source rock from which they originate, and reservoir rocks, where hydrocarbons leaching from the source rock are contained and concentrated. The purpose of exploration activities is, therefore, to ascertain if hydrocarbons 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 hydrocarbons and then to ascertain if 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 hydrocarbons. 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 hydrocarbon-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 hydrocarbons 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 construction (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:

- Construction and placement of production facilities, constructions on the seabed (wells and pipelines) 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 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 hydrocarbons related infrastructure. In relation to the North Sea oil fields, this has been a source of much discussion and research, in particular regarding contaminants in the seabed contained in drill cuttings (e.g. mercury) and on the constructions as well as the issue of the constructions 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 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 hydrocarbons 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 hydrocarbon 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 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 hydrocarbons 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 hydrocarbon 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 and 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 sesimic 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 hydrocarbon activities in the Barents Sea, impacts on northern shrimp and fishery of this resource were evaluated, and both the population and the fishery were considered relatively robust against impacts (Østby et al. 2003).

**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 sandeels, neither in cage experiments nor in grab samples taken at night when sandeels were buried in the sediment (Hassel et al. 2004).

The studies described above indicate that behavioural and physiological reactions to seismic sounds among fish may vary between species, i.e. depending on whether they are territorial or pelagic, 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 was 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 no effects have been observed in West Greenland where seismic surveys have overlapped with trawling grounds for Greenland halibut.

**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) (Cranford et al. 2003, 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, Stone and Tasker (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 and 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 and 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 $\mu Pa^2 s^{-1}$) 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 2007). The ability of humpback whales to find prey in different locations may suggest that they would have access to alternative foraging areas if they were displaced from one area by a seismic activity. However, even though many areas can be used, a few key zones seem to be especially important. The satellite tracked humpback whales favoured a zone on the shelf with high concentrations of sandeel (Heide-Jørgensen & Laidre 2007). Similarly, a modelling study based on cetacean and prey surveys showed that rorquals (fin, sei, blue, minke and humpback whale) and krill aggregate in three high density areas on the West Greenland banks (Laidre et al. 2010). Thus, displacement from such important feeding areas potentially 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 in Dunn & Hernandez 2009). The corresponding distance in meters will depend on the source level of the airgun array and the salinity and temperature layers of the water 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 and 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 57 and 60).

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).

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).

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 Sund, 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 hydrocarbon 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 a hydrocarbon reservoir is encountered, the well is normally tested to see whether the reservoir is viable for production. Wells unsuitable for further development are sealed below the seabed and tested to ensure that they are fully secure before being abandoned. If a hydrocarbon 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 hydrocarbons 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 hydrocarbons 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 and 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 (WBMs), oil based (OBMs) or based on synthetic fluids (SBMs). 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 OBMs and SBMs are only used where the mud and the cuttings can be brought to land for treatment or can be deposited safely. After the drilling, water-based muds (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. (cf. Chapter 8). 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 8.3.1.

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 tonnes 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 8.3.1 about the Greenland mud strategy.

OBMs are still used in Norway, mainly for special drillings under difficult conditions, and afterwards cuttings and mud are either reinjected or transported to land for treatment at specialised facilities. 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 OBMs (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. 2016b) showed that 2000 tonnes 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 wil 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 6.1). There mercury content in barite used for drilling in Greenland shall therefore be the lowest possible in accordance with the Minimata 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 150-160 million $m^3$/year (Norsk olje & gass 2014, Beyer et al. 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). Some of the chemicals are persistent and have the potential to bio-accumulate. Moreover, the produced water is the major source of oil pollution from normal operations, in Norway for instance up to 88%. See also Lee and 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). 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.

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, which especially could impact the composition of primary producers (planktonic algae) (Rivkin et al. 2000).

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 2010b).

### 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 (Anon 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 tonnes 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 tonnes. The drilling of the three exploration wells in 2010 in the Disko West area resulted in the emission of 105,000 tonnes $CO_2$. 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 tonnes $NO_x$ 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 (Anon 2003). This lack of knowledge also applies to the terrestrial environment bordering the assessment area.

Finally, is emission of black carbon (BC) from combustion is 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 a hydrocarbons 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 of 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 hydrocarbons 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 and cold-water corals which are considered as particularly sensitive (OSPAR, Link) (Campbell & Simms 2009). Cold-water corals 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 destroy ship antennae and other constructions (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).

Placement of constructions will affect fisheries due to exclusion (safety) zones around the hydrocarbons activities, 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 (Anon 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 a hydrocarbons 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. 2017a). Particularly walruses hauled out on ice are sensitive to this activity, and there is risk of displacement of walruses from critical feeding grounds. Walruses have a narrow foraging niche restricted to the shallow parts of the shelf and activities in these areas may displace the walruses to suboptimal feeding grounds.

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 a period 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 tonnes would occur once every 4600 years (small-scale development scenario) and once every 1700 years in an intensive development scenario (Anon 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 (Anon 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 meager (Acona 2012).

Drilling in deep waters[4] and ultra-deep waters[5] 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).

4 > 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).

5 > 5000 feet ≈ 1524 m according to US authorities (cf. Graham et al. 2011).

Simulations of oil spill trajectories in the assessment area was modelled by DMI (Nielsen et al. 2008) and by SINTEF (Johansen 2008) – see Chapter 9.4.

General knowledge on the potential fate and degradation of spilled oil relevant for the Greenland marine environments has been reviewed by Pritchard and Karlson (2002), Vergeynst et al. (2018) and Wegeberg et al. (2018a). 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 (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. 2016b), 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 Subsurf8ace 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 tonnes 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 tonnes of natural gas were 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. 2018b). 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. 2018a).

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 Fig. 6.3.1.

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 8.1).

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.

### 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 pro-

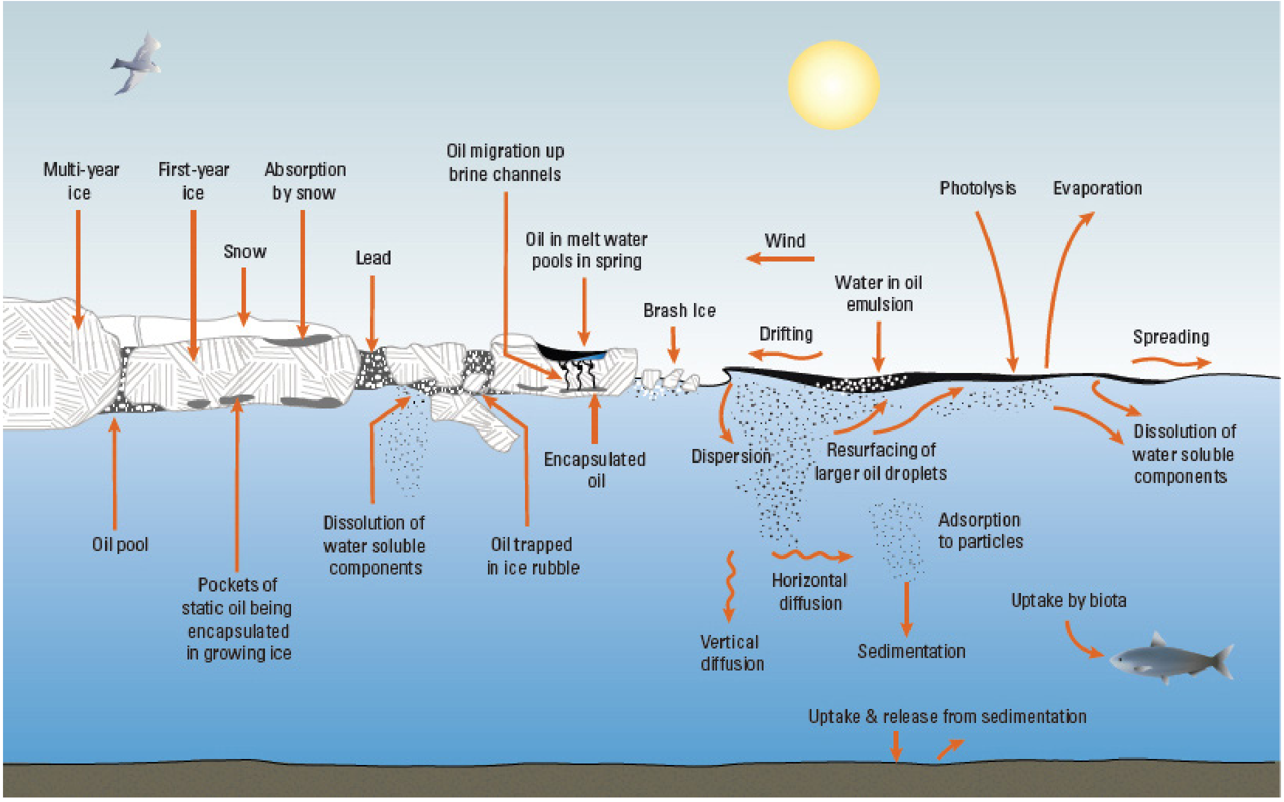



**Figure 6.3.1.** Environmental processes that affect oil behaviour and weathering in open water and in ice. SOURCE: National Research Council (2014).

cess 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, sublethal 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 Chapters 5.1, 7.4.1 and 8.4.

**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 PAHs 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.

**Oil spill impact 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. 2013, Hansen et al. 2013, Nørregaard et al. 2015, Toxværd et al. 2018b). A recent study showed strong delayed effects on fecal production, egg production and high sensitivity to oil contamination (Toxværd et al. 2018b), 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. 2008) and on survival of females, feeding status, and nucleic acid content in *Microsetella* spp. from Western Greenland (Hjorth & Dahllöf 2008). The pyrene concentrations applied were, however, difficult to compare to actual spill situations. 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. 2012a).

Comparison of acute toxicity, expressed as mortality of herbivorous copepods (*Acartia tonsa*) and growth inhibition of a primary producer (*Skeletonema* *costatum*) of WAFs from non-weathered and naturally weathered oil, shows a general decrease in effect as a function of weathering degree (Faksness et al. 2015) 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). 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).

Sublethal 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 WAFs of field-collected *Deepwater Horizon* spill oil samples caused specific dose-dependent defects in cardiac function in embryos of three pelagic fish: bluefin tuna, 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 edema, 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). Given the high degree of spawning mortality, any year in which spawning fails on a large scale will be detrimental to the population. Hence, an oil spill near spawning beaches can be extremely damaging to the local capelin stocks (Mosbech et al. 2004b). 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 et al. 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.

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 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. 2020a, Gustavson et al. In prep). 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. In prep).

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. 2020a).

There are different reports on the impact of oil contamination on macroalgal vegetation and communities. After the *Exxon Valdez* oil spill in 1989 in Alaska, the macroalgae cover in the littoral zone (mainly *Fucus gardneri*) was lost. It has taken many years to fully re-establish these areas, and some areas were still considered as recovering in 2010 (NOAA 2010). Strong fluctuations in the cover were observed during the recovery phase, and they may be a result of the interactions between grazers and the macroalgae, as was the case after the *Torrey Canyon* accident at the coast of Cornwall, UK (Hawkins et al. 2002). Regarding Prince William Sound, the fluctuations were considered as a result of homogeneity of the recovering *Fucus* population (for example genetics, size and age), which made it more vulnerable to natural environmental impacts (for example no adult *Fucus* plants to protect and assure recruitment), thus resulting in a longer time span to restore *Fucus* population heterogeneity (Driskell et al. 2001). 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). As noted above, the study by Wegeberg et al. (2020a) also showed that effects from some oil types, on a specific Arctic macro-algae, may be short-term.

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 (on the northern border 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).

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 (2002a, Camus et al. 2002b, 2003, Olsen et al. 2007, Bach et al. 2009, Hannam et al. 2009, Bach et al. 2010, Hannam et al. 2010). Effects occur especially in shallow water (< 50 m), where toxic concentrations can reach the seafloor. In such areas, intensive mortality has been recorded following an oil spill, for example among crustaceans and molluscs (McCay et al. 2003a, 2003b, 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 were impacted by 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). 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 (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 sublethal 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, 2010a, 2010b, 2010c, 2010d).

The question is how sensitive the ice-associated ecosystem is to oil spills. The available knowledge is very limited (Camus & Dahle 2007, AMAP 2010b), 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 2010b).

**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 2014c, 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 and Michel (2018) estimated that 227 tonnes 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 (Wiese et al. 2004). 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. 2014b, a). 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.

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. 2016b).

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. 2017).

Marine mammals in the water need to breathe at the surface. Inhalation of vapours of Volatile Organic Compounds (VOCs) from an oil spill is therefore a potential hazard. Some of the marine mammal mortality after the *Exxon Valdez*-spill has been ascribed to this kind of exposure. The loss of killer whales was probably related to inhalation of VOCs from the spill (Matkin et al. 2008) (see details below), and the death of harbour seals was also related to VOCs (Spraker et al. 1994). In periods with ice-coverage when oil can fill the spaces between the ice floes, the risk of inhalation of toxic VOCs may be even higher because marine mammals are forced to surface in these 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. Although the sensory abilities of seals should allow them to detect oil spills though sight and smell, seals have been observed swimming in the midst of oil slicks (St Aubin 1990). Harbour seals found dead shortly after the Exxon Valdez oil spill had evidence of brain lesions caused by VOC exposure, and many of these seals were disoriented and lethargic ('solvent syndrome') over a period of time before they died (Spraker et al. 1994).

Oil spills in ice pose a special threat to seals 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.

The bearded seals which feed on benthic organisms may also be exposed to oil contaminated food.

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. 1989). Mortality of several species of benthic invertebrate including bivalve molluscs has been observed as a direct effect of oil spills (North 1967, Percy & Mullin 1975). Furthermore, sublethal 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.

No information is 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 & Würsig 1995, Anon 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, Anon 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. 2017).

After the *Deepwater Horizon* spill in the Gulf of Mexico, increased mortality and many sublethal effects have been described in bottlenose dolphins in oil affected areas (Litz et al. 2014, Schwacke et al. 2014, 2015a, Venn-Watson et al. 2015b, 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 (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, Stirling 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 2014a, 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. 2017).

### 6.3.9 Oil spill impacts on 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 and 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

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This chapter gives an overview of potential environmental impacts from oil and gas activities and their effects on the Valued Ecosystem Components (VEC's) in the Davis Strait 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 accelerates – 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, Merkel & Tremblay 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, may affect the fishing activity 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). Tab. 7.1.1 summarize the impacts and their potential significance.

### 7.1.1 Impacts from seismic noise

The most noise-vulnerable whale species in the assessment area belong to the baleen whales – minke, fin, blue and humpback whale – and the toothed whales – sperm whale and bottlenose whale – all of which all are present in the area during the ice-free months when seismic surveys usually take place. There will be a risk for displacement of individuals of these whales from important feeding grounds. The studies of Heide-Jørgensen and Laidre (2007) indicated that the whales have alternative feeding grounds, making them less sensitive to displacement.

White whales, narwhals and bowhead whales are also sensitive to seismic sounds, but are present in the area during wintertime only. Bowhead whales, for example, migrate through a part of the assessment area in December-January (Heide-Jørgensen & Laidre 2010). The risk of overlap between these species and seismic operations is therefore confined to winter.

It is unknown to which degree seismic noise may affect seabirds in the assessment area. It has recently been shown that cormorants have a high ability to hear under water sound (Larsen et al. 2020) and murres respond to underwater noise (Hansen et al. 2020). The presence of seismic ships may have a dis-

**Table 7.1.1.** Basic 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 lasted 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 | Remarks |
|---|---|---|---|---|---|---|---|---|
| Underwater noise | Seismic surveys, shipping, drilling | Displacement of marine mammals and fish | Exploration | Regional | Short-term | minke, fin, blue and humpback whale, 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. |
| Drilling mud and cuttings, release to seabed and water column | Drilling from ships and platforms | Sedimentation, suspended material in water column, toxic chemichals | Production | Local | Long-term | Seabed organisms | Pot. medium | Risk for cumulative effects in case of multiple drillings |
| | | | All | Local | Long-term | | | |
| Produced water | Production platforms | Contamination | Production | Regional | Long-term | Primary production hotspots, perhaps polar cod egg and larvae | 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/ regi onal | 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/ dis placement of wildlife | Exploration | Local | Short-term | Seabird concentrations, walrus, whales | Low | |
| | | | Production | Regional | Long-term | | Pot. high | |
| Prescense of people | Primarily at shore- based facilities | Disturbing/ displ acement 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 | |

turbance 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.

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

**Table 7.1.2.** 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 | – | – | – | – |
| Atlantic cod | pot. large | 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) | – | – |
| 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 | – | – | – | – |

most fish species spawn in a dispersed manner in winter or spring. When the seismic surveys take 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, sand eel 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 reduced catches in periods when simultaneous fishery and seismic surveys took place in the same areas in the 2000´s (Boertmann et al. 2013).

Tab. 7.1.2 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 the baleen whales such as fin, minke and humpback whales

**Table 7.1.3.** 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.

| 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 |
| Atlantic 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 |
| 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) | – | – |

and toothed whales such as sperm whale and harbour porpoise. The walruses occurring at the northern edge of the assessment area are also highly vulnerable. If alternative habitats are available to the whales no long-term effects are expected, but if several rigs operate in the same region there is a risk for cumulative effects and displacement from key 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 licence blocks, exploration may last for decades resulting in extensive cumulative impacts, which potentially may displace the whales permanently.

Tab. 7.1.3 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 (Tab. 7.1.3, 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 VME's. A candidate for a soft coral garden VME is located within one of the licence blocks applied for in the assessment area (see Chapter 3.4 and Fig. 3.4.6).

### 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, plankton production hotspots could be exposed and impacted. If concentrations of polar cod eggs occur below ice in the assessment area, these are also at risk.

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.

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 CO2 emission from the Statfjord field in Norway, for example, was in 2003 (Chapter 6.2.6) almost three times the total current Greenland CO2 emission, which in 2017 was 573,800 tonnes (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 emmissions in the assessment area.

### 7.1.5 Impacts from constructions and presence of infrastructure

Placement of infrastructure facilities 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 northern edge of the assessment where the shallow (<50 m) parts of Store Hellefiskebanke is important for king eiders, walrus and bearded seals in winter, all feeding on the rich benthic communities (Christensen et al. 2016, Wegeberg et al. 2016b). Offshore Nuuk, the Fyllas Banke is also important for king eiders in some winters and may be sensitive.

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 infrastructures 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 infrastructures 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 et al. 2016a) 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. However, 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, breeding thick-billed murres and moulting seaducks will be particularly vulnerable to this activity (see also Chapter 6.2.8). The result will in worst case be displacement while reduced time to forage will be more likely.

Especially the walruses wintering on the northern edge of 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).

## 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 2010b). 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 2010b). 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 northwestern part of the assessment area is dynamic and moves with the surface currents, thus, contribute to spreading the oil. Moreover, spilled oil in an almost un-weathered condition may be released from the melting sea ice to open waters far from the spill site.

Some of the conclusions from a report from DCE assessing oil spill impacts and particularly the fate of dispersed oil on Store Hellefiskebanke and Disko Bay (Wegeberg et al. 2016b) are also relevant for the Davis Strait assessment area:

- 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.

- 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.
- 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.
- The toxic effects of oil components may be transmitted through the food web causing cascading effects.

**Primary production and zooplankton 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 and upwelling areas 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. However, 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 risk of dispersed oil after an oil spill will be confined to the mixing layer, which usually reach a maximum depth of 10 - 20 m (Li et al. 2013). The actual concentration in the water column depends on the amount of oil released, the weather conditions and the water exchange and dilution capacity in the specific area. As an example, the model study carried out for the Store Hellefiskebanke just north of the assessment area (Wegeberg et al. 2016b), showed that the vertical distribution of toxic oil concentrations would reach down to app. 10 m of the water column and thus, overlap with the zone having high densities of plankton (mainly down to 50 m).

Besides the toxic concentrations of oil components, dispersion 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, dispersion 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 impacts on the recruitment to the polar cod population in the assessment area. However, there is currently no knowledge on aggregations of spawning polar cod and subsequent accumulation of eggs and larvae in the assessment area, although larvae have been observed in period May - July (Chapter 3.2.5, Fig. 3.2.5).

**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 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 eiders are affected.

The shorelines will be more sensitive to oiling than in areas with winter ice, because the flora and fauna is better developed and in low sedimentary coasts the oil may potentially be buried like it happened in Prince William Sound during the Exxon Valdez spill in 1989 (see Chapter 7.3.8).

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 organisms 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. A vulnerable VEC in this habitat could be spawning polar cods, if they occur.

**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 sandeels (a key species in the bank ecology), as they are very stationary on the banks. As several important sandeel locations are known from the shelf area, there is no question that the assessment area is a critical area for sandeels in West Greenland.

Fish egg and larvae are on the other hand sensitive to oil spills (see section on plankton and oil spills above).

**Seabirds and oil spills**

Around 20 species of seabirds breed regularly along the coast or in the fjords of the assessment area (Chapter 3.7). Of these most are more or less colonial 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.

Several breeding colonies of thick-billed murre are known from the assessment area, mainly in the Maniitsoq area. 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. The breeding population is declining and therefore particularly sensitive to additional mortality.

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 no hunting. Recovery from a similar situation in the assessment area, where there is also a considerable hunting pressure on the murre population, will take longer time – and might not happen at all.

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. (see Chapter 3.7).

During autumn and winter, a large oil spill in the assessment area may potentially affect seabirds from many areas of the North Atlantic, due to Southwest Greenland being an international important foraging area throughout most of the year. The visitors include non-breeding birds from Europe and the southern hemisphere (e.g., black-legged kittiwakes and great shearwaters, respectively), moulting birds from Canada (e.g., harlequin ducks) and wintering birds from a range of breeding areas in the North Atlantic (e.g., murres). Just in the coastal area of Southwest Greenland, the number of wintering birds is estimated to be more than 3.5 million and a very large proportion of these are found within the assessment area. In addition, king eiders utilise the shallow water off- shore on banks and an unknown but large number of murres, puffins, kittiwakes and especially little auks utilise areas further offshore. A large number of eiders, murres and little auks are also passing through the assessment area when migrating back and forth to breeding areas in the northern Baffin Bay or eastern Canada (see details and references in Chapter 3.7). The number of birds potentially affected by a large oil spill in the assessment area could therefore be extensive. On their northwards spring migration through the Davis Strait, murres and little auks are assumed to follow the ice edge of the western pack ice, where also oil will tend to accumulate in case of a spill.

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**

Marine mammals species affected by an oil spill during winter in the as- sessment area could include bearded seal, hooded seal, ringed seal, harbour seal, bowhead whale, narwhal, white whale, polar bear, harbour porpoise and occasionally also walrus, bottlenose whale and sperm whale.

Harbour seals are especially vulnerable because they are endangered in Greenland and conservation of the remnant populations still existing in the assessment area is crucial for the recovery of the population. The hooded seal is also highly vulnerable due to whelping patches on the eastern edge of the Davis Strait pack ice. The winter distribution of the Davis Strait subpopulation of polar bears appears to overlap with these whelping patches. Consequently, the polar bear is also vulnerable to oil spill at the edge of the Davis Strait pack ice. As the bears move over considerable distances, many individuals could be at risk of being fouled by a single oil spill. However, given the observed decrease in sea ice in Davis Strait and the prediction of future decrease, the whelping seals and the polar bears may disappear from the assessment area.

Marine mammals common in the area during summer include harp seal, hooded seal, ringed seal, harbour seal, fin whale, humpback whale, minke whale, sei whale, harbour porpoise, white beaked dolphin, bottlenose whale, sperm whale, and pilot whale. Blue whale occurs only rarely in the assessment area, but is vulnerable due to a very small population and the survival of single individuals is important for the recovery of the population. However, in general the whales are considered less sensitive to oil spills during summer, as they are not restricted by ice in their surfacing behavior.

The banks on the shelf of the assessment area are important feeding grounds for seals and baleen whales. If the prey species are contaminated with toxic substances after an oil spill this may affect the top-predators relying on this feeding area. In case of a fouling of the seabed in the northern part of the assessment area (Store Hellefiskebanke), essential walrus foraging areas may be destroyed.

**Fisheries**

Tainting (unpleasant smell or taste) of fish flesh is a severe problem related to oil spills. This problem may apply to the large-scale commercial Greenland halibut and northern shrimp fisheries within the assessment area, as well as to the local fisheries targeting Atlantic cod, lumpsucker, capelin, wolfish and Atlantic halibut. The fishing ground will be closed if swept by and oil spill, and economic consequences as well as reputational damage of the products must be expected for fishermen and local fishing industries.

Within the assessment area, the offshore fisheries for Greenland halibut west off Nuuk constitute a significant proportion of the overall Greenland/Canada fishery in Davis Strait. If closing such an area there is risk that closure zones could extend further west and also cover Canadian fishing grounds. This is because Greenland halibut moves considerable distances over a very short time, and contaminated (tainted) fish may move out of the assessment area and be caught far from a spill site.

Normally the problem with tainting is most pronounced in shallow waters, where high oil concentrations can persist for longer periods, compared to spills on deeper waters where degradation, dispersion and dilution reduce oil concentrations to very low levels. In the drift models reported in Chapter 8.3, only some of the oil reach the coast in two of six simulations. The main oil spill trajectory was towards southwest in all six simulations. In four of them the area affected by oil covered a large part of the main Greenland halibut fishing area west of Nuuk. In all simulations, small proportions of the oil (< 5%) could potentially reach the seabed and indicate that tainting is a possibility.

**Long-term effects of oil spills**

In certain areas of Prince William Sound recovery lasted more than 25 years after the Exxon Valdez oil spill (Esler et al. 2017). 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. 2017). 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.

Tab. 7.2.1 provides an overview of potential impacts from a large oil spill.

## 7.3 Oil spill sensitivity mapping

The coast of the assessment area has been mapped according to its sensitivity to oil spills (Mosbech et al. 2000). This atlas integrates important knowledge on coastal morphology, biology, resource use and archaeology. It also classifies coastal segments of approx. 50 km in length according to their sensitivity to marine oil spills. This classification is shown on map sheets, and other map sheets show coastal type, logistics and proposed oil spill countermeasure methods. Extensive descriptions of ice conditions, climate and oceanography are also included.

An overview of the sensitivity classification of the coastlines in the assessment area is shown in Fig. 7.3.1. A large proportion of the coastline is classified as highly or extremely sensitive to oil spills, especially in the central and northern part of the assessment area. It should be noted that this sensitivity atlas (Mosbech et al. 2000) was published 20 years ago and an updated version incorporating the new information is recommended.

### 7.3.1 Seasonal summary of offshore oil spill sensitivity

As part of the previous assessment (Merkel et al. 2012), the offshore areas were classified according to oil spill sensitivity (Fig 7.3.2). The offshore areas

**Table 7.2.1.** Overview of potential impacts of a large oil spill on VECs in the Davis Strait assessment area. See Table 5.4.1 for explanation. This assessment assumes the application of current (2012) mitigation guidelines, see text for details.

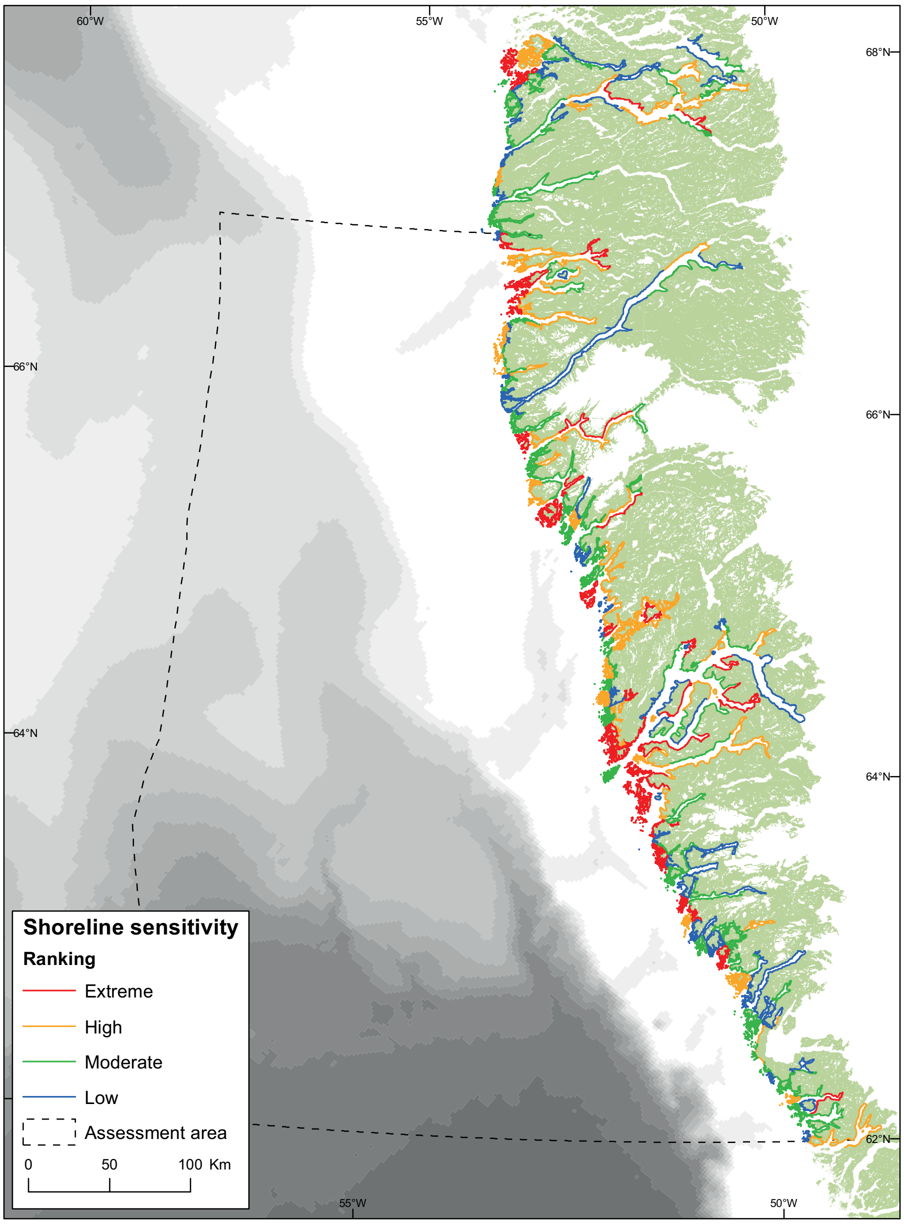
| VEC | Potential overlap | Risk of impact on critical habitats | Potential impacts – worst case | | |
|---|---|---|---|---|---|
| | | | Duration | Sublethal effects | Direct mortality |
| Prim. produktion. | large | yes | short term | minor | minor |
| Zooplankton | large | yes | short term | minor | 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 | small | yes | short term | major (L) | major (L) |
| Greenland halibut | large | yes | short term | minor (L) | none |
| Arctic char | large | yes | long term | major (L) | minor (L) |
| Polar cod under ice | small | 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 | small | 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) |
| Hooded seal | large | yes | ?? | ?? | major |
| Narwhal | small | yes | long term | major (R) | minor (R) |
| White whale | small | yes | long term | major (R) | minor (R) |
| Bowhead whale | small | 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 | small | yes | long term | moderate (R) | major (R) |
| Com. fisheries | large | yes | long term | – | – |
| Hunting | large | yes | long term | – | – |
| Tourism | large | yes | long term | – | – |

were delineated according to a cluster analysis in order to obtain ecologically meaningful areas, and the four seasons were calculated separately. The cluster analysis included twelve variables: air temperature, air pressure, sea surface temperature (two different measurements), temperature at a depth of 30 m, salinity at the surface and at 30 m in depth, wind speed, ice coverage, sea depth, slope of seabed and distance to coast (Mosbech et al. 2004b).

For each season and offshore area various symbols are shown in Fig. 7.3.2 for important species or species groups according to their relative abundance. For each season the relative sensitivity to oil spill is calculated for each offshore area, ranging from low to extreme sensitivity. This classification is based on the relative abundance of resources, but also species-specific sensitivity values, an oil residency index, a human use factor and a few other parameters. It should be noted that the sensitivity ranking shown in Fig. 7.3.2 is relative for each season and therefore cannot be directly compared between seasons.

A direct comparison of seasons for the assessment area, based on absolute sensitivity values and averaged across all offshore areas, shows that winter is most sensitive to oil spill (index value 48), closely followed by spring and autumn (both value 46), while summer is least sensitive to oil spill (value 36). One general reason that winter, spring and autumn are relatively more sensitive than summer, is the large number of wintering/migrating seabirds, which all are very sensitive to oil (especially auks and seaducks). For more details see the seasonal description below.

Figure. 7.3.1. Oil spill sensitivity of coastlines in the assessment area according to the oil spill sensitivity atlas (Mosbech et al. 2000).




**Spring (April/May-June)**

Depending on the winter conditions the ice edge of the western pack ice may still be present in the northern and western part of the assessment area, but in early May there is normally open water throughout the area. As the sea ice also disintegrates and retreats elsewhere, large numbers of wintering auks and seaducks start migrating out of the assessment area towards breeding areas north, west or east of Southwest Greenland. Large numbers of surface feeders (kittiwakes and fulmars), which winter further south, also pass through the assessment area on their way to breeding colonies further north. While many bird species leave or pass through the assessment area during spring, baleen whales move in from the south to use the assessment area as part of their summer foraging area. They take advantage of the productive upwelling areas of the banks and prey on items such as krill, capelin and sandeels, which are especially important for the whales. Also in spring, large schools of capelin and lumpsucker move towards the coasts, where they spawn in the intertidal zone. This attracts both seabirds and marine mammals.

The sensitivity classification of the offshore areas (Fig. 7.3.2) shows that the near-coastal offshore areas are classified as highly sensitive or extremely sen-

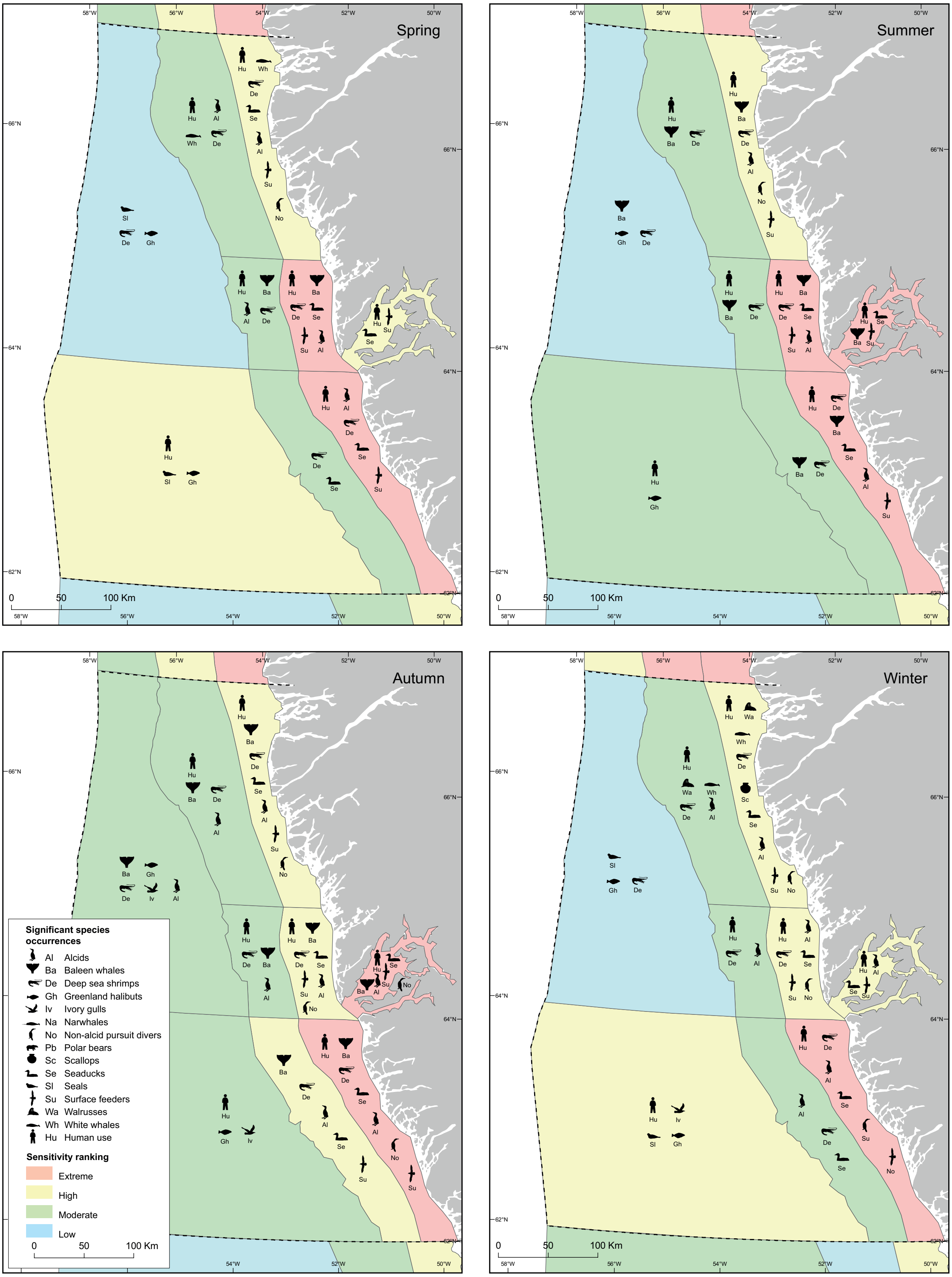



**Figure 7.3.2.** Oil spill sensitivity of offshore areas in the assessment area partly based on the oil spill sensitivity atlas (Mosbech et al. 2000) and further developed in Merkel et al. (2012). Symbols for species or species groups relate to their relative abundance, while the sensitivity ranking also includes other parameters, such as species-specific oil sensitivity, oil residency and human use.

sitive to oil spills during spring. This is mainly due to the large numbers of wintering/migrating birds and extensive human use. Especially the fishery for northern shrimp and snow crab is important in the near-coastal offshore blocks, but also hunting and small-scale fisheries. The offshore block in the southwest corner of the assessment area is also classified as highly sensitive to oil spill due to the extensive Greenland halibut fishery (Fig. 5.3.3) and whelping areas for hooded seals in the western pack ice in March and April.

**Summer (July-August)**

For many of the same reasons as mentioned above for the spring period (baleen whales, human use of northern shrimp and snow crab and seabirds) the near-coastal offshore areas are classified as highly sensitive or extremely sensitive to oil spills during summer (Fig. 7.3.2); although relatively less than during the other seasons (see above). Even though most wintering birds now have left the assessment area, there is still a variety of breeding birds (around 20 species), which largely forage in offshore areas. In addition, over-summering (non-breeding) seabirds utilise the shelf areas and other non-breeding seabirds utilise near-coastal areas during moulting.

**Autumn (September-November)**

During autumn the near-coastal offshore areas are still classified as the most sensitive areas (high or extreme) with respect to oil spills (Fig. 7.3.2). Auks and seaducks from a variety of breeding locations now return to the assessment area, boost bird densities and add to the human use factor. The baleen whales gradually start their migration southwards, but densities remain high throughout most of the period. The northern shrimp and snow crab fishery is still important.

During autumn also the middle offshore block in the south is classified as highly sensitive to oil spills. This is mainly due to a large influx of auks (murres, little auks and puffins) and surface feeders (shearwaters, kittiwakes and fulmars).

**Winter (December-April)**

In general, winter is the most sensitive period among seasons when considering absolute sensitivity values and averaged across all offshore areas in the assessment area. As mentioned above, this is highly influenced by the large number of oil-sensitive seabirds overwintering in the assessment area.

Once again, the near-coastal offshore areas classify as some of the more sensitive blocks within the season (Fig. 7.3.2). In addition to use by seabirds, human use is extensive throughout the period (seabird hunting, northern shrimp and snow crab fishery) and the wintering area for belugas and narwhals extend into the northeastern offshore block. During cold winters the southern areas become increasingly important as the western pack ice may force animals to the south.

As in spring, the offshore block in the southwest corner of the assessment area is classified as highly sensitive to oil spill. Again the extensive Greenland halibut fishery (Fig. 5.3.3) and the whelping area for hooded seals in the western pack ice during March and April are the main contributors to the sensitivity index.

## 7.4 Mitigation of impacts from oil activities

### 7.4.1 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.

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 MMOs or MMSOs (Marine Mammal Observers or Marine Mammal and Seabird Observer). 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. 2005a). 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) 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 MMSOs 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 bioaccumulation 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 OBMs. 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 not been evaluated under Arctic conditions regarding degradation and toxicity. Such evaluation is in high demand for assessing environmental impacts of hydrocarbon activities in Greenland.

In Norway, releases to the marine environment of environmentally hazardous substances 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 are classified according to the OSPAR guidelines, to Norwegian and Danish guidelines, and that they are recorded in the Danish product register PROBAS.
- The use of more rigorous requirements for the documentation of chemicals critical in an environmental context, including the Norwegian requirements to offshore chemicals.
- The use 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.
- 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 & gass 2018). If produced water is to be discharged, international standards (OSPAR) must be applied, i.e. 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 & 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 hydrocarbon 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 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, shipowners must in 2020 largely choose between a fuel inherently low in sulphur (e.g. Marine Diesel Oil or Liquified 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.

**dMitigation 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 structures 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.

### 7.4.2 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 the northwestern part 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. 2016b). 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 blow-out 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 (Mosbech et al. 2000). 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. For example, the ability to compensate for extra mortality due to an oil spill could be increased by a reduction in the hunting pressure (Fig. 7.4.1).

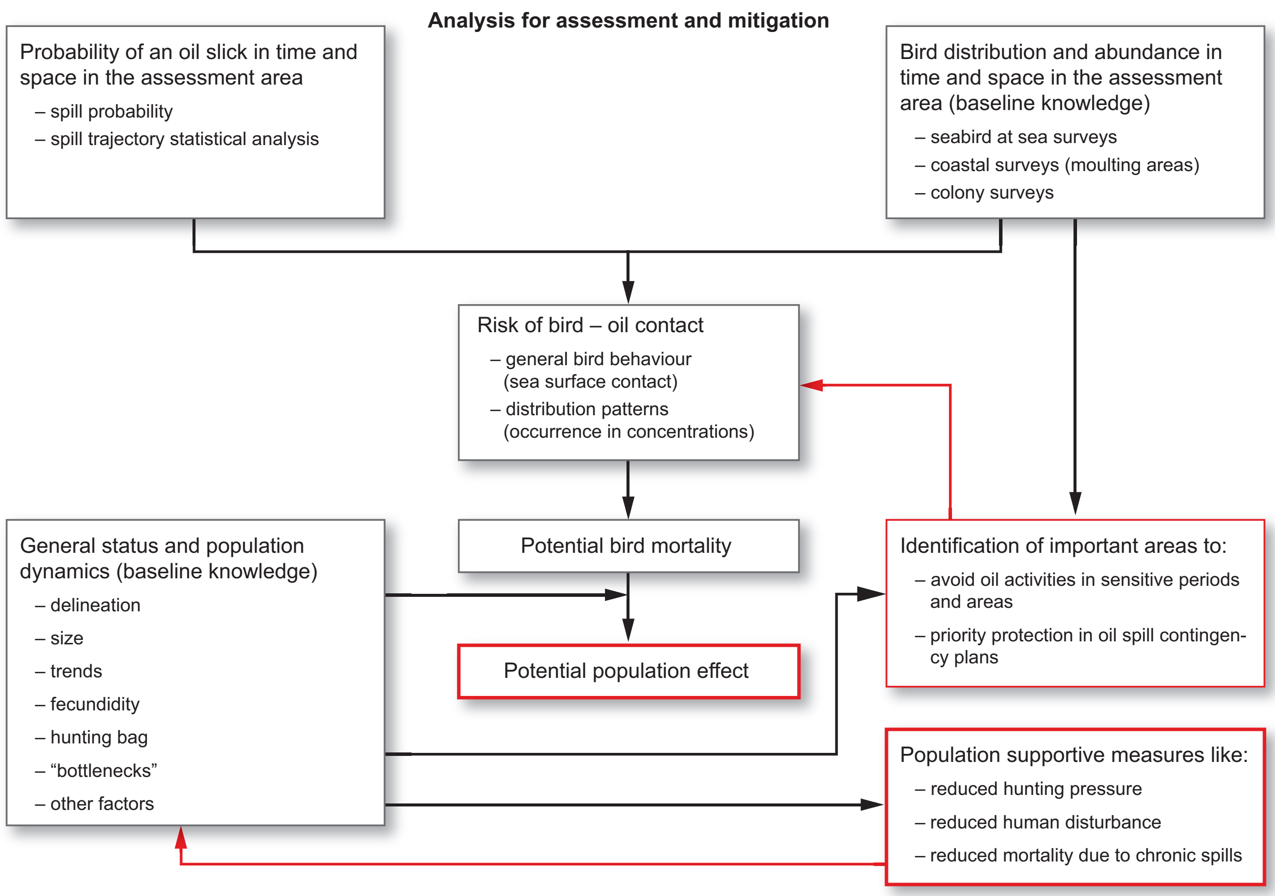



**Figure 7.4.1.** Basic principles of assessing the vulnerability of seabird populations to oil spills. Black lines indicate main effects on bird populations, red lines indicate effect of potential mitigative measures. Indirect effects not included for simplicity (based on Mosbech 1997).

### 7.4.3 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 or site of activity of emission or disturbance, to monitor levels of potentially hazardous substances or physical or biological impacts,
- In the surrounding environment, to document amounts and how far away impacts have occurred. This monitoring should proceed after the activities 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 infrastructure 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) could contribute substantially to minimise impacts.

## 7.5 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 hydrocarbon exploration and exploitation off shore Greenland: Link, Environmental Impact Assessment (EIA) report related to stratigraphic drilling offshore Greenland: Link). An 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

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## 8.1 Preparedness and response

A serious threat to the environment from oil exploration/exploitation activities in the Davis Strait will be a large oil spill (see Chapter 6.3 and 7.2). 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.

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.

If an oil spill occurs during winter, the oil can be trapped in ice. During freezing, ice is developed in the water/ice interface, e.g., the ice grows downwards (Faksness 2008). The oil is also expected to be found in the water/ice interface due to its buoyancy; thus, the oil can be built into the ice during freezing and will thus move with the ice. The oil can migrate vertically in the ice through small brine channels and will be released in spring when the ice melts. 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 Chapter 6.3.5 and Fig. 6.3.1).

In the assessment area, first-year sea ice is present mainly in the northern and western part during late winter and spring, with densities up to 100% ice cover, whereas the south-eastern part is more or less ice free all year around. During cold winters first-year sea ice is also formed in the innermost parts of the fjords. Occasionally during spring, multi-year ice drift into the assessment area from the south. Local glaciers produce many small icebergs in the assessment area, but large icebergs (mainly from East Greenland) usually occur in low numbers. More details about the ice conditions are given in Chapter 2.

In this chapter, measures to respond to marine oil spills are described. The focus is on the Arctic and, in particular, the conditions relevant for the Davis Strait region.

### 8.1.1 Oil spill response planning

Arctic Preventing and avoiding oil spill accidents from exploration and exploitation activities involve the highest health, safety and environment (HSE) standards as well as the technical standards (best available technique (BAT) and best environmental principle (BEP)) together with strict regulations by the authorities and careful planning of the entire process.

In a case of a spill it is important to be well-prepared for a fast and robust response. This includes that the 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 must be available. It is also important to avoid risks for human health during the response activities, why HSE equipment for personnel must 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 by e.g. 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 and the resources at risk and also include oil spill sensitivity of offshore areas segregated by season. An EOS is a desktop analysis that, from an environmental point of view, evaluates decisions regarding inclusion of mechanical recovery, in situ burning and chemical dispersants 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.

Among the mitigating efforts during the exploration drillings offshore in West Greenland in 2010 and 2011, in the Disko West 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 Davis Strait area was completed in 2012, the large Arctic Response Technology Joint Industry Project was undertaken to improve the Arctic oil spill response capabilities (Link). The results of this effort have been drawn upon 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.

### 8.2.1 Mechanical recovery

Mechanical recovery is the method of first choice in many countries, including the countries covering the Arctic, as this method removes the oil from the environment. 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 in some cases.

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. In the northern/western part of the assessment area the ice cover will often be higher than 0-30% during late winter and spring. The southern/eastern part of the assessment area is normally ice-free all year around, but multi-year sea ice can drift into this area in late spring / early summer (see Chapter 2).

Skimmers are available for oil spilled amongst ice; these recovery systems should be able to perform effective ice processing to gain access to the oil for an effective removal. 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, 12% of the oil spilled from Exxon Valdez was recovered mechanically and only 3% after the Deepwater Horizon spill (Beyer et al. 2010, Shigenaka 2014).

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 to increase the natural dispersion of the oil by adding a chemical (the dispersant) to the oil slick. With sufficient mixing energy the oil then breaks up into droplets less than 70 µm, 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 subsea 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 unknown. 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 2007). Dense ice cover (> 60%) would likely increase the window of opportunity for the method, due to a slower weathering of the oil (Lewis & Daling 2007).

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 2007). 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 such as 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. In addition, the dispersants are toxic in themselves or can 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 biodegradation of dispersed oil in the Greenland is discussed in Chapter 8.4, but appears to be rather limited (Johnsen et al. 2019). If chemical dispersant are to be used as an oil spill response method, Johnsen et al. (2019) suggests to include the application of mineral nutrients ('fertilizers') to enhance the degradation.

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 (helitorch from helicopter or, as the latest development, a drone ignition devise). The burning efficiency is considered to be high; e.g. during the Deepwater Horizon incident more than 400 burns took place and the estimated burning efficiency was around 85% (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 dense 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 thicknesses in 30-60 % ice covers (Buist et al. 2017). 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 poorly 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 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 Davis Strait region. The potential success of an in situ burning operation depends to a large extent on the specific ice conditions, the oil type and weathering of the oil and 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 (DNV-GL 2015).

The environmental side effects of the method relate 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 subsequently increased melting of the ice cover, is an issue to consider, although this might be of minor importance for the assessment area.

### 8.2.4 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.

Often shoreline clean-up is a three step operation: First step includes removing the bulk to avoid remobilisation of the oil, followed by the removal of stranded oil and oiled shoreline material and, finally, the cleaning of less contaminated sites (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 Oil spill drift simulations

No oil spill fate simulations have been prepared for the assessment area in connection with previous versions of the SEIA. Oil drift models have been prepared by DMI for the Disko West area and for areas south of the assessment area.

Hence, to give examples of the possible spreading and areas of potential impact from an oil spill in the assessment area, six oil spill simulations were prepared by use of the Seatrack Web model. Note that these simulations are only examples of the oil fate and should *not* be seen as a real oil spill modelling assembly analysis. Such a full analysis is recommended to gain a better understanding of the fate and behaviour of an oil spill in the assessment area.

The Seatrack Web (STW) is the official HELCOM drift model used for calculating the fate of oil spills. It is available online for national authorities and certain research organisations, and in this case assess was provided by the Danish Defence Centre for Operational Oceanography. The Seatrack Web system consists of three main parts: forcing in form of forecasted flow and wind fields, an oil drift model and a graphical user interface (Liungman & Mattsson 2011). For oil weathering, the Seatrack Web build on the SINTEF Oil Weathering Model. The oil drift model does not explicitly consider ice as a moving physical barrier, but focuses on the effect of ice on oil at the surface. Hence, the ice input in the model are ice concentrations and drift velocities (Liungman & Mattsson 2011). The simulation results include trajectories, changes in the oil properties and the overall fate of the spill.

Simulations were carried out for six locations. Three of the spills were located close to the coast on the shelf and three were located offshore outside the shelf area (Fig. 8.3.1). All spills were surface spills, as previously oil spill modelling has shown that due to a fast rise of the oil, no major differences were seen between surface and bottom release continuous oil spills (Nielsen et al. 2006).

For each of the spill locations a continuous oil spill (3.000 tonnes/day for 10 days, total 30.000 tonnes of oil) were simulated with a total simulation length of 20 days. The simulation weather period included data from 1 May- 20 May 2020.

The crude oil Statfjord was used in the modelling as it has previously been selected by GEUS as the most representative oil to potentially be discovered (Boertmann et al. 2013). Statfjord crude oil is a paraffinic and relatively light oil type, API density 886.3 kg/m$^3$, 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.

The results for the six simulations are shown in Fig. 8.3.1. In general, for the oil spill simulations offshore, the oil spill trajectory is towards southwest, potentially affecting an offshore area between Greenland and Canada with a rough estimation of 70.000 km$^2$. For the spill locations on the shelf closer to the coast, the northern and middle location had a somewhat similar behavior as the corresponding offshore locations. However, for the southernmost location on the shelf, the overall trajectory indicates a north-going path before it bends of towards west. Generally, the majority of the oil is found on the surface, around 65-70% of the total oil volume and less than 4% end up in the seabed. For site “South, near shore” and “Mid, near shore”, approximately 3% and 15%, respectively, of the total oil amount is found on the shore at the end of the simulation period. Approximately 30% of the oil evaporates and a 70% water-in-oil emulsion is found after 20 days.

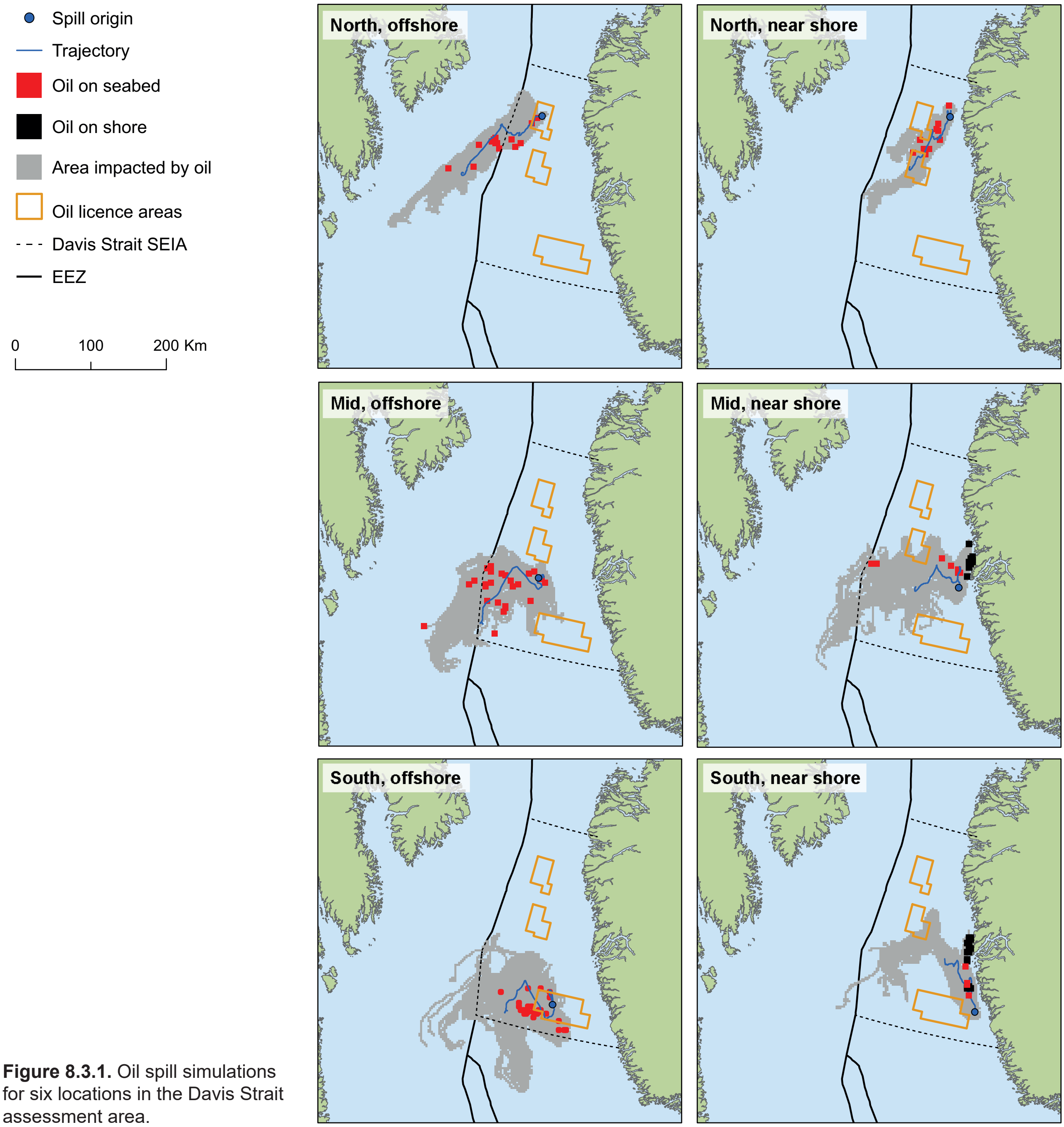
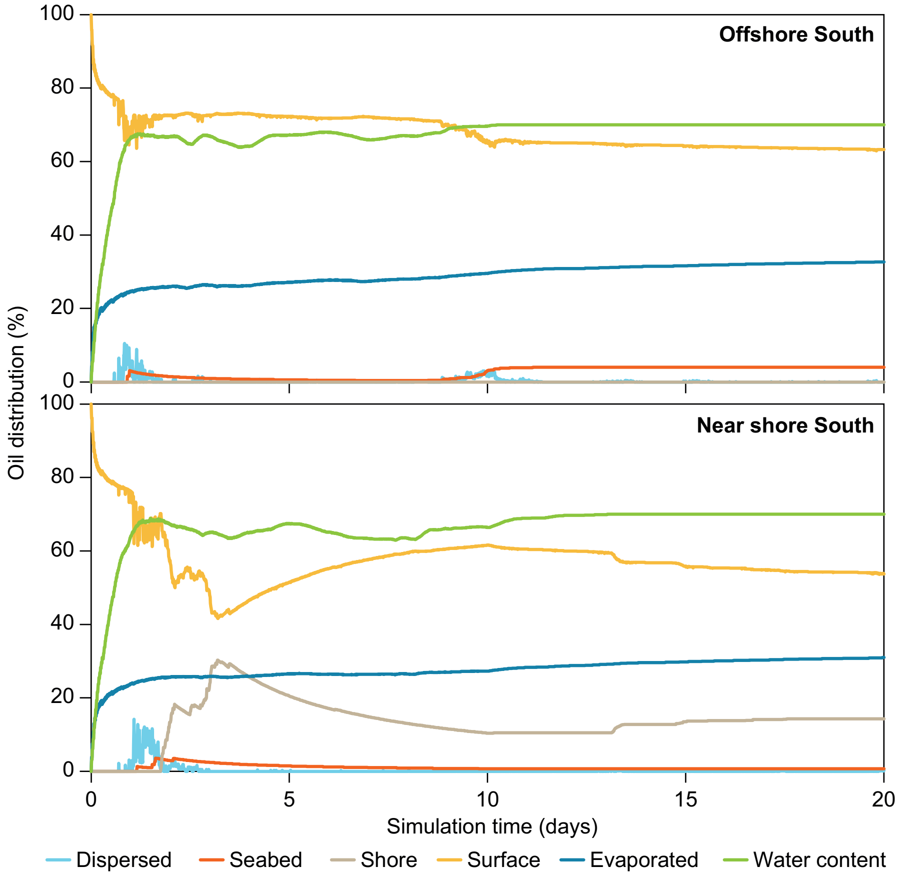



**Figure 8.3.1.** Oil spill simulations for six locations in the Davis Strait assessment area.

A minor dispersion of oil (<10%) was seen around day 2 for all the sites as a result of harsh weather and highlights the specific weather conditions importance of the actual oil fate. Examples of the oil distribution for the two southern most locations are shown in Fig. 8.3.2. The "offshore south" modelling is representative for the locations where the oil is not reaching shore.

The oil spill drift simulations were based on a predefined oil type, predefined spill sites, and to some extent predefined weather and no ice influence. Thus, 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 e.g. the oil viscosity, and a different oil type could for example change the outcome significantly. The spreading of the oil in the simulations is rarely uniform, but large varia-

**Figure 8.3.2.** Examples of oil distribution over time for the two southern locations.




tions in oil film thickness should be expected, and 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, wind and current direction and weather conditions.

## 8.4 Biodegradation of oil

Microbial degradation is a significant factor in the removal of spilled oil in the environment. For example, a large part of the spilled oil from the Deepwater Horizon spill in the Gulf of Mexico was probably removed from the environment by biodegradation (see Chapter 7.3.4). 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. 2018a).

The potential for biodegradation in the Arctic areas is more or less unknown, but several factors such as low temperatures, sea ice and low levels of nutrients may limit the ability for microbial degradation of oil spills (Vergeynst et al. 2018). Knowledge on biodegradation of oil in Greenland waters is limited to a few studies in the Disko Bay area (Kristensen et al. 2015, Scheibye et al. 2017, Brakstad et al. 2018a) and one in the Greenland Sea area (Johnsen et al. 2019).

For the 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 poly aromatic hydrocarbons (PAHs), 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. 2018a), however, found microbial communities capapble of degrading oil compunds, but compared to waters from Norway, the degradation was significantly slower.

In incubation studies with water and sediments from the Greenland Sea (Johnsen et al. 2019) it was found 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).

## 8.5 Concluding remarks on oil spill countermeasures

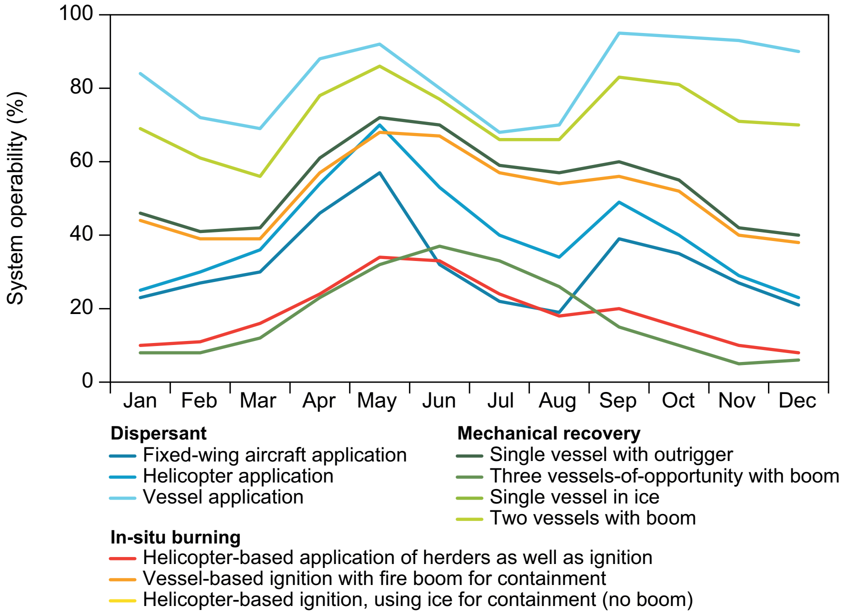
Three overall response techniques are available for combating oil spills in the marine environment: mechanical recovery, chemical dispersion and in situ burning.

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. Relying only on this method for large-scale oil spills will most likely be ineffective. In the assessment area, mechanical recovery is most relevant for minor spills and spills in small confined areas.

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, chemical herding agents can act as barriers containing oil into thicker films suited for burning and thereby in situ burning might be an option. In more dense ice conditions, the ice can act as the containment of the oil. These methods have proved very successful in experiments (laboratory and field), but are not yet developed and implemented at full operational scale. Moreover, strong winds and high waves may also affect the results negatively. Hence, in situ burning might be an effective response option, but under the right conditions.

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 oil between ice floes and secure sufficient mixing are still to be implemented at full operational scale. While chemical dispersion in theory can be effective in removing oil from the surface and facilitate a dilution process, it is only expected to cause a limited increase in the biodegradation processes.

**Figure 8.5.1.** Operational viability of 10 different predefined oil spill response systems for the assessment area. Data input from the portal Circumpolar Oil Spill Response Viability Analysis (Link)




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 ate 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 was published in a report (EPPR 2017) and recently a portal Circumpolar Oil Spill Response Viability Analysis (COSRVA) was made available as a product of the results (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 Fig. 8.5.1. The levels reflect system operability that includes the proportion of time where conditions are favorable or marginal[6] for operability of a specific system. The numbers do 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 particular vessel application of chemical dispersant seems to be relatively high all year round. 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

6 Favourable conditions is when the tactic could be expected to be deployed safely and operate as intended, whereas marginal conditions is when the tactic could be deployed, but operations may be challenged or compromised.

burning also have some potential, particular 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).

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 northern and western part of the assessment area in winter and spring.

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# 9 Area restrictions and knowledge gaps

## 9.1 Area restrictions

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

DCE/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 keep certain areas free from oil exploration (hydrocarbon licences) 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 large areas in Greenland were appointed as no-go areas for oil activities (Mosbech et al. 2019). These areas are especially valuable on a national (and international) scale, in terms of ecological and biological value and sensitivity to oil spills. Other especially valuable and sensitive areas identified in this assessment is also included under criterion 1, unless already covered by criteria 2 or 3.

**Critierion 2: Distance to coast**. Areas close to the coast (baseline) are generally more likely to suffer long-time impact from an oil spill than offshore areas. Moreover, will longer distances from the coast allow for more time for oil spill combat, natural degradation and dispersion of the oil. When DCE/GNIR assessed applications for licence blocks in Baffin Bay and Disko West in 2010 (NERI 2010), special focus was 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 licence areas planned to be opened, should be given a specific environmental assessment, which in particular should 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 6.3.5). 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 seasonally ice-covered Arctic 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(II)/20/REDEG pre-meeting/7. 2/): Status of Offshore Oil and Gas Activities and Regulatory Frameworks in the Arctic*) President Obama stopped leasing consideration of 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 licences is taking place 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:

*"Calls on the EU to promote 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 "Barents Sea Integrated Management Plan" it was decided in the parliament 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):

*p. 132 " 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."*

However, the scientific recommendations for the update of the Integrated Management Plan 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).*

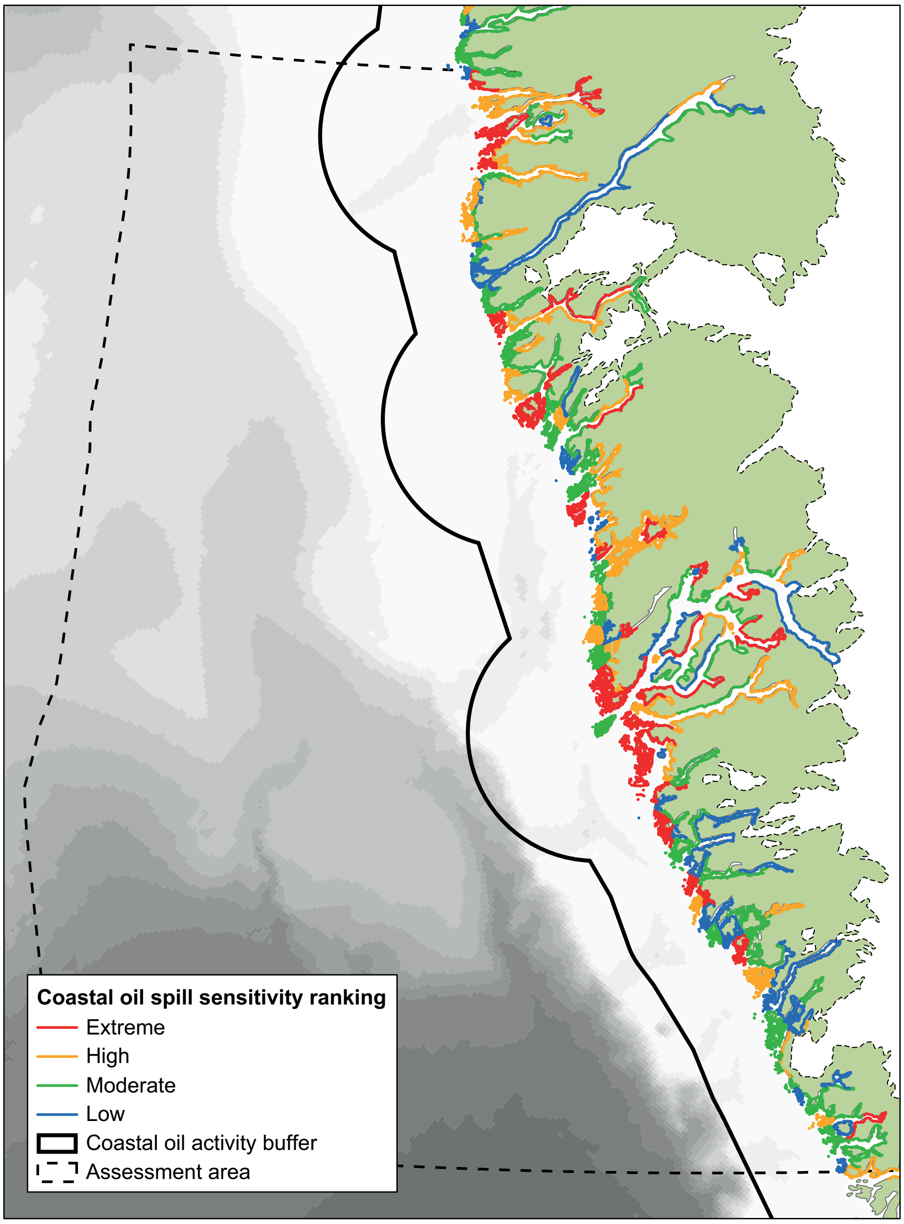
Regarding coastal sensitivity to oil spills, the coast of mainland North Norway is considered vulnerable to oil spills and a 35 km zone from the coast is closed for oil and gas exploration. At coasts considered particularly vulnerable (such as the island Bjørnøya) this zone is 65 km (Klima- og Miljødepartementet 2020).

### 9.1.2 DCE/GINR recommendations on area restrictions

On the basis of the three criteria described above and the current international standards, DCE/GINR recommend the following:

**Critierion 1: Especially valuable areas**
None of the three most valuable and sensitive areas previously identified on a national scale is located within the Davis Strait assessment area (Mosbech

**Figure 9.1.1.** Oil spill sensitivity of the coastline (see Chapter 7.3) and the recommend coastal protection zone of 35 km and 65 km in areas with high biological value and high sensitivity.




et al. 2019). Among other important areas identified or confirmed within the assessment area, most are covered by criteria 2 or 3 (Fig. 9.1.1 – 9.1.3). However, this is not the case for the offshore soft coral garden and VME-candidate identified in Chapter 3.4 (Fig. 3.4.3 and 3.4.6). For this strategy period, it is recommended to consider restrictions in this area also, although the relative importance of this area may change in the future (see benthic knowledge gaps in Chapter 9.2).

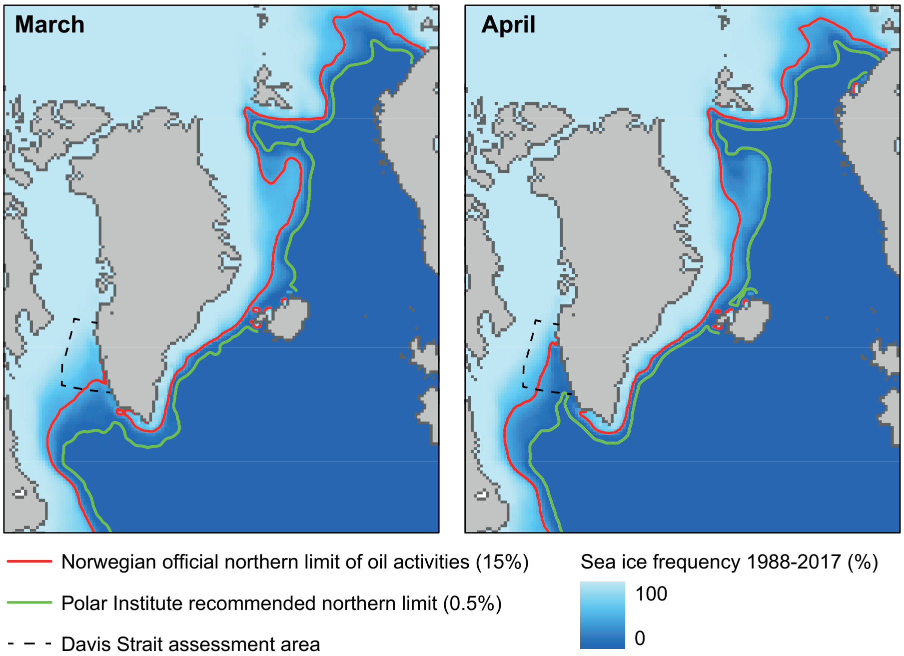
**Critierion 2: Distance to coast**

DCE/GINR recommend to apply the Norwegian criteria for distance to coasts in the Barents Sea. Based on this criteria DCE/GINR recommend to apply a 65 km coastal protection zone in three areas with high biological value and high sensitivity (Fig. 9.1.1, see also Chapter 7.3). The three areas are 1) the fjords and surroundings of Nuuk, 2) the fjords and surroundings of Maniitsoq and 3) an area south of Sisimiut. DCE/GINR recommend that a 35 km coastal protection zone is applied in the remaining Davis Strait assessment area, corresponding to the zone for mainland Norway.

**Critierion 3: Ice cover**

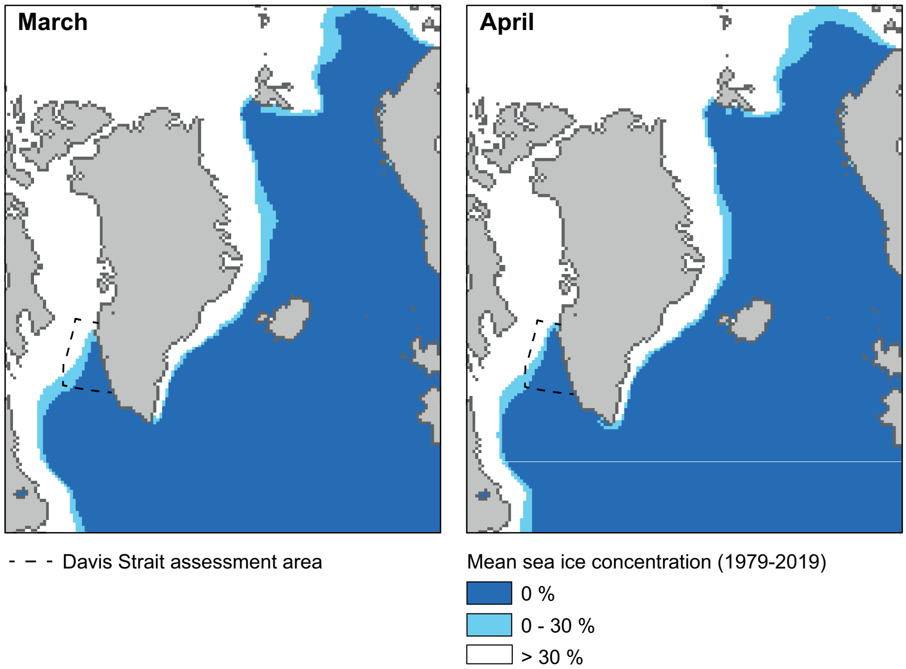
In Fig. 9.1.2 we have applied the Norwegian criteria for maximum frequency of ice cover to Greenland waters for March (the month with maximum ice cover) and April (maximum ice cover in the Barents Sea). When applied to Greenland waters both the 15% frequency limit decided by the parliament in Norway, and the 0.5% frequency limit recommended by the Norwegian research institutions (see above) significantly constrains oil activities in the Davis Strait assessment area.

However, a relevant question is if the ecological conditions and the sensitivity to oil spill of the Barents Sea and the Davis Strait are comparable and in the same range? Significant ecological features in the Barents Sea are the Polar Front, where cold and Arctic waters meet warmer Atlantic waters and the Marginal Ice Zone. The spatial position of the marginal ice zone is highly variable. The primary production is very high at the marginal ice zone in the Barents Sea, and is used by fish, seabirds and marine mammals (Quillfeldt 2017). The situation off West Greenland is to some degree similar to the Barents Sea, because the waters in the western part can be ice-covered in winter and spring and warm and cold waters meet and create fronts. The marginal ice zone is less well studied in Davis Strait than in the Barents Sea and is probably less important for the eastern Davis Strait ecosystem. The primary production in Eastern Davis Strait is known also to be driven by tidal upwelling events along the banks. The primary production fuels the food web, and is important for fish, seabirds and marine mammals. Consequently, the shrimp and fish populations, sustaining the important fishery in Davis Strait, are probably to a lesser extent than the fish populations in the Barents Sea fueled by




**Fiure. 9.1.2.** In Norway, the politically agreed northern limit of oil activities was in 2020 set at 15% frequency (probability) 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) (Klima- og Miljødepartementet 2020). The recommendation from the Norwegian Polar Institute and Marine research Institute was that the threshold should be lowered to 0.5% probability of ice cover in April, based on the ecological importance of the marginal ice zone (Havforskningsinstituttet 2020, Norsk Polarinstitutt 2020). In the map, we have calculated both of these threshold values for ice cover in 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). An area is defined as ice covered if the sea ice concentration exceeds 15%. See also Annex A (Fig. A1) for a supplementary ice analysis.

**Figure 9.1.3.** Mean sea ice concentrations in March and April over the time series 1979-2019, based on data from National Snow and Ice Data Center (Stroeve & Meier 2018). See also Annex A (Fig. A1) for a supplementary ice analysis.




the primary production in the marginal ice zone. However, in spring, also concentrations of seabirds of international importance are found in the open water area and along the ice edge in the Davis Strait and there is a whelping area for hooded seal in the marginal ice zone (Chapter 3.7, LeBlanc et al. 2019, Merkel et al. 2019).

Conventional methods for combatting oil spills are in general not effective in more than 30% ice cover and there are yet no proven methods available for handling major oil spill in drift ice and in the dark (see Chapter 8). The 30% mean sea ice cover in March and April in the assessment area is shown in Fig. 9.1.3. Further, research and development of such method are halted after the major oil companies have withdrawn from the Arctic.

As the relative ecological importance and sensitivity of the marginal ice zone in the eastern Davis Strait is assessed to be somewhat less than in the Barents Sea and further north in West Greenland, a comparable environmental risk might be obtained by using a line between the one defined by the Norwegian criterion of 15% ice frequency (Fig. 9.1.2) and the 30% mean sea ice cover in March (Fig 9.1.3). During the internal hearing in the Greenland administration in 2021, a supplementary ice analysis has been received from Nunaoil, see Annex A.

### 9.1.3 Conclusion on area restrictions for oil exploration (hydrocarbon licences)

Based on the three criteria and the above analysis and to be in line with high international environmental standards, DCE/GINR recommend for this strategy period (2020-24) to consider:

- applying a coastal protection zone of 35 km and 65 km as indicated in Fig. 9.1.1 and supplemented by the offshore area for the VME candidate shown on Fig. 3.4.3.
- applying an ice cover limitation between the one defined by the Norwegian criteria of 15% ice frequency and the 30% mean sea ice cover in March (Fig. 9.1.2 and 9.1.3).

For the recommendation on area restrictions based on distance to coast (criteria 2), it is not likely that there will be new information changing this recommendation in the near future. However, the recommendation based on criteria 3 may change, as this rely on the mean ice cover and the lack of proven methods available for handling major oil spill in drift ice and in the dark. With climate change mean ice cover is expected to decrease and better methods for handling oil spills may be developed. Further, there is some uncertainty on the assessment of the key ecological importance and sensitivity of the marginal ice zone in this region. It is therefore recommended to study the ecological importance and sensitivity of the marginal ice zone within the assessment area.

## 9.2 Knowledge gaps

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In general, information is needed for three important tasks in relation to oil activities: a) assess, plan and regulate activities so the risk of impacts is minimized; b) identify the most sensitive areas, and c) provide a baseline for 'before and after' studies in case of impacts from large accidents. Moreover, climate change in the Arctic is rapid, altering the ecological conditions and demanding long-term studies and monitoring to understand the ecosystem dynamics and the effects of human activities. Long time series are invaluable and a coordinated long-term monitoring programme should be considered. A programme of this kind could take advantage of existing monitoring of utilised species and of international standards being developed by the Circumpolar Biodiversity Monitoring Programme under the Arctic Council's Commission for the Conservation of Arctic Flora and Fauna (CAFF).

Below is an annotated list of the main information needs and knowledge gaps identified in relation to oil and gas activities in the Davis Strait assessment area. This list is not exhaustive; new gaps may appear, for example when the implications of climate change become more apparent.

Some knowledge gaps are specific to the assessment area while others are generic to oil activities in the Arctic, *cf.* the Arctic Council's Oil and Gas Assessment (Skjoldal et al. 2007). The latter should be addressed by cooperative international research, and participation by Greenland can secure that specific Greenland perspectives are included. The most important of these are also listed below.

### 9.2.1 Specific knowledge gaps for the assessment area

**Location of recurrent offshore hot spots for biological productivity and biodiversity**

*Relevance*: These hot spots include recurrent (predictable) areas with localised (in time and space) primary production, high concentrations of fish and shrimp larvae, zooplankton, seabirds and marine mammals. The sites are sensitive to oil spills and possibly release of produced water (formation water with oil residues discharged during oil production). In general, knowledge from the offshore areas is limited, including the biological role of the western pack ice. Recently, a southward current along the Southwest Greenland continental shelf was discovered and may imply that Arctic zooplankton is more important in the offshore areas, compared to the more studied coastal areas, which is dominated by sub-Arctic species.

*Methods*: Surveys, remote sensing and modelling of oceanographic data.

**Shrimp larvae and snow crab larvae distribution, drift and settling in the Davis Strait**
*Relevance*: The northern shrimp fishery is the single most important industry in Greenland and snow crab is also an important fishery. The larvae move passively in the upper part of the water column, where they can be exposed to oil spills and produced water. It is important to identify recruitment areas and recurrent concentrations including the larvae depth distribution. Some studies have been conducted (see Chapter 3.6.1), however the northward movement of the fishery indicate that further updated studies are needed. It is unknown whether the northward movement of the shrimp is caused by increased predation by the returning cod in southern Greenland, due to increased bottom temperatures or some other factors.

*Methods*: Studies of the early life history of northern shrimp and snow crab, including larval drift, variation in settling and occurrence of benthic stages and interaction with climate change. Dedicated field studies and modelling.

**Benthic flora and fauna – identification of sensitive areas and baseline (diversity, spatial variation, biomass, primary production)**
*Relevance*: Benthic flora and fauna is sensitive to oil spills, to placement of structures and to release of drilling mud. Sponge gardens and cold-water coral reefs are especially sensitive to sedimentation of drilling mud and cuttings. Sensitive benthic areas are important to consider when subsea activities are to take place and when drilling locations are identified. Recent studies have shown that sensitive benthic VME's are present within the assessment area, but present monitoring is biased towards the more trawl impacted areas. Data from the untrawled areas, that likely sustain more pristine habitats, are generally lacking. For shore habitats (sub tidal and intertidal zone) knowledge on benthic flora and fauna is especially important for identification of the most oil spill sensitive areas, where shoreline protection measurements can potentially be established during an oil spill. Local studies on macroalgal diversity, biomass, production and spatial variation have recently been conducted in Southwest Greenland, however, information is still missing for a large part of the assessment area.

*Methods*: Dedicated regional (strategic) field surveys in combination with ongoing monitoring at GINR/DCE and studies carried out by the licence holders during site surveys.

**Fish – biology, spawning areas, stock relationships of important species (esp. Greenland halibut, capelin, sandeel, lumpsucker, Atlantic cod and polar cod)**
*Relevance*: Fish, especially egg and larvae, can be sensitive to oil spills and produced water and fish can be tainted if there are oil components in the sediment. Adult fish can be displaced by acoustic activities, such as seismic surveys, and this displacement can influence stock recruitment if spawning fish are scared away from optimal spawning areas. Very little is known about polar cod within the assessment area. Larvae have been observed, but it is unknown if they spawn within the assessment area, i.e. in the western pack ice.

*Methods*: Dedicated surveys, tagging, modelling and other methods for identification of important spawning sites, including the depth at which spawning occurs, larval drift and retention areas with high concentrations of larvae. This is especially pertinent for Greenland halibut, for which the main spawning grounds are in the central Davis Strait, and for species that spawn in coastal areas where oil concentrations are more likely to be high during an oil spill.

Behavioural and physiological experiments on the reaction of selected local fish to sound from seismic surveys.

**Fish and shellfish - linking recruitment and the physical environment**
*Relevance*: A better understanding of the dynamics between the physical environment and the variability in the fishery resources is important to be able to assess the vulnerability of the resources and how this may change as a consequence of climate change. A better understanding of the recruitment success of fish and shellfish requires comparative studies of zooplankton, fish larvae, hydrography and climate, from inshore to offshore areas. The exact mechanisms determining plankton community distribution and the specific adaptations of these communities to physical and chemical gradients are still unknown. Currently, such studies are only made in the mouth of Nuup Kangerlua as part of the MarinBasis program in Nuuk.

*Methods*: Dedicated surveys and modelling.

**Seabirds – distribution and abundance of breeding and wintering birds, migratory movements and concentrations, population delineation and population dynamics, especially for declining or less known species**
*Relevance*: Seabirds are very sensitive to oil spills and knowledge of seabird concentration areas is important to mitigate impacts. The assessment area is an internationally important key wintering area for seabirds from all over the North Atlantic. For some species, especially murres and kittiwakes, knowledge on migratory movements has improved since the previous assessment (see Chapter 3.7), leading to better opportunities for planning, mitigation and regulation of oil activities and management in general (e.g. Frederiksen et al. 2019)

*Methods*: Surveys and ecological studies in breeding colonies. Tracking of migrating birds by satellite telemetry, and geo-locators, bio-loggers, and molecular techniques combined with dedicated surveys by ship and aircraft (in combination with the hot-spot studies listed above). For some species, especially murres and kittiwakes, knowledge on migratory movements has improved since the previous assessment (see Chapter 3.7), leading to improved planning, mitigation and regulation of oil activities and management in general (e.g. Frederiksen et al. 2019)

**Marine mammals – distribution and abundance, relationship to sea ice, stock identity and movement, general biological knowledge of less known species and of endangered species**
*Relevance*: Marine mammals are sensitive to oil spills and to anthropogenic noise. To mitigate impacts and understand the consequences of these impacts it is important to know where marine mammals are, why they are there and what their status is. The recent observations that some species of baleen whales appear to have shifted their main distribution from West- to East Greenland needs to be studied further.

*Methods*: Tracking by means of satellite transmitters and bio-loggers, dedicated surveys, passive acoustic monitoring, molecular studies and mark-recapture (tags, biopsies or photo-ID, depending of species).

**Marine mammals – reactions to noise from drilling and seismic studies**
*Relevance*: Marine mammals are sensitive to noise and there is a risk of displacement from critical habitats especially for whales if there is a cumulative

impact from concurrent activities in several licence blocks. Knowledge on reaction distance and the potential for habituation to noise is important.

*Methods*: Field studies, passive acoustic monitoring, satellite tracking.

**Oil spill sensitivity atlas - update**
*Relevance*: The oil spill sensitivity atlas is an important tool when deciding on future oil activities, in oil spill contingency planning and when responding to an oil spill. For the assessment area, the sensitivity atlas was published 20 years ago (Mosbech et al. 2000) and an updated version incorporating the new available information is recommended.

*Methods*: GIS mapping and analyses.

### 9.2.2 Knowledge gaps generic to the Arctic

The effects of oil and different oil components on marine organisms have to some degree been studied in laboratories. However, effects in the field and especially in the Arctic are less well known and because the Arctic food web is dependent on a few key species, effects on these would be very relevant to study in order to assess and mitigate potential impacts. Assessment criteria and adequate monitoring strategies should be established.

Below some important issues that should be addressed before production activities are initiated in Greenland are listed. Some of these should be addressed by international research cooperation. Many relate to how spills and releases behave and impact organisms under Arctic conditions.

In relation to oil spills some important issues to address include:
- Biological effects and sensitivity to PAHs and other oil components of key species (e.g. sandeel, capelin) under Arctic conditions
- Rate of degradation of oil and chemicals in Arctic water and sediment
- Oil vapours and their effects on marine mammals

Similar issues relating to produced water are:
- Fate, behaviour and toxicity of produced water in cold and ice-covered waters
- Biological effects and sensitivity of key species (e.g. sandeel, capelin) to the different components of produced water

Interaction of contaminants:
- There are knowledge gaps concerning the interactions between impacts of oil related pollution and other contaminants such as POPs and heavy metals in relevant species living in the assessment area. Integrated studies on these issues are needed.

### 9.2.3 Ecotoxicological monitoring

Assessment criteria have to be established when using biological indicators to assess whether there is an unacceptable impact from discharges. These will be based on ecotoxicological tests that cover the sensitivity range of relevant species at different trophic levels. To establish such environmental assessment criteria (EAC) toxicological tests have to be developed or adapted using relevant species from the Davis Strait. Knowledge concerning species' sensitivity, assessment criteria as well as an adequate monitoring strategy should be developed.

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# Annex A: Supplementary ice analysis

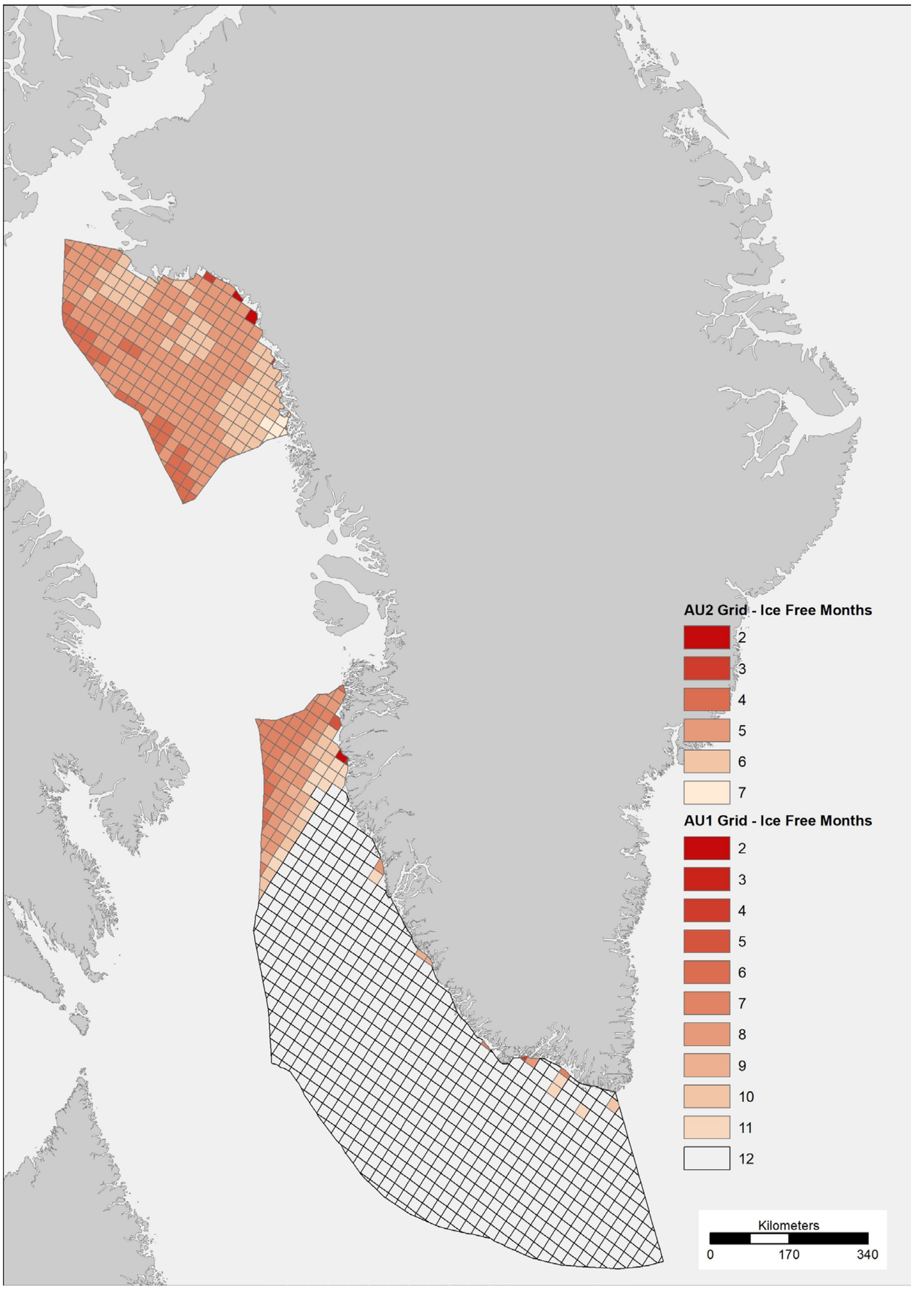


**Figure A1.** Map prepared by NUNAOIL showing the number of "ice free months" per year, defined as the number of months per year where sea ice cover is <10 %. The calculation is based on two sea ice cover maps per month (start and mid-month) for one full year (2019-20) (n=24), using the datasetSea Ice Index Version 3 from National Snow and Ice Data Center (Fetterer et al. 2017). 10 % was used as threshold, as NUNAOIL considers oil exploration activities to be unaffected by sea ice at concentrations below this value. The map is included in the report, because The Ministry of Foreign Affairs and Energy, Government of Greenland Government, suggested this during the internal hearing process. Most other sea ice maps in the report are based on much longer time series (Fig. 2.3.2, 9.1.2, 9.1.3), and as the current map is based on only one year of data, and we know that there is a large variation in ice conditions between years, these data does not change the conclusion of the report. However, this map can be considered as an example of a year with little ice, which is expected to become more frequent in the future.

# Annex B: Names of animals (vertebrates) mentioned in the report

| BIRDS<br>Vernacular name (alphabetical) | Aves<br>Scientific name | Fugle<br>Dansk navn | Timmisat<br>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 | Appaliarsuk |
| 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 | ? |

# Annex C: Abbreviations and acronyms

| | |
|---|---|
| AAW | Arctic Atlantic Water |
| AMAP | Arctic Monitoring and Assessment Programme, working group under Arctic Council |
| AMOC | Atlantic meridional overturning circulation |
| 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 |
| BBPW | Baffin Bay Polar Water |
| BC | Black carbon |
| BCB | Bering-Chukchi-Beaufort Sea |
| BEP | Best Environmental Practice |
| BFR | Brominated flame retardants |
| BIC | Baffin Island Current |
| BIOS | Baffin Island Oil Spill study |
| BMP | Bureau of Mineral and Petroleum, Greenland Government |
| BTX | Benzene, Toluene and Xylene components in oil, constitute a part of the VOCs |
| BTEX | Benzene, Toluene, Ethylbenzene and Xylene, constitute a part of the VOCs |
| 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 |
| dSPMW | deep Subpolar Mode Water |

| | |
|---|---|
| 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 |
| EGC | East Greenland Current |
| 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 |
| WGC | West Greenland Current |
| WG-SBI | West Greenland-Southeast Baffin Island population of walrus |
| WGSC | West Greenland Slope Current |
| WSF | Water Soluble Fraction |
| ww | Wet weight |
| ZSL | Zoological Society of London |

# DAVIS STRAIT – AN UPDATED STRATEGIC ENVIRONMENTAL IMPACT ASSESSMENT OF OIL AND GAS ACTIVITIES IN THE EASTERN DAVIS STRAIT

This report is an updated strategic environmental impact assessment of activities related to exploration, development and exploitation of oil and gas in the eastern part of the Davis Strait between 62° and 67° N – the Davis Strait licensing round area. The previous version from 2012 needed an update. The report includes new research results from the area and a new assessment. 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. The report further compares the general level of environmental risk for oil activities in seasonally ice covered areas in Eastern Davis Strait with the criteria recently implemented by Norway in the updated Barents Sea Management Plan. DCE/GINR recommends to consider further area restrictions for oil licensing within the present strategy period (2020-2024).

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