GREENLAND SEA – AN UPDATED STRATEGIC ENVIRONMENTAL IMPACT ASSESSMENT OF PETROLEUM ACTIVITIES

2nd revised edition

Scientific Report from DCE – Danish Centre for Environment and Energy No. 375 2020

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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 Greenland See off northeast Greenland. The original version from 2012 needed an update before the area will be subject to new licencing rounds in 2021 and 2022. The report includes the results of an extensive research program in the area in 2016-2019, a program initiated to improve the knowledge base for future regulation and planning of oil activities. 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 recommends to consider not to open the assessment area for oil licences in this strategy period (2020-24 strategy).
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Content

Preface

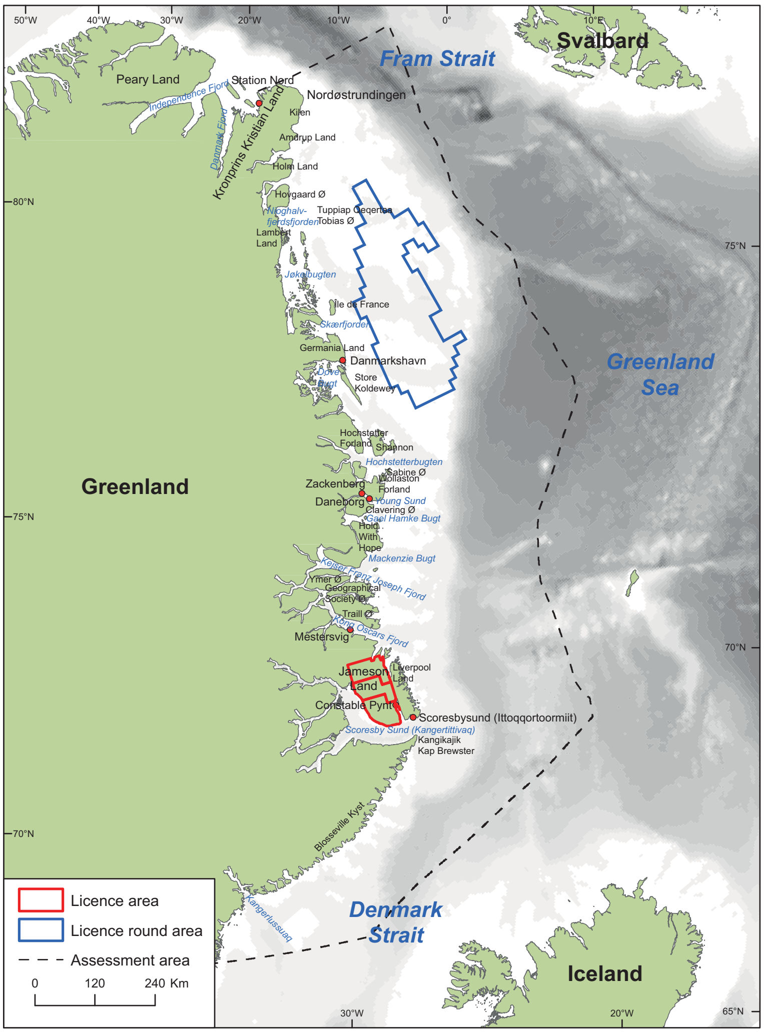
The previous version of this strategic environmental impact assessment covering the western Greenland Sea (Boertmann & Mosbech 2012) included a section on information needs. These needs were transformed into a catalogue of relevant research projects (*Strategic Environmental Study Plan for Northeast Greenland*) to be presented to the licence holders of the five licence blocks on the Northeast Greenland shelf. The licence obligations include support to environmental background studies, and this support funded (via the Government of Greenland) a number of the studies proposed in the catalogue. The results of these studies are the foundation of the new information incorporated in this updated strategic environmental impact assessment.

Meanwhile, all five licences have been handed back, and today no petroleum exploration activities take place in the Greenland part of the Greenland Sea. However, the Oil and Gas Strategy 2020-2024 include the opening of the sea off Northeast Greenland for new applications in 2021 and the sea off central East Greenland in 2022 (Grønlands Selvstyre 2020).

Preface to 2nd revised edition

The revisions are based on the comments recieved during the hearing process, which ended 30 Nov. 2020. This coincided with the decision of new management plans for activities in the Norwegian waters in 2020 including new limits for oil and gas exploration in the Barents Sea. This new regulation is referred to in the present update.

Summary and conclusions



Summary figure 1. The assessment area with the most important place names shown. Red dots indicate inhabited sites: Towns (only one: Ittoqqortoormiit/Scoresbysund), military outposts, weather and research stations etc. See also text. There are currently no offshore hydrocarbon licences in the area. The perimeter of the offshore blocks available in the licencing round in 2012 is shown in blue and the three active GGO onshore hydrocarbon licence blocks in Jameson Land are shown in red.

This document is an updated strategic environmental impact assessment (SEIA) of activities related to exploration, development and exploitation of oil and gas in the sea off Northeast Greenland between 68° and 82° N; the Greenland Sea assessment area (Summary figure 1).

The previous version was issued in 2012 (Boertmann & Mosbech 2012), and this is now updated with new environmental information, primarily obtained during the *Strategic Environmental Study Program for Northeast Greenland*, carried out in the years 2016-2019.

This study program was based on the Strategic Environmental Study Plan for Northeast Greenland developed in 2013 which included the information needs identified in the previous edition of this SEIA (see Annex C). The aim of this was to provide the necessary environmental information for planning and regulating oil exploration activities and oil spill response in the western Greenland Sea. The plan included projects on marine ecology, biodiversity as well as toxicology, degradation of oil and contaminants, an oil spill sensitivity atlas, and an updated SEIA (present document). The plan focused on three key questions, which address the main environmental concerns related to oil activities in the area:

1. How to conduct and regulate increased seismic activities in the Greenland Sea so that significant impacts from underwater noise on marine mammal populations are avoided or minimized?
2. How to regulate discharge of drilling mud and chemicals from exploration drilling in the Greenland Sea, so it is certain that significant impacts are avoided, and the best solution is selected based on specific information on toxicity and degradation in the high Arctic environment?
3. How to minimize the environmental impacts if an oil spill occurs based on:
   a) Planning of exploration activities so the most sensitive areas and periods are avoided.
   b) Planning of oil spill preparedness and response so efficient and environmentally beneficial response options for the Greenland Sea are available and can be selected operationally using a Net Environmental Benefit Analysis (NEBA).

These key questions were then addressed by eleven interlinked themes with a number of project proposals. The study plan was presented to the licence holders of the five licence blocks, and most of the proposed studies were subsequently funded by these companies. The Strategic Environmental Study

Program for Northeast Greenland studies included (the results published so far quoted in brackets):

- A ship-based integrated survey of oceanography and ecology in the Greenland Sea in August/September 2017 (Hansen et al. 2019b, Møller et al. 2019, Jørgensen et al. 2019, Bouchard 2020).
- Studies of benthic communities (Hansen et al. 2019b, Wegeberg 2020b).
- A study of tidal and subtidal macroalgal communities in 2017 and 2018 (Wegeberg et al. 2019).
- Seabird studies: an aerial survey of seabirds offshore Northeast Greenland simultaneously with the ship-based survey in August/September 2017, studies of ecology and distribution of ivory and Sabine's gulls in 2017, 2018 and 2019 (Boertmann et al. 2019a, b, Frederiksen et al. 2019).
- Marine mammal studies: aerial surveys winter and summer 2017 and 2018 and deployment of passive acoustic monitors (PAM) in 2016 and 2017, effect studies of seismic noise on narwhals and satellite tracking of bowhead whales, harp seals, ringed seals and polar bears (Hansen et al. 2019a, Heide-Jørgensen et al. 2019a, b, Laidre et al. 2019, Rosing-Asvid & Dietz 2018, Rosing-Asvid & Zinglersen 2018, Videsen et al. 2019, Williams et al. 2017).
- Effects of oil compounds on Calanus hyperboreus, on bivalves and other benthic organisms (Agersted et al. 2018, Gustavson et al. in prep.).
- Effects of dispersed oil on macroalgae (Wegeberg et al. 2020a, in prep.).
- Degradation of oil in water and sediment of the Greenland Sea (Johnsen et al. 2019).
- In situ burning: environmental impacts of residues and burning in ice (Fritt-Rasmussen et al. in prep. a, b).
- Development of an oil spill sensitivity atlas covering Northeast and Southeast Greenland (in preparation).
- Analysis of hunting habits in Ittoqqortoormiit and Tasiilaq (Flora et al. 2019).

The results of these studies are incorporated in the chapters and text boxes in this report and are presented in the above mentioned references and summarised in Annex D. These results have considerably improved the knowledge base on both ecological and oil spill issues in the assessment area.

This new version of the SEIA was prepared by the DCE – Danish Centre for Environment and Energy and the Greenland Institute of Natural Resources (GINR). It was a part of the *Strategic Environmental Study Program for Northeast Greenland*, funded by the Government of Greenland (Mineral Licence and Safety Authority – MLSA and the Environmental Agency for Mineral Resource Activities – EAMRA).

The assessment area is shown in Figure 1, and is the region which could potentially be impacted by oil exploration and exploitation activities within the licensing area. However, an oil spill may drift beyond the borders of this area.

Exploration activities are likely to take place during summer and early autumn, because darkness, harsh weather and particularly sea ice hamper activities in winter and spring. However, if oil production is initiated, activities will take place throughout the year.

Glossary to some terms used in the SEIA

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

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

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

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

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

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

The physical environment

The physical environment of the study area is briefly described with focus on oceanography and ice conditions. Sea ice and icebergs are present throughout the year, with the lowest concentrations of sea ice in August and September. One of the most important physical features for the biological environment is the polynyas (ice-free or almost ice-free areas surrounded by sea ice). The most important polynyas are found at the entrance to Scoresby Sund, at Wollaston Forland (the Sirius Water Polynya) and at the northeast corner of Greenland (the Northeast Water Polynya), see Figure 12. These polynyas become free of ice very early in spring (April) and also have ice-free parts throughout the winter.

More detailed accounts of physical conditions in the assessment area have been issued by the Danish Meteorological Institute (DMI) in 2008 and 2011 (Hvidegaard et al. 2008, Pedersen et al. 2011).

The biological environment

The assessment area is situated within the Arctic, with all the typical biological properties of this climatic region: low biodiversity, with some species very abundant, and a relatively simple food web that has only a few levels from primary producers to top predators, and key species that play important roles in the ecology of the region (Figure 21).

The primary production in the assessment area is generally low, but locally there are areas with enhanced production - predominantly in the Northeast Water Polynya and probably also in the other polynyas. The 2017 studies showed that nitrate depletion occurred on the shelf in late summer, but there was a relatively high production above the shelfbreak. Previous studies have also shown relatively high production in the marginal ice zone.

The zooplankton is an important link between the primary producers and the higher levels of the food chain. The large copepods (*Calanus*) play a major role here. The 2017 study showed that community composition was clearly associated with the oceanography and bathymetry of the area, with the highest biomass of zooplankton over the shelfbreak where *Calanus* were abundant. High biomass was also found locally near the coast, and here it was dominated by larger zooplankton, such as krill. Composition of species reflected the origin of the water: the North Atlantic *Calanus finmarchicus* was present at all stations, but much more abundant at the stations off the shelf in the Greenland Sea. The larger Arctic *Calanus* species *C. glacialis* and *C. hyberboreus*, on the other hand, had the opposite patterns, and were not found at all in the upper 50 m off the shelf break. Earlier studies in the Northeast Water Polynya indicated relatively low biomass of zooplankton, and a large part of the primary production there apparently ends up in the benthos (pelagic-benthic coupling).

There is no vegetation in the tidal zone due to the impacts of sea ice. Below this zone there is a well-developed vegetation of macroalgae, which is however very heterogeneous, and determined by light, substrate and ice. If conditions are favourable, kelp can be found down to depths of 40 m, and red algae even deeper. Kelp forests were found as far north as the survey in 2017 covered (76° 45′ N). Locally, the macroalgae vegetation can be very rich in the form of kelp forests and seaweed meadows.

Benthos is the fauna living on and in the seabed. Benthic macrofauna species (molluscs, crustaceans, echinoderms etc.) are an important component of coastal ecosystems. The communities have a high biodiversity and many of the organisms are long-lived, but compared to West Greenland, biomass and abundances are low. The benthos consume a significant fraction of the available production and are in turn an important food source for fish, seabirds and mammals. Studies in 2017 (*Strategic Environmental Study Program for Northeast Greenland*) found rich benthic communities in coastal waters and also on the shelfbreak, where a cold-water coral community was located.

In and on the underside of the sea ice a specialised community exists, called the sympagic flora and fauna. Algae live here and are grazed upon by crustaceans, which in turn sustain populations of polar cod and Arctic cod. In other areas, the primary production in and below the sea ice varies considerably depending on sea ice diversity and longevity. The ice cover is important for spawning of polar cod, and their eggs accumulate along the underside of the ice.

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

Both diversity and abundance of fish in the assessment area is low. The most important species is polar cod, which is a key species as it constitutes an important link in the food web between zooplankton, seabirds and marine mammals. It was caught on almost all trawl stations during the *Strategic Environmental Study Program for Northeast Greenland* in 2017, and high biomasses were found on the shelf break. The 2017 studies also revealed aggregations of lanternfish in waters more than 400 m deep. An important fish in the coastal waters is Arctic char, which spend the summer in coastal waters, and spawn and winter in many rivers.

Seabirds are an important component of the ecosystem of the assessment area, and they show wide variation in abundance within the area and throughout the year. In the breeding season (summer), they assemble in colonies along the coasts, and high numbers are found particularly at the large polynyas. This is most pronounced in the mouth of Scoresby Sund, where millions of little auks breed in numerous colonies and where two colonies of thick-billed murres are located. At the Northeast Water there are large colonies of northern fulmar, and ivory gulls have their primary breeding area in Greenland here. At the Sirius Water Polynya, kittiwakes and common eiders breed in high numbers. Some of the seabird species utilise the adjacent waters more than 100 km away from their nests. A study in 2017 and 2018 focused on the habitat use of Sabine's gulls and ivory gulls, and showed that the Sabine's gulls were feeding in waters close to the breeding site (30-40 km), while the ivory gulls were feeding up to 500 km away from their nests. In autumn and probably also spring, densities of seabirds on the shelf are generally low, but little auks in particular may occur in high densities where the birds moult after the breeding season. Such high density spots were frequent above the shelf break in August/September 2017. Almost all birds leave the assessment area for the winter, except for the southernmost part, where some thick-billed murres, little auks and black-legged kittiwakes spend the winter.

Thick-billed murre and black-legged kittiwake are red-listed in Greenland due to declining populations. Other red-listed (threatened or near threatened) bird species which occur in the marine part of the assessment area include Sabine's gull, Arctic tern and light-bellied brent goose. Ivory gull is also red-listed (both nationally and internationally), mainly because of the expected reductions in its primary habitat – sea ice. The coasts of the Northeast Water is a stronghold for this species.

Marine mammals constitute the top levels in the marine food web, with seals, whales and on top of them all polar bears. They exhibit very different life strategies: ringed seals and polar bears usually stay within the assessment area year round, although especially the bears extensively use both the coasts and the ice-covered offshore areas (documented by tracked individuals in 2017-2019); narwhals perform regular migrations between distinct summer habitats in the fjordlands and winter habitats on the shelfbreak; bowhead whales perform long trips to Svalbard and further east (documented by tracked individuals in 2017-2019); harp seals and hooded seals have specific whelping grounds on the drift ice and disperse widely in the North Atlantic after the whelping season (harp seal movements documented in 2017-2018); and walrus males and females assemble on specific and segregated haul-outs on the coast. In spring large whales (fin, blue, humpback, and sperm) arrive from the south and utilise particularly the productive waters above the shelfbreak. Aerial surveys in 2017 and 2018 showed that the Northeast Water is an important habitat for the now increasing population of bowhead whale both in winter and summer; that narwhals have important summer habitats in Dove Bugt and off Jøkel Bugt; and that the walrus population may be smaller than hitherto assessed. Only five walrus haul-out sites seem to have been used regularly in recent years. Other sources have recently found a spring aggregation area for bowhead whales over the shelfbreak between 76° and 78° N. Polar bears were tracked in 2018-2019, and they used the entire shelf off Northeast Greenland extensively when covered by ice. The inshore area appears to be key habitat for adult females with young cubs (cubs of the year (COY) and yearlings). Females with new cubs (COYs) move into the offshore areas, when cubs are ready to travel on the pack ice.

Polar bear, walrus and bowhead whale are red-listed because their populations are small, declining or expected to decline because of climate change (polar bear). Blue whale is also red-listed, and the assessment area is likely a very important habitat for this species.

Human use of natural resources only occurs in the southern part of the assessment area. Subsistence hunting (marine mammals and seabirds) and fishing is carried out near the town of Ittoqqortoormiit/Scoresbysund and hunters from Tasiilaq venture as far north as the southernmost part of the assessment area to hunt narwhal (Figure 71).

Commercial fishery is limited to Greenland halibut and this takes place in offshore areas in the southern part of the assessment area. The catches are small compared to other parts of Greenland (Figure 73).

A GIS overlay analysis with multiple layers showing species and ecological elements' spatial and temporal distribution was applied to guide the designation of particularly important biological areas (Figure 68 and Figure 69), and of areas sensitive to oil spills and disturbing activities (Figure 70).

Other environmental pressures

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

Knowledge on background levels of contaminants such as hydrocarbons, Persistent Organic Pollutants (POPs) and heavy metals is important in assessing environmental impacts from petroleum activities. The available knowledge on background levels of hydrocarbons in the assessment area is limited, but the general picture is that levels are low. However, ivory gulls, polar bears and killer whales (south of the assessment area) show concerning high levels of certain POPs and mercury from long-transported pollution.

Assessment

The assessments presented here are based on our present knowledge concerning the distribution of species and their tolerance and threshold levels toward human activities in relation to oil exploration. However, the Arctic is changing due to climate change, and this process moreover seems to be accelerating, which means conclusions and assessments may not apply to future conditions. Furthermore, the assessment area is remote and in many ways still poorly studied, and an increase in knowledge may also contribute to future adjustments of assessments and conclusions.

Presently, we do not know much about the adaptation capacity of important species in the assessment area and how their sensitivity to human impacts might change under changing environmental conditions. Changes in habitat availability, e.g. due to reduced ice coverage, are to be expected, with consequences for the local fauna. This, as well as increased temperatures will affect the distribution patterns of relevant species, with consequences for the food web. Northward range expansion of fish targeted by commercial fisheries could for example result in increased fishing activities in the assessment area.

Normal operations

During exploration, the environmental impacts of most concern are underwater noise from seismic surveys, and release of drilling mud and cuttings to the seabed.

Seismic surveys have the potential to displace noise sensitive species in the assessment area. These are walrus, narwhal and bowhead whale. Depending on the extent, duration and number of the seismic surveys in the area, these species are at risk of being scared away from critical habitats with population decrease as the ultimate effect. In the Ittoqqortoormiit-area, this effect may also apply to areas where these species are hunted. In 2017 and 2018 narwhal response to seismic noise was studied in the assessment area, indicating behavioural effects of the noise. If seismic surveys are carried out in the southern part of the assessment area, there will be a risk of affecting the Greenland halibut fishery, with reduced catches for a period during and after the seismic survey because the fish are temporarily scared away.

Release of drilling mud and drill cuttings to the seabed will impact the seabed around the drill platform. The degree depends on the amounts and content of offshore chemicals. Greenlandic regulation requires the use of environmentally safe chemicals, meaning effects are expected to be low and localized, in accordance with recognized good international practice, as set out in the Mineral Resources Act of Greenland.

Exploration activities are temporary, but may be followed by development and production. If no viable finds are made, the activities will be terminated and the environmental impacts will stop, indicating that the effects will be temporary.

However, production is long-lasting with a high risk of permanent effects on the environment. The impact giving most concern will be the continuous underwater noise from offshore installations, release of produced water, emissions to the atmosphere and transport by ship and helicopters.

The continuous noise has the potential to displace narwhals, bowhead whales and walrus from critical habitats, with risk of population decrease.

The discharges, besides drilling mud and cuttings, giving most reason for environmental concern relate to produced water from production facilities. Some studies have indicated that low concentrations of oil and nutrients from produced water in the North Sea can impact fish and primary production, and there is also indications of effects on several of the other marine ecosystem components. Potential effects of produced water in the assessment area are difficult to evaluate, but for example, polar cod and especially their egg concentrations below ice could be exposed and impacted if oil from produced water accumulates in the upper waters below the ice.

Another risk is the release of non-native and invasive species from ballast water and ship hulls, a risk which will increase with increasing ship transport and sea water temperatures. It will therefore be important to implement high international standards (IMO) to mitigate this threat.

Sewage and sanitary wastewater will be released from rigs and ships. Such releases will be regulated by the OSPAR convention, indicating environmental impacts of these discharges in the assessment area will be minor, at least from a single drilling rig or production facility, but releases from many facilities and/or over long time periods could be of concern.

A producing oilfield will also emit substantial amounts of greenhouse gasses to the atmosphere. These will contribute significantly to Greenland's greenhouse gas emissions. In a larger context, the produced oil will contribute even more greenhouse gas when it is combusted by end users. The emission of black carbon (BC) to the atmosphere from combustion of fuel oil is also of concern as BC contributes to increased snow and ice melt in the Arctic.

Installations and infrastructure (buildings, pipelines, storage areas, installations on the seabed, etc.) impact the environment by physically covering ground and seabed, with the risk of habitat loss for rare and sensitive organisms. Moreover, the presence of people may have a disturbing impact on wildlife onshore, for example the terrestrial haul-outs for walrus will be sensitive to human activity. Safety zones established around offshore installation will exclude fishery, which to date is only relevant in the southern part of the assessment area as there is no fishery in the northern part.

Facilities both on- and offshore may also impact traditional hunting grounds. This issue will be relevant to consider when planning activities in the southern part of the assessment area, near Ittoqqortoormiit and Kangerlussuaq. On shore, aesthetic impacts are also an issue to consider, especially in relation to tourist activities.

Both exploration and exploitation requires extensive transport operations. In the assessment area this will be by ship, airplane and helicopter, increasing the volume of these activities manyfold compared to the present day situation. Shipping contributes to the underwater noise and to emissions to the atmosphere and increases the risk of oil spills. Helicopter transport is noisy and has potential to disturb both marine mammals and seabirds. Some of these impacts can be mitigated by limiting sailing and flying to specific corridors and in case of helicopter to certain flight levels.

Mitigation

All these environmental impacts related to the normal operations can be mitigated by planning, applying 'Best Available Techniques' and 'Best Environmental Practice' and by regulation by the authorities. Such regulation is in place for exploration activities in Greenland, but as no producible oil has been located yet, no regulation to mitigate impacts from production has been implemented in Greenland.

Oil spills

A large oil spill from a tanker or a blowout would be the worst environmental impact from oil and gas exploration and exploitation in the assessment area. The risk of ship accidents with oil released to the sea is elevated in the assessment area due to icebergs and sea ice. The effects of a large oil spill in the area are difficult to predict, because they depend greatly on location, current weather, season and oil type, but some more general considerations can be described.

Primary production and plankton: It is not likely that primary production will be impacted significantly from even a large surface spill. But it cannot be excluded in case of a subsurface spill like the one from *Deepwater Horizon*. The same applies to fish eggs and larvae, except for polar cod eggs, which accumulate along the underside of the sea ice where spilled oil also tends to accumulate. The survey in August/September 2017 indicated high abundance of larvae on the northern shelf edge, but generally there is limited knowledge on the distribution of spawning polar cod.

Benthic communities: Many of the species of the benthic communities are sensitive to high oil concentrations in the water column. This is a risk mainly in shallow coastal waters, where wind and waves can cause toxic oil concentrations to reach the seabed. But subsurface spills may also impact benthic communities in deeper waters (cf. *Deepwater Horizon*). Rich benthic communities are found on the shelf in the assessment area and also on the shelfbreak in the form of coral gardens. In contrast, the tidal zone in large parts of the assessment area has little marine life due to the effects of the sea-ice. The benthos is important as a food resource for many species, such as walrus, bearded seal and the two eider species, which means oil contamination of benthos can cause toxic effects at the higher trophic levels.

Marine vegetation: Effects on the high Arctic marine vegetation (kelp and other macroalgae) have been documented, although the response between species and communities varies considerably.

Fish: Arctic char and other fish species that assemble in coastal waters can be exposed to oil spills, which may impact the local spawning stocks. Besides the Arctic char this also applies to capelin, which in the southern part of the assessment area spawn in the intertidal and subtidal zones.

Seabirds: There are many seabird concentrations that are vulnerable to oil spills in the assessment area, and heavy losses to the populations must be expected in case such concentrations are hit by an oil spill. The most important concentrations in the breeding season are the thick-billed murres and the little auks. The thick-billed murres are particularly vulnerable, because the local breeding population is decreasing. In autumn, little auk offshore concentrations and ivory gulls migrating over the shelf will be particularly vulnerable. In spring, concentrations of common and king eiders in the polynyas are at risk of being exposed.

Marine mammals: The whelping harp and hooded seals are among the most oil spill sensitive marine mammals in the assessment area. In the whelping areas, high numbers can be exposed to oil, and especially the hooded seal population is vulnerable because it is decreasing. The walrus is also sensitive, because many individuals potentially can be fouled by oil and their benthic feeding grounds can be impacted.

Polar bears are especially sensitive to oil spills, as oiled individuals most likely will succumb. They move over considerable distances and many may be exposed to an oil spill in the ice-covered parts of the assessment area.

The whale populations most vulnerable to oil spills in the assessment area are the narwhal and the bowhead whale. With the effects on the killer whales in Prince William Sound in mind (two local pods never recovered from the impact), there will be concern for the local populations of narwhals, if their habitats are hit by an oil spill, especially in ice-covered waters where the whales can be forced to surface in oil covered leads. Summary table 1 gives an overview of the activities and their assessed impacts.

Summary table 1. Overview of the assessment and the impacts described in this report. Main activities and their impacts shown. Pot. = potential. Spatial extend: *Local* refer to the near surroundings of the source and the project area. *Regional* refer to the region in which the activity takes place, in this case the assessment area. Duration: *Short-term* refer to a definite period, of up to a few years before the impacted elements have recovered. In this case typical for impacts caused by exploration activities. *Long-term* is longer than that and often much more. In the case of the *Exxon Valdez* impacts more than 25 years, but also the lifetime of a production field and potentially indefinite (irreversible impact). Significance of impact: *Low* will recover shortly after the activity and without permanent ecological consequences (reversible impacts). *Medium* are localised impacts, which may take a long time to recover, but due to their limited extend the ecological consequences are limited. *High* are when e.g. populations are reduced and their recovery is delayed and also when background levels and exposure limits for pollutants are exceeded. *Extreme* are when the ecosystem is impacted including the ecosystem services, which the local population benefits from.

Impact	Activity/ source	Effect	Project phase	Spatial extend	Duration	Vulnerable VEC	Signifi-cance	Remark
Underwater noise	Seismic surveys, shipping	Displacement of marine mammals and fish	Exploration	Regional	Short-term	Narwhal, bowhead whale, walrus, fishery	Pot. high	Potential population impact if key foraging areas or spawning areas are abandoned. Fishery in southern part will not or only be slightly affected. Risk for cumulative effects in case of multiple surveys.
			Production	Local	Long-term			
Drilling mud and cuttings, release to seabed and water column	Drill ship and platforms	Sedimentation, suspended material in water column, toxic chemichals	All	Local	Long-term	Seabed organisms	Pot. medium	Risk for cumulative effects in case of multiple drillings
Produced water	Production platforms	Contamination	Production	Regional	Long-term	Polar cod egg and larvae and primary production hotspots	Pot. high	
Invasive species	Ships	Replacement of native species, food web disruption	All	Regional	Long-term	The ecosystem	Pot. medium	
Sewage and waste water	Rigs and ships	Eutrophication, chemical pollution	Exploration	Local	Short-term	The ecosystem	Low	
			Production	Local/ regional	Long-term	The ecosystem	Pot. medium	Risk for cumulative effects in case of multiple platforms
Emissions to atmosphere	All mechanical processes	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	Low	The coral gardens localized in 2017, Arctic char rivers and trawl fishery in the southern part are all example of vulnerable elements
			Production	Local	Long-term		Pot. high	
Transportation	Ships, aircrafts, helicopters	Disturbing/ displacement of wildlife	Exploration	Local	Short-term	Walrus haul-outs, moulting geese, seabird breeding colonies	Low	
			Production	Regional	Long-term		Pot. high	
Prescense of people	Primarily at shore-based facilities	Disturbing/ displacement of wildlife	Exploration	Local	Short-term	Walrus haul-outs, moulting geese, seabird breeding colonies	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	

Response

The best way to mitigate oil spills is by prevention and mitigation. To prevent and avoid oil spill accidents from for example exploration drilling, the highest health, safety and environment (HSE) standards and technical standards (BEP and BAT) must be applied together with strict regulations by the authorities, and careful planning of the entire process.

If a spill happens, there are three overall oil spill response technologies available for combatting oil spills in the marine environment: mechanical recovery, chemical dispersion and in situ burning. All three methods have their limitations in an arctic environment with drifting ice, such as in the assessment area. Recovery of oil from a sea surface covered with more or less ice is challenging and not a realistic option for a large spill in the assessment area. Ice edges can act as barriers containing oil in thicker layers suited for burning, a method which has proved very successful in experiments but is not yet developed and implemented in full operational scale. So far, no effective response methods have been developed for recovering or removing a large oil spill from waters with dynamic drift ice.

Oil spill response is also challenged by the dark winter period, the general weather conditions and the remoteness of the assessment area. It is therefore likely that very little – if any – oil can be recovered in case of an oil spill in the ice-covered parts of the assessment area.

The potential for biodegradation in Arctic areas is generally unknown, but several factors such as low temperatures, sea ice and low nutrient amounts may limit the ability of the microbes to degrade oil. The issue was therefore studied under the *Strategic Environmental Study Program for Northeast Greenland.*

The study showed that there is a biodegradation potential in the water column at the shelf break if the intrinsic microbial degraders can be activated, but the degradation will be hampered by 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.

The study clearly showed that, in general, in situ concentrations of mineral nutrients in the Greenland Sea during autumn are strongly limiting for biodegradation of oil. This most likely applies to the entire area and for most of the year. Natural degradation of oil will thus be very limited in the water column and is not a removal process to be counted on.

DCE and GINR recommendation on area restrictions

With the new information summarized in this report, it is now well documented that:

a. A large part of the Greenland Sea must be considered critical habitat for nationally and globally red-listed species. For a number of high arctic species the Greenland Sea is an especially important habitat (see Table 9 and 10 and ecosystem and species accounts in Chapter 3). With proliferating Arctic climate change and increased annual variability, the Greenland Sea is expected to have increasing importance to secure habitats for the high Arctic biodiversity. This is in a multidecadal perspective, as the Greenland Sea will continue to be a main outlet of drift ice from the polar basin in many decades ahead.
b. A large oil spill may cause significant mortality and long-term population effects for seabirds and some marine mammal populations in the Greenland Sea and if an oil spill hits the coast in the Northeast Greenland National Park and beyond, the experience from the *Exxon Valdez* spill indicates that impacts can be expected to last for decades (Chapter 7 and 8, Table 19).

c. Drift ice occurs in the northern part of the assessment area year round and in the southern part at least in winter and spring. Climate modelling predicts that the Greenland Sea will continue to be a main outlet of drift ice from the polar basin in many decades. However, the oil industry has not yet presented spill response technology and methods which can effectively retrieve oil from a large spill in an environment with broken, drifting and refreezing ice conditions (see Chapter 8). The seasonal darkness and the remoteness of the area will increase the challenge. The potential for natural biodegradation of oil following a large oil spill is meagre (Chapter 8). Depending on oil type and circumstances, the oil will only slowly weather, dilute and disperse in the water column, which means that a large part of the oil may drift out from the spill area. It is likely that oil will be transported south along the Greenland coast with the prevailing current. For oil stranding on the coast, the natural degradation may take decades.

In the scientific recommendations to the Government of Greenlands new oil and gas strategy, DCE and GINR prior to the present assessment recommended that the areas north of 80° N in the Greenland Sea, and in some other areas, should be closed to oil and gas exploration for the next strategy period in order to safeguard the environment (Mosbech et al. 2019). This recommendation was based on an assessment of:

- The documented biodiversity values, which are of global significance.
- The sensitivity of key ecosystem components to a large oil spill and underwater noise.
- The lack of proven technology to significantly reduce underwater noise during exploration, development and production from an oil field.
- The lack of proven technology to manage a large oil spill in a sea covered with dynamic drift ice throughout the year in an area with seasonal darkness.

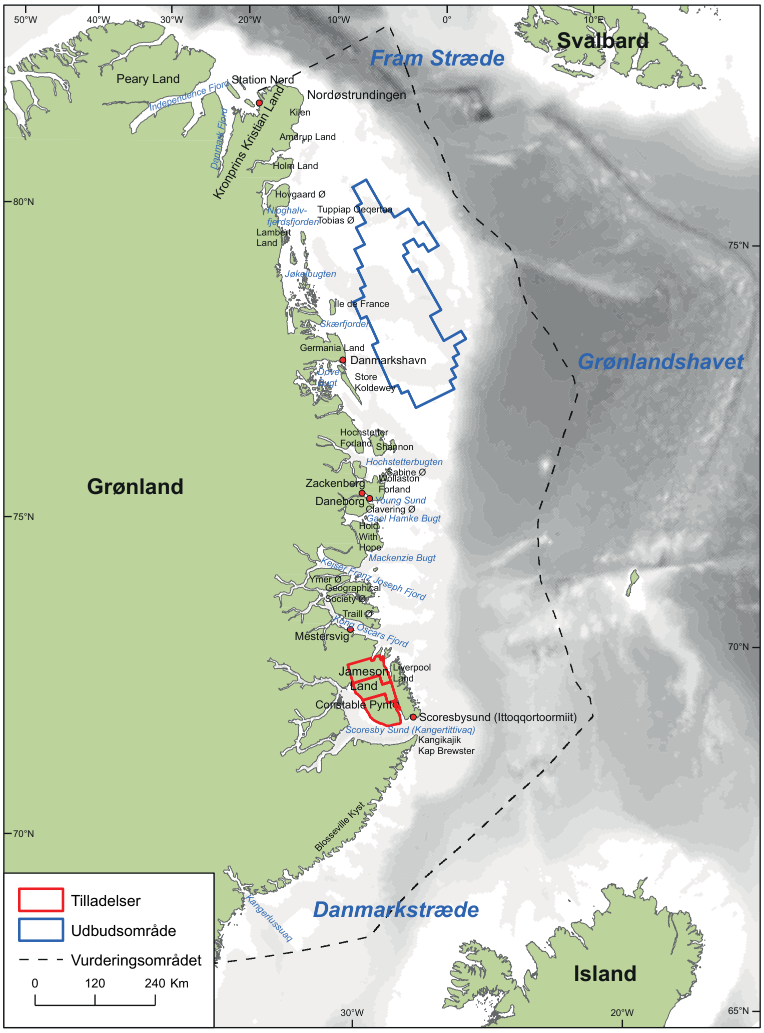
With the new information summarized in this report, the recommendations for area restrictions in the Greenland Sea have been reassessed by DCE and GINR. In conclusion, the assessment area holds very important biodiversity values, and the potential environmental impact of a large oil spill in the assessment area is assessed to be significantly elevated compared to similar activities in ice-free and seasonally ice-free marine areas. It is therefore recommended by DCE and GN to consider not to open the assessment area for oil licences in this strategy period (2020-24 strategy). The assessment criteria used by DCE and GINR in this recommendation are in line with recommendations from the Norwegian Polar Institute concerning oil licensing in northern Barents Sea, the EU policy (European Parliament resolution of 16 March 2017 on an integrated European Union policy for the Arctic Link) and in Canada, the Nunavut Impact Review Board (NIRB) has recommended to prolong the 2016 moratorium on oil and gas development in Baffin Bay and Davis Strait for a decade, while it is recommended to address the risks related to large oil spills before lifting the current moratorium (see chapter 10 for specific references and quotations). It is worth noting, that the present recommendation is temporary. If other criteria are applied or improved oil spill countermeasures in icy waters are developed, the situation is changed and a new assessment may lead to another recommendation. This could for example – if less strict criteria are applied – include a zonation (related to sensitivity of oil spills and disturbing activities) of the assessment area.

Following the recommendation above there is a need to develop effective large-scale methods for countermeasures to oil spills in dynamic drift ice. Drift ice occurs in the northern part of the assessment area year round and in the southern part at least in winter and spring. No methods for large-scale countermeasures to spilled oil in drift ice have yet been proven effective, and it is recommended that exploration drilling and production of oil should not be initiated before such methods are developed.

Dansk resumé og konklusioner*

* Dette resumé afviger fra det engelske ved at være mere udbygget omkring påvirkninger og vurderinger.

Nærværende rapport ”Strategisk miljøvurdering af olieaktiviteter i den grønlandske del af Grønlandshavet” er en opdateret version af en strategisk miljøvurdering af aktiviteter forbundet med olieefterforskning og -udvinding i den grønlandske del af Grønlandshavet. Den oprindelige rapport blev udgivet i 2012 i forbindelse med åbningen af havet ud for Nordøstgrønland for olieefterforskning. Der blev givet fem tilladelser og der blev gennemført seismiske undersøgelser, men alle fem tilladelser blev givet tilbage efter nogle år. Nu planlægges havområdet udbudt igen i 2021 og 2022.



Resumé Figur 1. Området, som denne strategiske miljøvurdering dækker (*vurderingsområde*). De røde pletter viser beboede steder: Én by (Ittoqqortoormiit), en forskningsstation, en vejrstation og tre militærbaser. Der foregår for tiden ingen olieefterforskning til havs i området, men der er tildelt tre tilladelser på land i Jameson Land (de røde felter). Kortet viser desuden udbudsområdet fra 2012 (Udbudsområde).

Rapporten dækker farvandet mellem 68° og 82° N (Resumé figur 1). Dette område betegnes som vurderingsområdet i Grønlandshavet (*Greenland Sea assessment area*).

Blandt betingelserne for tildeling af tilladelserne var, at firmaerne skulle bidrage til miljøarbejde i området, og disse midler forvaltedes af Miljøstyrelsen for Råstofområdet (EAMRA). De blev blandt andet brugt til at finansiere en række undersøgelser i årene 2016-2019, betegnet som *Strategic Environmental Study Program for Northeast Greenland*, med henblik på at forbedre den viden, der skal indgå i miljøregulering af aktiviteter i området.

Dette forskningsprogram var baseret på en plan udviklet i 2013 på baggrund af de vidensghuller, der blev identificeret i den forrige version af den strategiske miljøvurdering (se Annex C). Formålet med planen var at fremskaffe viden om miljøet, der skulle kunne bruges i forbindelse med planlægning og regulering af efterforskningsaktiviteter og i forbindelse med udvikling af oliespildsberedskab i den vestlige del af Grønlandshavet. Planen indeholdt forskning (marin økologi, biodiversitet, toxikologi og nedbrydning af olie), udvikling af et atlas over områder følsomme overfor oliespild og denne opdaterede strategiske miljøvurdering. Planen fokuserede på de tre overordnede spørgsmål, der var af størst betydning for at minimere effekterne af olieaktiviteter i området:

1. Hvordan kan seismiske undersøgelser gennemføres og reguleres sådan, at de væsentlige påvirkninger fra undervandsstøj på havpattedyr undgås eller minimeres.
2. Hvordan kan udledning af boremudder og kemikalier fra efterforskningsboringer reguleres sådan, at man med sikkerhed undgår væsentlige miljøpåvirkninger; herunder udvælgelse af de mest miljøvenlige metoder baseret på specifik viden om de anvendte stoffers giftighed og nedbrydning under højarktiske forhold.
3. Hvordan minimeres miljøpåvirkningerne i tilfælde af et oliespild, baseret på:
   a. planlægning af efterforskningsaktiviteter, sådan at de mest sårbare områder og perioder undgås,

b. planlægning af oliespildsberedskab, sådan at effektive og miljøvenlige bekæmpelsesmetoder er tilgængelige i området og kan være til rådighed og udvælges ved en miljøafvejningsanalyse (Net Environmental Benefit Analysis – NEBA) i tilfælde af et spild.

Disse tre spørgsmål blev belyst af elleve sammenhængende temaer, med en lang række forslag til undersøgelser.

Planen blev derpå forelagt de olieselskaber, som havde de fem efterforsknings- og udvindingstilladelser i området, og de fleste af de foreslåede undersøgelser blev finansieret af disse selskaber gennem det grønlandske selvstyre. Planen blev herefter til et forskningsprogram, betegnet: Det strategiske miljøforskningsprogram i Nordøstgrønland (Strategic Environmental Study Program for Northeast Greenland). Det indeholdt følgende (med de indtil nu publicerede resultater citeret i parentes):

- Et skibsbaseret togt der undersøgte oceanografi og økologi i Grønlandshavet i august/september 2017 (Hansen et al. 2019b, Møller et al. 2019, Jørgensen et al. 2019, Bouchard 2020).
- Undersøgelser af havbundens dyre- og planteliv (Hansen et al. 2019b, Wegeberg 2020b).
- Undersøgelser af tangsamfundene nær kysten og i tidevandszonen i 2017 og 2018 (Wegeberg et al. 2019).
- Havfuglestudier; herunder samtidige optællinger fra skib og fly i 2017 samt biologiske og økologiske undersøgelser af ismåger og Sabinemåger i 2017, 2018 og 2019 (Boertmann et al. 2019a, b, Frederiksen et al. 2019).
- Havpattedyr; herunder optællinger fra fly vinter og sommer i 2017 og 2018, udlægning af lyttebøjer i 2016 og 2017, studier af seismisk støjs påvirkning af narhvaler og sporing af grønlandshvalers, grønlandssælers, ringsælers og isbjørnes vandringer med satellit (Hansen et al. 2019a, Heide-Jørgensen et al. 2019a, b, Laidre et al. 2019, Rosing-Asvid & Dietz 2018, Rosing-Asvid & Zinglersen 2018, Videsen et al. 2019, Williams et al. 2017).
- Oliekomponenters giftighed for vandlopper, muslinger og andre bundlevende dyr (Agersted et al. 2018, Gustavson et al. in prep.).
- Dispergeret olies påvirkning af tang (Wegeberg et al. 2020a, in prep.).
- Naturlig nedbrydning af olie i Grønlandshavet (Johnsen et al. 2019).
- Afbrænding af olie i is og miljøpåvirkningerne fra afbrændingsresterne (Fritt-Rasmussen et al. in prep. a, b).
- Udvikling af et atlas over oliespildsfølsommer områder i Østgrønland (under udvikling).
- Beskrivelse og analyse af fangsten i Ittoqqortoormiit and Tasiilaq (Flora et al. 2019).

Resultaterne af disse undersøgelser er baggrunden for denne rapport, og de præsenteres i kapitler og tekstbokse i det følgende, ligesom de er publiceret særskilt (se citeringerne ovenfor). De refereres også i Annex D. Resultaterne har i høj grad bidraget til en forbedret vidensbasis omkring økologien og oliespild i vurderingsområdet.

Rapporten her er udført af Nationalt Center for Miljø og Energi (DCE) og Grønlands Naturinstitut (GN).

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

Området er beliggende i den højarktiske zone og har de for denne zone karakteristiske biologiske træk: Forholdsvis lav biodiversitet (undtaget de bundlevende dyr), korte fødekæder, og områder med meget høje koncentrationer af organismer. Den lave biodiversitet modsvares af, at visse arter er uhyre talrige, og nogle af disse er nøglearter i fødekæderne. Dvs. at de højere trofiske niveauer er afhængige af disse nøglearters forekomst i tid og rum.

Forklaring af termer benyttet i det følgende

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

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

Effekt eller virkning af (*effect*). Bruges om virkningen af specifikke aktiviteter eller stoffer udledt til miljøet, som f.eks. giftpåvirkning af kemikalier i boremudder eller hvordan seismisk støj påvirker havpattedyr ved bortskræmning eller midlertidigt høretab.

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

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

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

Biologien

Det vurderede område er lokalt meget rigt i biologisk/økologisk forstand, men der er også store områder med sparsomt liv. Primærproduktionen om foråret er visse steder høj, der er rige dyresamfund på havbunden ligesom der er store og meget vigtige forekomster af både fugle og havpattedyr. De nye undersøgelser viste, at der særligt langs kontinentalskrænten var høj produktion, og der blev her fundet områder med tætte bestande af koldtvandskoraller.

Blandt fuglene forekommer der vigtige (både nationalt og internationalt) og rødlistede arter som polarlomvie (nationalt rødlistet) og ismåge (internationalt og nationalt rødlistet) og på kysterne af polynyet ved Scoresby Sund yngler flere millioner par søkonger (national ansvarsart). Om foråret og efteråret trækker mange fugle gennem eller langs med østsiden af vurderingsområdet på vej mellem ynglepladser på Svalbard og i Rusland og vinterkvarterer på havet ud for Canada og Sydvestgrønland. De talrigeste arter er søkonge og polarlomvie, og en meget stor del af den samlede bestand af den fåtallige ismåge foretager dette træk. Om foråret samles store flokke af ederfugle i polynyerne, og om efteråret bevæger søkongerne fra ynglepladserne ved Scoresbysund sig op på det åbne hav mellem Svalbard og Grønland.

Havpattedyrerne udgør toppen af fødekæderne med sæler, hvaler og øverst isbjørn, og de forekommer i hele vurderingsområdet. Isbjørne for eksempel bevæger sig rundt overalt, hvor der er havis (Figur 44, 45), nathvaler fortager regelmæssige vandringer mellem sommeropholdssteder i fjorde og kystnære områder til kontinentalskrænten om vinteren. Dove Bugt viste sig at være et vigtig sommeropholdssted under undersøgelserne i 2017 og 2018. Grønlandshvaler opholder sig mest på kontinentalsoklen, og nogle af dem foretager lange vandringer mod øst forbi Svalbard. Om foråret er der for nyligt fundet større ansamlinger omkring kontinentalskrænten mellem 76° og 78° N. Grønlandssæler og klapmydser samles på isen om foråret i den centrale del og føder her deres unger. Hvalrosserne er om vinteren i polynyerne især Nordøstvandet, og om sommeren på en række landgangspladser i områdets centrale del. Om sommeren ankommer fin-, blå- og pukkelhvaler sydfra sammen med kaskelotter og opholder sig især over kontinentalskrænten. Flere af havpattedyrerne vurderes som truede (rødlistede) på verdensplan – herunder isbjørn, hvalros, blåhval finhval og grønlandshval.

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

Hellefisk udnyttes kommercielt i den sydligste del af vurderingsområdet (Figur 73), og fangst og fiskeri til lokalt brug er vigtige aktiviteter for beboerne i Ittoqqortoormiit og for de fangere fra Tasiilaq, der tager på fangst mod nord til vurderingsområdet (Figur 71). Endelig er der turistaktiviteter i områder, dels med udgangspunkt i Ittoqqortoormiit og dels med krydstogtskibe.

Vurderingsgrundlag

Aktiviteterne fra en komplet livscyklus for et oliefelt er så vidt muligt vurderet med vægt på de aktiviteter og hændelser, som erfaringsmæssigt giver de væsentligste miljøpåvirkninger. Men da der ikke er erfaringer med udvinding af olie i Grønland, er vurderinger af aktiviteter i denne forbindelse ikke konkrete, men bygger på erfaringer fra andre områder med så vidt muligt sammenlignelige forhold. Der er især trukket på den meget omfangsrige litteratur om de store oliespild i Prince William Sund i Alaska i 1989 og i den Mexicanske Golf i 2010, på den norske miljøvurdering af olieaktiviteter i Barentshavet (2003) og på Arktisk Råds *Arctic Oil and Gas Assessment* (AMAP 2010a).

Vurderingerne i denne rapport bygger på de eksisterende klimatiske forhold. Klimaændringer påvirker miljøet i vurderingsområdet, og især isens forekomst har allerede ændret sig meget. Det betyder ændrede leveforhold, som vil medføre, at nogle arter reduceres i forekomst og udbredelse, mens andre vil begunstiges og nye arter vil indvandre og etablere sig.

Vurderingerne bygger på den tilgængelige biologiske viden, som ved undersøgelserne i perioden 2016-2019 er væsentligt forbedret.

Efterforskning

Efterforskningsaktiviteter er midlertidige, de varer typisk nogle år og vil for det meste være spredt ud over de tildelte licensområder. De udføres desuden kun i den isfrie periode, dvs. om sommeren og efteråret, formentlig i perioden juli til oktober. Seismiske undersøgelser er dog gennemført ved hjælp af isbryder i perioden 2010-2016.

Hvis efterforskningen ikke påviser olie eller evt. gas, det kan betale sig at udvinde, vil aktiviteterne ophøre og alt udstyr fjernes. Findes der derimod olie, som efter en vurderingsperiode (*appraisal*) viser sig muligt at udnytte, vil aktiviteterne overgå til en udvikling af oliefeltet med afgrænsningsboringer og udbygning af faciliteter og derpå en egentlig udvinding af den fundne olie (se nedenfor).

Blandt de væsentligste påvirkninger fra efterforskningsaktiviteter er forstyrrelser fra støjende aktiviteter (f.eks. seismiske undersøgelser, boring og helikopterflyvning). Der forventes relativt svage, midlertidige og lokalt forekommende påvirkninger, idet mere omfattende påvirkninger kan undgås med forebyggende tiltag, som f.eks. ved at undgå aktiviteter i særligt følsomme områder eller perioder. Dog kan de særlige 3D-seismiske undersøgelser, der foregår i begrænsede områder, give anledning til mere markante påvirkninger, som i yderste konsekvens kan påvirke særligt sårbare bestande – inden for vurderingsområdet især narhval, grønlandshval og hvalros. Flere aktiviteter i samme område vil desuden kunne give anledning til kumulative påvirkninger, et forhold der bør tages højde for i planlægningen af for eksempel seismiske undersøgelser.

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

Der er en risiko for, at havpattedyr vil søge bort fra vigtige fødesøgningsområder og trækruter pga. forstyrrelserne fra seismiske undersøgelser. Det forventes dog, at påvirkningen fra en enkelt seismisk undersøgelse vil være midlertidig (varighed uger til måneder), fordi aktiviteten ophører. Men kumulative påvirkninger fra flere aktiviteter kan forstærke effekterne på dyrene. Seismiske undersøgelser i Grønland er underlagt regulering, som skal forebygge egentlige skader på havpattedyr (særligt hvaler) og der er udpeget en række beskyttelsesområder for narhval, grønlandshval og hvalros for at begrænse forstyrrelser i vigtige områder.

Det er påvist, at trykbølgen fra de luftkanoner, der benyttes ved seismiske undersøgelser, kan slå fiskeæg og -larver ihjel ud i en afstand af maks. 5 m. I Norge er der bekymring for at meget intensive seismiske undersøgelser i områder med høje koncentrationer kan dræbe så meget fiskeyngel, at det kan påvirke rekrutteringen til bestanden af voksne fisk. Tilsvarende høje koncentrationer af fiskeyngel kendes ikke i grønlandske farvande, og de højeste koncentrationer forekommer desuden om foråret før seismiske undersøgelser normalt udføres. Det kan derfor konkluderes, at seismiske undersøgelser ikke giver anledning til risiko for væsentlige påvirkninger af fiskebestandene i den grønlandske del af Grønlandshavet.

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

Der er også risiko for midlertidig fortrængning af blå-, fin-, våge- og pukkelhval i sommermånederne.

Fangst på havpattedyr vil kunne påvirkes, hvis byttedyr bortjages fra traditionelle fangstpladser, hvilket kan være aktuelt i den sydlige del af vurderingsområdet nær byen Ittoqqortoormiit og ved fangstområderne som Tasiilaq-beboerne benytter omkring Kangerlussuaq.

Ved en efterforskningsboring benyttes boremudder til at smøre boret, kontrollere trykket i borehullet og til at transportere det udborede materiale (borespåner) op til platformen. Er dette vandbaseret udledes det ofte til havet efter endt boring, mens de oliebaserede typer, som er mere miljøskadelige, i dag normalt bringes til land for at blive behandlet eller deponeret under kontrollerede forhold.

I Grønland er der hidtil kun benyttet vandbaseret boremudder. Ved de tre boringer ud for Disko i 2010 blev der i alt udledt 6000 tons boremudder og 2261 m^3 borespåner. Der må tillige kun bruges de mere miljøvenlige "grønne" og "gule" tilsætningskemikalier (jvf. OSPARs klassifikation). "Røde" og sorte" er ikke tilladte. Dog kan der gives tilladelse til "røde" (som er svært nedbrydelige), hvis det kan godtgøres, at brugen bidrager til på anden vis at gøre en boring mere miljøvenlig. Dette svarer til reglerne for brug af borekemikalier i Norge. Det skal dog nævnes, at man tillige benytter oliebaseret boremudder i Norge, men under betingelse af at det deponeres/behandles på land og dermed ikke udledes til havmiljøet. Dette er siden boringerne i 2010'erne blevet muligt i Grønland.

Ved udledning af vandbaseret boremudder og borespåner er der en risiko for at påvirke bundfaunaen i nærheden af udledningsstedet ved sedimentation af materiale og forplumring af vandet. Det er vanskeligt at vurdere virkninger af udledning af boremudder og -spåner i Grønlandshavet. Men det forventes, at udledningerne fra en enkelt efterforskningsboring kun vil give minimale og lokale påvirkninger, hvis de mest miljøvenlige typer af boremudder benyttes. Men for eksempel vil de netop opdagede koralhaver være meget sårbare.

Påvirkninger kan undgås ved at undlade at udlede boremudder og -spåner, men i stedet bringe det i land eller pumpe det tilbage i borehullet ved endt boring. Men dette giver også miljøpåvirkninger, som skal afvejes mod dem fra udledningen.

Endelig er prøveboringer meget energikrævende, hvilket resulterer i store udslip af drivhusgasser. De tre boringer i 2010 ud for Disko forøgede det samlede grønlandske bidrag med 15 %.

Den væsentligste risiko for miljøpåvirkninger under en efterforskningsboring opstår i forbindelse med uheld (*blowout*), som medfører et stort oliespild. De mulige følger af oliespild er omtalt nedenfor.

Udvikling og produktion

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

Produktionsvand (der pumpes op sammen med olien) udgør langt den største udledning til havmiljøet. Et oliefelt kan udlede op til 30.000 m^3 om dagen, og på årsbasis udledes der på den norske sokkel 160 millioner m^3. Der er i de senere år udtrykt en vis bekymring for udledning af produktionsvand, på trods af at det er behandlet og overholder internationale miljøstandarder. Der knytter sig desuden specielle problemer til udledning af produktionsvand i et isdækket hav, der har reduceret opblanding i overfladelaget. Miljøproblemerne ved produktionsvand kan for eksempel undgås ved skærpede krav til indholdsstoffer eller endnu bedre ved at pumpe vandet tilbage i oliebrønden (*re-injection*).

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

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

Selve placeringen af installationer og de forstyrrelser, der kommer fra disse, kan påvirke havpattedyr, sådan at de fortrænges permanent fra vigtige fourageringsområder eller således at de ændrer trækruter. I Grønlandshavet er det især narhval, grønlandhval og hvalros, der er på tale i denne sammenhæng. Dette kan desuden vanskeliggøre fangst på de jagtbare af disse arter.

Bunddyrsamfund, som koralhaverne fundet i 2017, vil også være sårbare over for placering af installationer på havbunden.

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

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

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

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

Det skal påpeges, at det er meget vanskeligt at vurdere de påvirkninger eventuel udvikling og produktion kan medføre, fordi lokaliseringen, omfanget, varigheden og typen af aktiviteter ligesom de tekniske løsninger ikke er kendt.

Oliespild

De mest alvorlige miljøpåvirkninger, der kan forekomme i forbindelse med olieaktiviteter, er store oliespild. De forekommer enten fra udblæsninger (*blowouts*), hvor kontrollen med borehullet mistes, eller fra uheld i forbindelse med opbevaring og transport af olie, f.eks. ved forlis af tankskibe.

Store oliespild forekommer meget sjældent i dag, fordi teknikken og sikkerhedsforanstaltningerne hele tiden forbedres. Men risikoen er til stede, og særligt i *frontier*-områder, som de grønlandske farvande med tilstedeværelsen af en særlig risikofaktor i form af isbjerge, er muligheden for uheld og ulykker forhøjet. AMAP (2010a) vurderer at risikoen for oliespild i Arktis er størst i forbindelse med transport af olie.

DMI og SINTEF har modelleret drivbanerne for oliespild i Grønlandshavet med udgangspunkt i tre spildsteder forholdsvis langt fra kysten (Figur 81, 82, 83). I enkelte af DMIs simuleringer når olien kysten op til flere hundrede km fra spildstedet. I flere af SINTEFs simuleringer driver olien ind på lange kyststrækninger på mere end hundrede km. Dvs. at også kysterne i vurderingsområdet er i risiko for at blive ramt af oliespild fra fremtidige oliebrønde.

Oliespild i kystnære farvande regnes generelt som meget mere ødelæggende end oliespild på åbent hav. Men i et område som Grønlandshavet må denne generalisering modificeres. Det hænger sammen med forekomsten af is, som kan holde på olien og transportere den over lange afstande uden, at den nedbrydes væsentligt. Men isen kan også medvirke til at begrænse et spilds udbredelse sammenlignet med et spild i isfrie farvande. Den foreliggende viden om oliespilds adfærd og skæbne i isdækkede farvande er begrænset.

Grunden til at kystnære farvande er mest sårbare over for oliespild er, at olien her kan påvirke områder med høj biodiversitet og med tætte dyrebestande, som f.eks. banker med bunddyr, som hvalrosser lever af og områder med store fugleforekomster. Olien kan fanges i bugter og fjorde, hvor høje og giftige koncentrationer af oliekomponenter kan bygges op i vandsøjlen og nå bunden. Der er også risiko for, at olie kan fanges i bundsedimenter eller på strande med rullesten, hvorfra olie langsomt kan frigives til det omgivende miljø med risiko for langtidsvirkninger f.eks. på fuglebestande som udnytter kysterne. Dette var tilfældet i Prince William Sund, hvor der stadig efter spildet i 1989, findes olie på sådanne steder. Mange kyster i vurderingsområdet er af samme beskaffenhed som i Prince William Sund. Endelig udnyttes de kystnære farvande i den sydlige del af det vurderede område af lokale indbyggere til fangst og fiskeri, en aktivitet, som kan blive påvirket af et oliespild.

På åbent hav er fortyndingseffekten med til at mindske miljøeffekterne af et oliespild. I og nær vurderingsområdet i Grønlandshavet er der områder langt fra kysten, som alligevel er særligt sårbare over for oliespild. F.eks. samles søkonger fra ynglekolonierne ved Scoresby Sund og på Svalbard i store koncentrationer på kontinentalsoklen og særligt langs kontinentalskrænten om efteråret. Frontzoner mellem vandmasser, *up-welling*-områder langs kontinentalskrænten og de ydre dele af drivisen (*marginal ice zone*), hvor primærproduktionen er særligt høj om foråret, og hvor høje koncentrationer af planktoniske alger og dyrisk plankton forekommer i den øvre del af vandsøjlen kan også være sårbare overfor oliespild, især hvis der er tale om udslip fra havbunden, som ved *Deepwater Horizon*-ulykken in 2010.

Et oliespild vil dog næppe påvirke bestanden af hellefisk, den eneste fiskeart der udnyttes kommercielt i den sydlige del af vurderingsområdet, men fiskeriet kan blive påvirket, fordi området kan blive lukket for fiskeri.

Fugle er særligt sårbare overfor oliespild på havoverfladen, og i Grønlandshavet er der lokalt mange sårbare fugleforekomster. For eksempel de store ynglekolonier af polarlomvie og søkonge, forårskoncentrationer af ederfugle og den fåtallige ismåge. Der er også koncentrationer af fældende ederfugle og kongeederfugle langs kysterne i sensommeren. Fældende søkonger på åbent hav om efteråret er også sårbare.

Havpattedyr kan påvirkes af oliespild på havoverfladen. I vurderingsområdet vil hvalros være særligt udsat, fordi hvalrosserne forekommer meget koncentreret omkring nogle få vigtige fødesøgningsområder. Spækhuggere (og dermed formentlig også andre hvaler) viste sig efter *Exxon Valdez*-ulykken i 1989 at være sårbare over for indånding af oliedampe over et spild, et forhold som kan blive aktuelt ved oliespild i is (se nedenfor).

Isbjørne er specielt sårbare, fordi olien ødelægger pelsens isolerende effekt, og fordi de har en tendens til at rense olie af pelsen ved at slikke den ren og derved blive forgiftet af den indtagne olie.

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

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

Det meget store oliespild fra *Deepwater Horizon*-ulykken i den Mexicanske Golf havde udgangspunkt på havbunden på meget stor dybde (ca. 1500 m). Det resulterede i dannelsen af store skyer af dispergeret olie i vandsøjlen. Olien forblev her og drev vidt omkring. Udbudsområdet i den grønlandske del af Grønlandshavet ligger inde på kontinentalsoklen, med vanddybder op til 530 m, hvorfor det er mindre sandsynligt, at olie der strømmer ud fra havbunden, vil opføre sig på denne måde her. Men det kan ikke udelukkes, da det formentlig også skete på kun 50 m vand under det store *Ixtoc*-spild i 1979. Se også Resumétabel 1 med en oversigt over aktiviteter og vurdering af deres påvirkninger.

Områder følsomme overfor oliespild

På kortene på Figur 68 og 69 er der udpeget en række områder, som er biologisk særligt vigtige. Disse kort er baseret på en ny GIS-analyse, hvor den nyeste viden om områdets dyrearter og andre økologiske elementer (polynyer, lavvandede områder osv.) samles i separate kortlag, som derpå integreres i en *overlay*-analyse. Disse kort indgår derpå i en udpegning af områder særligt følsomme over for oliespild og forstyrrelser (Figur 70). Disse udpegninger giver anledning til forslag til ændringer af de forskellige beskyttelsesområder udpeget i de såkaldte 'feltregler' (Vigtige områder for dyrelivet) og til ændringer af de områder, der i DCE og GNs miljøbidrag til råstofstrategien (2019) foreslås friholdt for olie- og gasefterforskning.

Oversigt over påvirkninger og vurderinger af effekter af olieaktiviteter i vurderingsområdet

Følgende tabel giver en oversigt over de væsentligste påvirkninger fra olieaktiviteter i vurderingsområdet samt en kortfattet miljøvurdering af dem.

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

Påvirkning	Kilde	Konsekvens	Projektfase	Rumlig udbredelse	Varighed	Sårbare elementer (VEC)	Grad af påvirkning	Bemærkning
Undervandsstøj	Seismiske undersøgelser, skibsfart	Bortskræmning af havpattedyr og fisk	Efterforskning	Regional	Kortvarig	Narhval, grønlandshval, hvalros, fiskeri	Pot. høj	Tilbagegang i bestande er mulige, hvis vigtige fødesøgnings- eller gydeområder forlades. Fiskeriet i den sydlige del vil formentlig ikke blive eller kun svagt. Ved flere seismiske undersøgelser i samme område er der risiko for kumulative konsekvenser.
			Produktion	Lokal	Langvarig			
Udledning af boremudder og borespåner	Boreskibe og -platforme	Sedimentation, opslemmet materiale, giftige kemikalier	Alle	Lokal	Langvarig	Havbundsdyr	Pot. middel	Der er risiko for kumulative konsekvenser ved flere boringer i samme område
Produktionsvand	Produktionsplatforme	Forurening	Produktion	Regional	Langvarig	Æg og larver af polartorsk, hotspots for primær produktion	Pot. høj	Der er risko for kumulative konsekvenser i tilfælde af udledning fra flere platforme
Invasive arter	Skibe	Fordrivelse af hjemmehørende arter	Alle	Regional	Langvarig	Økosystemet	Pot. middel	
Spildevand	Platforme og skibe	Gødningseffekt, kemisk forurening	Efterforskning	Lokal	Kortvarig	Økosystemet	Lav	Der er risiko for kumulative konsekvenser i tilfælde af udledning fra flere platforme
			Produktion	Lokal/ regional	Langvarig	Økosystemet	Pot. middel	
Udslip af drivhusgasser	Maskineri	Klimaændringer	Efterforskning	Global	Long-term	Det arktiske økosystem		
			Produktion	Global	Long-term			
Anlæg og bygninger	Anlæg i land og til havs (havbunden)	Tab af levesteder, dannels af nye levesteder, æstetiske hensyn	Efterforskning	Lokal	Kortvarig	Sjældne arter med begrænset udbredelse	Lav	Eksempler på særlig sårbare forekomster: De i 2017 opdagede koralhaver, elve med opgang af fjeldørred, trawlfiskeri i den sydlige del
			Produktion	Lokal	Langvarig		Pot. høj	
Transport	Skibe, fastvingefly, helikoptere	Forstyrrelse/ bortskræmning af dyr	Efterforskning	Lokal	Kortvarig	Landgangspladser for hvalros, fældende gæs, ynglekolonier for havfugle	Lav	
			Produktion	Regional	Langvarig		Pot. høj	
Færdsel af mennesker	Primært ved installationer i land	Forstyrrelse/ bortskræmning af dyr	Efterforskning	Lokal	Kortvarig	Landgangspladser for hvalros, fældende gæs, ynglekolonier for havfugle	Lav	
			Produktion	Lokal	Langvarig		Pot. høj	
Stort oliespild	Uheld med skibe og rørledninger, blowouts fra oliebrønde ved overfladen eller havbunden	Tilsøling, forgiftning, direkte dødelighed, sublethale effekter	Boring og transport	Regional	Langvarig	Hele økosystemet, særligt sårbare er havfugle, bunddyr og fisk der gyder på lavt vand	Pot. ekstrem	

Bekæmpelse af oliespild

Oliespild skal først og fremmest undgås ved anvendelse af BAT og BEP, høje sikkerhedsstandarter og kvalificeret regulering. Men er uheldet ude kan oliespild bekæmpes på tre måder: Mekanisk opsamling, dispergering med kemiske midler og afbrænding. Mekanisk opsamling har ikke været særligt effektiv ved de store amerikanske oliespild i 1989 og 2010, og vanskeliggøres hvis der er is i det farvand, der arbejdes i.

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 (*Environment & Oil Spill Response*, EOS), før den evt. kan benyttes. Men den kan også fremme den naturlige nedbrydning ved, at olien findeles i vandet.

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.

Potentialet for olienedbrydning med de naturligt forekommende mikroorganismer blev undersøgt i vurderingsområdet i 2017. Der var i vandsøjlen over kontinentalskrænten et mindre potentiale, men i vandet over kontinentalsoklen og i bundsedimenter var nedbrydningspotentialet med de naturlige mikroorganismer meget lavt. Selv på kontinentalskrænten hvor der forekom olienedbrydende mikroorganismer var det en begrænsning for nedbrydningen, at der ikke var næringsstoffer nok i vandet til at holde mikroorganismerne i gang med at nedbryde olie.

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 inden metoderne bringes i anvendelse (*Spill Impact Mitigation Assessment*, SIMA).

DCE og Grønlands Naturinstituts anbefalinger vedr. områdebegrænsninger

Den nye viden indsamlet og beskrevet i denne strategiske miljøvurdering dokumenterer at:

a. En stor del af Grønlandshavet (på den grønlandske side) er kritisk levested for en række arter, der vurderes som truede (rødlistede) både internationalt og nationalt. Særligt for en række høj-arktiske arter er Grønlandshavet et vigtigt levested (se Tabel 9 og 10 og beskrivelserne i Kapitel 3). Med de omfattende klimaændringer, herunder stor variation mellem de enkelte år, må Grønlandshavet forventes at få større og større betydning som levested for disse arter, da polarisen i mange årtier fremover forventes at fortsætte med at strømme den vej ud fra Polhavet.
b. Et stort oliespild i vurderingsområdet vil kunne forårsage stor dødelighed og påvirke bestande af havfugle og visse havpattedyr over mange år. Hvis et sådant spild rammer kysterne i området (Nationalparken og længere væk), viser erfaringerne fra *Exxon Valdez*-spildet i Alaska i 1989, at påvirkningerne kan vare i årtier (Kapitel 7 og 8, Tabel 19).

c. Drivis forekommer i den nordlige del af vurderingsområdet hele året og i den sydlige i det mindste om vinteren og foråret. Fremskrivninger af udviklingen af isdækket på den nordlige halvkugle tyder på, at området vil blive tilført – som hidtil – drivis fra Polhavet i mange årtier fremover. Imidlertid har olieindustrien ikke udviklet metoder til bekæmpelse af oliespild, der effektivt kan rense olie op fra et stort spild i områder med drivende isflager og under omstændigheder, hvor vandet fryser til (Kapitel 8). Vintermørke og områdets afsides beliggenhed bidrager til at vanskeliggøre bekæmpelsen af et oliespild. Desuden viste undersøgelserne i 2017, at det naturlige potentiale for nedbrydning af olie var meget begrænset (Kapitel 8). Et oliespilds skæbne i området vil afhænge af olietype og vejrforhold, men generelt vil de kolde forhold medføre at nedbrydning, opløsning og dispergering foregår langsomt. Det medfører at sådan olie vil kunne drive ud af vurderingsområdet, og med stor sandsynlighed sydpå langs Grønland kyst. Hvis sådan olie driver i land, vil den naturlige nedbrydning kunne vare årtier.

Da DCE og Grønlands Naturinstitut (før denne strategiske miljøvurdering blev udarbejdet) indgav videnskabelige bidrag til forslaget for den nye olie- og gasstrategi, var en af anbefalingerne, at området nord for 80° N i Grønlandshavet (og en række andre områder) skulle friholdes for olie- og gasefterforskning i den kommende strategiperiode for at tilgodese miljøet (Mosbech et al. 2019). Denne anbefaling blev baseret på:

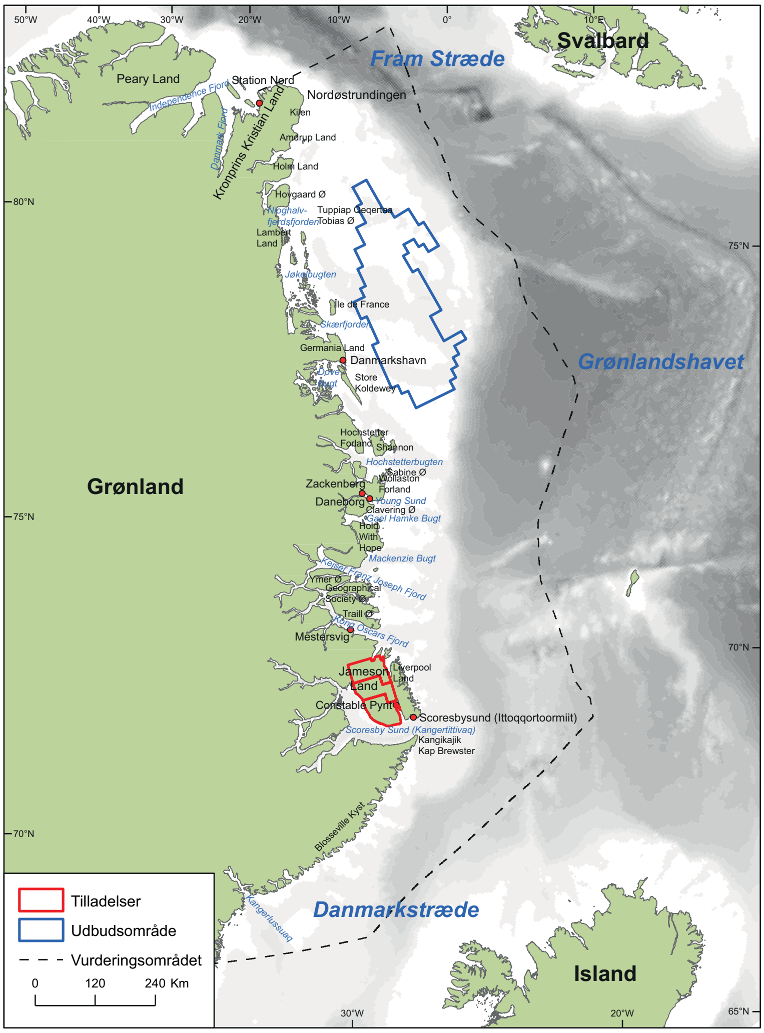
- Områdets biodiversitet, som er af global betydning.
- Høj følsomhed overfor oliespild og undervandsstøj blandt vigtige arter i økosystemet.
- Manglen på afprøvet teknologi, der kunne reducere den undervandsstøj der skabes under efterforskning, udvikling og produktion af olie til havs.
- Manglen på afprøvet teknologi, der kunne håndtere et stort oliespild i farvand med dynamisk drivis og vintermørke.

Den nye viden, som er beskrevet i nærværende rapport giver anledning til at revurdere anbefalingen. Det konkluderes nu at vurderingsområdet har store biodiversitetsværdier, og de potentielle påvirkninger fra et stort oliespild i området vurderes til at blive væsentligt værre sammenlignet med en tilsvarende situation i et område uden eller med sæsonbestemt forekomst af havis. Derfor anbefaler DCE og Grønlands Naturinstitut nu, at man i den nye strategiperiode (2020-24) ikke åbner vurderingsområdet for olieefterforskning.

De kriterier, som DCE og Grønlands Naturinstitut har benyttet ved denne anbefaling, er i tråd med anbefalinger fra Norsk Polarinstitutt omkring åbning af områder i det nordlige Barents Hav, med EU's politik (European Parliament resolution of 16 March 2017 on an integrated European Union policy for the Arctic Link) og med det canadiske Nunavut Impact Review Board (NIRB)'s anbefaling af en 10-års forlængelse af 2016-moratoriet for efterforskning af olie- og gas i Baffin Bugt og Davis Stræde (se nærmere i Kapitel 10, hvor der er referencer). Det skal understreges, at den foreliggende anbefaling er tidsbegrænset. Anvendes andre kriterier, og bliver der udviklet forbedret teknologi til bekæmpelse af oliespild, vil situationen være ændret, og en ny vurdering kan føre til en anden anbefaling. Det kan i givet fald give god mening, at zoneopdele vurderingsområdet, hvor nogle områder er mindre sårbare end andre overfor forstyrrelser og oliespild.

Denne anbefaling medfører et behov for udvikling af effektive, storskala-metoder til oprensning af oliespild i dynamisk drivis. Sådan is forekommer hele året i den nordlige del af vurderingsområdet og i den sydlige i det mindste vinter og forår. Det anbefales derfor ikke at foretage efterforskningsboringer eller at producere olie i vurderingsområdet før der er udviklet metoder til at bekæmpe oliespild i dynamisk drivis.

Kalaallisut imaqarniliaq inerniliussallu*



Eqikkaaneq Assiliartaliussaq 1. Sumiiffik, periusissiorfiusumik avatangiisinik naliliinerup matuma atuuffigisaa (*Sumiiffik naliliiviusoq*). Toornerit aappalaartut tassaapput sumiiffiit inoqarfiusut: Illoqarfik ataaseq (Ittoqqortoormiit), ilisimatusarfik, silasiorfik kiisalu sakkutooqarfiit pingasut. Massakkut tamaani uuliaqarneranik misissueqqissaartoqanngilaq, kisiannili Jameson Landimi nunami akuersissutit pingasut tunniunneqarsimapput (aappalaartumik nalunaaqqutsikkat). Nunap assingani takutinneqarputtaaq sumiiffiit 2012-imi neqeroorutigisat (Neqerooruteqarfiit).

*Naalisagaq una tuluttuuaniit allaavoq sunniutit naliliinerillu eqqarsaatigalugit sukumiinerusunik imaqarami.

Tunup imartaani uuliaqarneranik misissuinerit periusissiorfiusumik avatangiisitigut naliliivigineqarnerat.

Nalunaarusiaq una tassaavoq Tunup avannaata imartaani uuliaqarneranik misissueqqissaarnerit qalluinerillu avatangiisinut sunniutissaannik periusissiorfiusumik naliliinerit nutarternerat. Nalunaarusiaq siulleq Tunup avannaata imartaani uuliaqarneranik misissuiffiginissaanut ammarneqarneranut atatillugu 2012-imi suliarineqarpoq. Akuersissutit tallimat tunniunneqarput aammalu sajuppillatsitsisarluni misissuisoqarluni, ukiualuilli qaangiunneranni akuersissutit tallimat tamarmik utertinneqarput. Maanna imartat taakku 2021-imi kiisalu 2022-imi neqeroorutigeqqinneqarnissaat pilersaarutigineqalerpoq.

Nalunaarusiami imartaq allaaserineqartoq tassaavoq 68° og 82° N (Assiliartaliussaq 1). Sumiiffik taanna Tunup imartaani naliliivittut taaneqartarpoq (*Greenland Sea assessment area*).

Akuersissutinik tunniussinermi ilaatigut piumasarineqarpoq suliffeqarfiit tamaani avatangiisinut tunngasunik suliaqarnermut peqataassasut, aningaasallu taakku Aatsitalerivimmi Avatangiisinik Aqutsisoqarfimmit (EAMRA) nakkutigineqassasut. Aningaasat taakku ilaatigut 2016-2019-imi misissuisarnernut qassiinut aningaasalersuinermi atorneqarput, misissuinerillu taagorneqarput *Tunup avannaani avatangiisinik misissuinerit periusissiorfiusut*, tassanilu avatangiisit pillugit aqutsinermi ilisimasariaqakkanik pitsanngorsaanissaq siunertarineqarpoq. Ilisimasat taakku periusissiorfiusumik avatangiisinik naliliinerit nutarterinermi tunngavigineqassapput.

Ilisimatusarnikkut suliniut taanna, ilisimasatigut amigaatit siuliani periusissiorfiusumik avatangiisinik naliliinermi paasineqartut tunngavigalugit 2013-imi pilersaarusiarineqartumik tunngaveqarpoq. Pilersaarummi siunertarineqartoq tassaavoq avatangiisit pillugit ilisimasanik, Tunup avannaata imartaata kippasinnerusortaani uuliaqarneranik misissueqqissaarnerit pilersaarusiorneqarneranni aamma taakku malittarisassaqartitaanerani kiisalu uuliamik maqisoornissamut upalungaarsimanerup ineriartortinneqarnerani atugassanik, pissarsissalluni. Pilersaarummut ilaapput ilisimatusarneq (imaani uumassusileqarfiit, uumasut assigiinngissitaarnerat, toqunartut pillugit ilisimasat kiisalu uuliap nungujartortarnera), sumiiffiit uuliamik maqisoornermut misikkarissut nunap assiliussallugit kiisalu periusissiorfiusumik avatangiisinik naliliineq taanna nutartissallugu. Pilersaarummi apeqqutit pingaarnerit pingasut sammineqarput, tassalu:

1. Miluumasut imarmiut nipinit immap iluatigoortunit sunnerneqartussaajunnaarlugit imaluunniit sunniutit minnerpaasussanngorlugit sajuppillatsitsisarluni misissuinerit qanoq ingerlanneqarsinnaappat malittarisassaqartitaallutillu.

2. Mississueqqissaarluni qillerinerni marrarmik perrassaammik akuutissanillu aniatitsisarnerit qanoq malittarisassaqartitaasinnaappat avatangiisinut sunniutit annerit qularnaatsumik pinngitsoorneqartussanngorlugit; tamatumani ilanngullugu sananeqaatit atorneqartut toqunartoqassusiinik issittumilu nungujartortassusiinik ilisimasanik aalajangersimasunik tunngaveqarluni periaatsinik avatangiisinut pitsaanerpaanik toqqaaneq.

3. Uuliamik maqisoortoqarnerani avatangiisinut sunniutit qanoq minnerpaatinneqassappat makkuninnga tunngaveqarluni:

a. sumiiffiit piffissallu sunneriarfiunerpaat pinngitsoorneqartussanngorlugit mississueqqissaarluni qillerinernik pilersaarusiorneq
b. uuliamik maqisoornermut upalungaarsimanerup pilersaarusiorneqarnera, tamaani uuliaarluertoqarnerani uuliaarluernermik akiueriaatsit pitsaasut avatangiisinillu mianerinniffiusut pissarsiarineqarsinnaanngorlugit aammalu avatangiisinik nalilersuinikkut toqqarneqarsinnaanngorlugit (*Net Environmental Benefit Analysis* – NEBA).

Apeqqutit taakku pingasut qulequttatigut ataqatigiissutigut aqqanilitsigut qulaajarneqarput aammalu misissuinissat pillugit qasseersuarnik siunnersuuteqarfiullutik.

Tamatuma kingorna pilersaarusiaq uuliasiortitseqatigiiffinnut tamaani mississueqqissaarnissamut qalluinissamullu tallimanik akuersissutaateqartunut saqqummiunneqarpoq, misissuinerillu siunnersuutigineqartut amerlanerit ingerlatseqatigiiffinnit taakkunannga namminersorlutik oqartussat aqqutigalugit aningaasalersugaapput. Pilersaarusiaq tamatuma kingorna ilisimatusarnikkut suliutinngortinneqarpoq ima taaguuteqarluni: Tunup avannaani periusissiorfiusumik avatangiisinik misissuineq (*Strategic Environmental Study Program for Northeast* Greenland). Taanna makkuninnga imaqarpoq (angusat maannamut saqqummiunneqareersut ungaluuserlugit issuarneqarput):

- 2017-imi aggustimi / septembarimi Tunup avannaata imartaani imiarsuarmik aallaaveqarluni misissuineq immap pissusianik uumassusileqarfinnillu misissuiffiusoq. (Hansen et al. 2019b, Møller et al. 2019, Jørgensen et al. 2019, Bouchard 2020).
- Immap naqqata uumasuinik naasuinillu misissuineq (Hansen et al. 2019b, Wegeberg 2020b).
- 2017 aamma 2018-mi sinerissap qanittuani aammalu tinnuttagaani qeqquakkunnik misissuineq (Wegeberg et al. 2019).
- Timmissanik imarmiunik misissuineq; aamma 2017-imi umiarsuarmiit timmisartumiillu ataatsikkut kisitsinerit kiisalu 2017, 2018 aamma 2019-imi naajavaarsunnik taarteraarnanillu uumassusilittut uumaffiinillu misissuinerit. (Boertmann et al. 2019a, b, Frederiksen et al. 2019).
- Miluumasut imarmiut; aamma 2017-imi 2018-imilu ukiukkut aasakkullu timmisartumiit kisitsinerit, 2016 aamma 2017-imi naalaarutinik ikkussuinerit, sajuppillatsitsisarnerit qilalukkanut qernertanut sunniutaannik misissuinerit kiisalu qaammataasanut nassitsissutit atorlugit arfiviit, aataat, natsiit nannullu ingerlaartarnerinik misissuinerit (Hansen et al. 2019a, Heide-Jørgensen et al. 2019a, b, Laidre et al. 2019, Rosing-Asvid & Dietz 2018, Rosing-Asvid & Zinglersen 2018, Videsen et al. 2019, Williams et al. 2017).
- Uuliap akuisa illeqqanut, uillunut uumasunullu natermiunut allanut toqunartoqassusii (Agersted et al. 2018, Gustavson et al. in prep.).
- Uuliap aggorsimasup qeqqussanut sunniutai (Wegeberg et al. 2020a, in prep.).
- Tunup avannaata imartaani uuliap nungujartornera (Johnsen et al. 2019).
- Sikuusumi uuliap ikuallanneqarnera aamma ikummarlukut avatangiisinut sunniutaat (Fritt-Rasmussen et al. in prep. a, b).
- Tunumi sumiiffiit uuliaarluernermut misikkarissut assiliorneqarnerat (suliarineqarpoq.
- Ittoqqortoormiini Tasiilamilu piniarnerup oqaluttuarineqarnera mississoqqissaarneqarneralu (Flora et al. 2019).

Misissuinernit taakkunannga paasisat nalunaarusiami tassani tunngavigineqarput, taakkulu kapitalini paasissutissiivinnilu tulliuttuni saqqummiunneqarlutik, immikkoorlutilu aamma saqqummersinneqarput (siuliani issuakkat takukkit). Aamma Ilanngussami C-imi innersuussutigineqarput. Paasisat sumiiffimmi naliliiffiusumi uumassusileqarfiit uuliaarluernerlu pillugit ilisimasanik pitsanngorsaaqataapput.

Nalunaarusiaq Danmarkimi Avatangiisinik Nukissiutinillu Misissuisoqarfimmit kiisalu Pinngortitalerivimmit suliarineqarpoq.

Sumiiffik neqeroorutigineqartussatut naatsorsuutigineqartumit annerusoq nalunaarusiami samminegarpoq (takuuk Assiliartaliussaq 1). Uuliaarluernerit ungasissorujussuarmut tissukaanneqarsinnaassarnerata taamalu sumiiffiup neqeroorutigineqartussap avataanut pisinnaanerata ilanngullugit isiginiartariaqarnerat tamatumunga pissutaavoq.

Sumiiffik issittup avannaarsuaniippoq uumassuseqarnikkullu taavani ilisarnaataasartunik ilisarnaateqarluni; Uumasut assigiinngissitaartut amerlagisassaanngillat (natermiut eqqaassaanngikkaanni, nerisareqatigiiaat amerlanngillat, sumiiffiit ilaat uumassusilinnik amerlasoorujussuarnik peqartarput. Uumasut assigiinngissitaartut amerlanngitsuinnaanerat illuatungilerlugulusooq uumasut ataasiakkaat ilaat amerlasoorujussuusarput, uumasullu taakku ilaat nerisareqatigiinnermi pingaarutilerujussuusarlutik. Tassa uumasut pingaarutillit taakku piffissami sumiiffimilu amerlassusii nerisareqatigiinni qaffasinnerusunut assut pingaaruteqartarput.

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.

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

Sunniut (*effect*). Suliat aalajangersimasut imaluunniit sananeqaatit avatangiisinut aniatinneqartut sunniutaat pillugit atorneqartarpoq, soorlu marraap qillerinermi perrassaatigineqartup toqunartuisa sunniutaat pillugit, imaluunniit sajuppillatsitsisarluni misissuinerup nipiliornerisa miluumasunut imarmiunut nujoqqatsitsineri pillugit imaluunniit qoqersillutik tusaasaarukkallartitsinerat pillugu.

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

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.

Uumassuseqassuseq

Sumiiffiup naliliivigineqartup ilaa uumassuseqassuseq / uumassusileqarfiit eqqarsaatigalugit pisoorujussuuvoq, aammali sumiiffiit ilaat uumassusilinnik naammattuugassaqanngeqalutik. Upernaakkut sumiiffiit ilaanni uumasuaqqat pinngorartut amerlasoorujussuusarput, immap natermiui assigiinngissitaaqaat aammalu timmissat miluumasullu imarmiut amerlasaqalutik. Misissuinerit kingulliit takutippaat pingaartumik nunaviup avammut atanerata sinaa assorsuaq uumasuaqqat pinngorarfigisaraat, sumiiffiillu ilaanni immap nillertup koraaliinik amerlaqisunik nassaartoqarpoq.

Timmissat eqqarsaatigalugit timmissannik pingaarutilinnik (Kalaallit Nunaat kiisalu nunat tamalaat eqqarsaatigalugit) aammalu timmissanik navianartorsiortunik soorlu appanik (Kalaallit Nunaanni navianartorsiortutut nalunaagaasut) aammalu naajavaarsunnik (nunani tamalaani nunatsinnilu navianartorsiortutut nalunaagaasunik) naammattuugassaqarpoq kiisalu sinerissami Ittoqqortoormiit eqqaanni aakkarnersuaqarfinni appaliarsuit millionit qassiit piaqqiortarlutik (nunatsinnit akisussaaffigineqartut). Upernaakkut ukiakkullu sumiiffik naliliiviusoq aqqusaarlugu sanioqqullugulunniit timmiarpassuit Svalbardimi Ruslandimilu erniorfimmik Canadap Kitaatalu kujataata imartaanut ukiiffigisartakkamik akornanni ingerlaartarput. Uumasut amerlanerpaasartut tassaapput appaliarsuit appallu, aammalu naajavaarsuit ikittuinnaalersimaersut amerlanersaat tamaanna aqqusaartarlutik. upernaakkut mitit amerlasoorsuullutik aakkarnersuaqarfinni katersuuttarput, ukiakkullu appaliarsuit Ittoqqortoormiit eqqaanni erniorfimminniit Svalbardip Kalaallit Nunaatalu akornannut imaanut ingerlaartarlutik.

Miluumasut imarmiut nerisareqatigiiaanni qullerpaajullutik inissisimapput, taakkunanngali puisit, arferit qullerpaallu nannut sumiiffimmi naliliiviusumi tamarmi naammattuugassaasarlutik. Nannut assersuutigalugu imaq sikulik tamaat najortarpaat (assiliartaliussat 44, 45), qilalukkat qernertat akuttusinatik kangerlunni sinerissamilu aasiffimminniit ukiukkut nunaviup avammut atanerata killinganut ingerlaartarput. 2017 aamma 2018-imi misissuinerup nalaani paasineqarpoq Dove Bugt aasiffiusartuusoq pingaarutilik. Arfiviit annermik nunaviup avammut atanerata nalaaniittarput, ilaasalu ungasissumut ingerlallutik kangimut Svalbard qaangertarpaat. Upernaanerani qanittukkut naammattorneqarput nunaviup avammut atanerata killingani avannarpasissuseq 76° og 78°-imi attarmoortorpassuit. Aataat natsersuillu upernaakkut sumiiffiup tamatuma qiterpasissuani sikuni katersuuttarput tamaani piaqqisarlutik. Aarrit pingaartumik Tunup avannaata aakkarnersuaqarfiani (Nordøstvandet) ukiuunerani ittarput, aasaaneranilu sumiiffiup qiterpasissuani qassiinik nunami qassimasarfeqarlutik. Aasakkut tikaaguliusaat, tunnullit qipoqqaallu kiisalu kigutilissuit kujataaniit tikiuttarput nunaviullu avammut atarngata killinga najortarlugu. Miluumasut imarmiut qassiit nungutaanissamut nunarsuatsinni navianartorsiortutut isigineqarput (allassimaffimmi aappalaartumiittut) – soorlu nannut, aarrit, tunnulluit, tikaagulliusaat kiisalu arfiviit.

Imaani avatangiisini uumassuseqarfiit immikkut pingaarutillit tassaapput aakkarnersuaqarfiit, immami sikuugaluami annerusumik minnerusumilluunniit imaasartut. Aakkarnersuaqarfiit pingasut tassaapput Nordostrundingenip avataani Nordøstvandet, Wollaston Forlandip avataani Siriuspolyniet, kiisalu Kangerlussuup / Scoresby Sundip ammarnga. Aamma sineriak atorlugu minnerusunik allanik aakkarneqartarpoq. Aakkarnersuaqarfiit ukiuunerani imaakkajuttarput upernaakkullu annerulersarlutik.

Taamaannerat pissutigalugu sumiiffinnut eqqaanniittunut sanilliullugu tamaani uumasuaqqat siusinneroqisukkut pinngoralersarput. Taamaammallu miluumasut imarmiut tamaani ukiisinnaasarput, kiisalu timmissat ingerlaartut immamik sikuunngitsumik pisariaqartitsisut ukiup ingerlanerani sinerissami sumiiffinni allanut sanillliullugu siusinneroqisukkut taakkunani akunnissinnaasarlutik. Uumassuaqqat siunnerusukkut pinngoralersarnerat pissutigalugu miluumasut imarmiut timmisallu aggiasarput, kiisalu Ittoqqortoormiit illoqarfiata aakkarnersuaqarfiit ungasinngisaannut tunngavilerneqarsimanera nalaatsornerinnaanngilaq. Sumiiffimmi naliliiviusumi timmissat imarmiut ineqarfissui tamarmik aakkarnersuaqarfiit eqqaanniipput aammalu timerpasissup timmiai imersiortut tatsit taseqqallu sikuinnginnerini tamaaniittut amerlasaqalutik. Tamatuma aarri aakkarnersuaqarfinni ukiisarput tamatumanilu aakkarnersuaqarfik Nordøstvandet pingaaruteqaqaaq.

Qalerallit naliliiviup kujasinnerusortaani iluanaarniutigineqarput, aammalu nammineq atugassanik piniarneq aalisarnerlu Ittoqqoortoormiormiunut kiisalu Tasiilarmiunut avannamut sumiiffimmut naliliiviusumut piniariartartunut pingaaruteqarput. Aamma tamaani takornariartitsisoqartaproq, ilaatigut Ittoqqortoormiit aallaavigalugit kiisalu umiarsuit takornariutit atorlugit.

Naliliinermi tunngaviusut

Uuliaqarfiit atuunnerminni ingerlasarneri kiisalu misilittakkat naapertorlugit suliat pisartullu avatangiisinut sunniuteqarnerpaajusartut pingaarnerutillugit sapinngisamik naliliisoqarpoq. Kalaallilli Nunaanni uuliasiorneq misilittagaqarfigineqangimmat sulianik taakkuninnga naliliinerit tigussaanerunngillat kisiannili sumiiffinni allani assingusunik atugagaqarfiusuni misilittakkanik tunngaveqarlutik. Pingaartumik 1989-imi Alaskami Prince William Soundimi kiisalu 2010-imi Mexicop Kangerliumanersuani uuliamik maqisoornerujussuit pillugit allaaserisarpassuit, Barentshavimi uuliasiornerit pillugit norgemiut avatangiisinik naliliinerat (2003) kiisalu Issittumi Siunnersuisoqatigiit *Issittumi Uulioasiornermik Gassisiliornermillu Naliliinerat (*AMAP 2007) tunngavigineqarput.

Nalunaarusiami matumaninaliliinerit silap pissusianik atuuttunik tunngaveqarput. Silap pissusiata allanngorneri sumiiffimmi naliliiviusumi avatangiisinut sunniuteqartarput, pingaartumillu sikuusarnera maanna allannguuteqalereerpoq. Tamatuma malitsigisaanik uumaniarnermi pissutsit allanngormata uumasut ilaat ikilillutillu siammarsimannginnerulissapput, allallu iluaqusserneqassapput kiisalu nutaat takkullutik aalaakaasunngussallutik.

Naliliinerit uumassusillit pillugit ilisimasanik pissarsiassaasunik 2016-2019-imi misissuisarnertigut pitsanngorsimaqisunik tunngaveqarput.

Misissueqqissaarnerit

Misissueqqissaarnerit ingerlaavartuuneq ajorput, amerlanertigut ukiualunni ingerlasarput amerlanertigullu sumiiffimmi akuersissuteqarfiusumi tamarmi siammarsimasarlutik. Aammattaaq imaanerinnaani ingerlasarput, tassa aasakkut ukiakkullu, qularnanngitsumik juulimiit oktoberimut. Kisiannili sajuppillatsitsisarluni misissuinerit 2010-2016-imi sikunik aserorterut atorlugu ingerlanneqarput.

Misissueqqissaarneq uuliaqarneranik gasseqarneranillu takutitsiviunngippat taamalu misissueqqissaarnernik siammaanissaq akilersinnaanngippat misissueqqissaarnermi suliat unitsinneqassapput atortullu piiaarneqarlutik. Akerlianilli uuliaqarpat piffissami nalilersuiffimmi iluaqutigineqarsinnaasutut paasineqartumik, suliat qilleriviliornermut ikaarsaartinneqassapput tassanilu uuliaqarfiup killingi paasiniarlugit qillerisoqartassaaq, atortulersuutit sullissiviillu ikkussuunneqarlutik, kingornalu uuliamik nassaarineqartumik qalluivinik aallartinneqassalluni (matuma kingulia takuuk).

Misissueqqissaarnertigut akornusersuinerit annersaat sulianit nipiliorfiusunit pisarpoq (soorlu sajuppillatsitsisarluni misissuinernit, qillerinernit kiisalu qulimiguullit angalasarnerinit). Annertugisassaangitsunik, ataavartuunngitsunik sumiiffinnilu aalajangersimasuniinnaq atuuttunik sunniisoqartarnissaat naatsorsuutigineqarpoq, tassami sunniutit annerusut pinaveersaartitsiniarnikkut pinngitsoorneqarsinnaammata, soorlu sumiiffinni piffissaniluunniit misikkariffiulluartuni suliat pinngitsoortittarnerisigut. Taamaattorli sajuppillatsitsisarluni misissuinerit 3D-it immikkuullarissut sumiiffinni killilinni ingerlanneqartartut malunnaateqaqisuik sunniuteqarsinnaasarput, ingasannerpaagunillu uumasunut sunnertialluinnartunut naliliiviusup iluaniittunut sunniuteqarnerlussinnaallutik pingaartumik qilalukkanut qernertanut, arfivinnut aammalu aavernut. Aamma sumiiffimmi ataatsimi suliat arlaliugunik kattullutik sunniuteqarsinnaapput, tamannalu assersuutigalugu sajuppillatsitsisarluni misissuinissanik pilersaarusiornermi ilanngullugu isiginiartariaqarpoq.

Sajuppillatsitsisarluni misissuinerit sakkortuut aamma qaleralinnik piffissami aalajangersimasumi nujoqqatsitsisinnaapput, aalisarfinnilu pingaarutilinni tamanna pippat misissuinerit aamma aalisarnermut pitsaanngitsumik sunniuteqarsinnaallutik. Aalisakkanilli allanik misissuisarnerit naapertorlugit sunniutip taassuma ataavartuuneq ajornera malunnarpoq. Suffiviusartut sajuppillatsitsisarluni misissuinernut malussarilluinnartutut isigineqartarput, qalerallilli tamaani suffisanngillat, taamaammallu ajornartorsiut tamanna tamaani atuutinngilaq.

Miluumasut imarmiut sajuppillatsitsisarluni misissuinernit akornusersugaallutik neriniarfigisartakkaminnit ingerlaarfigisartakkaminnillu ingalatseratarsinnaapput. Kisiannili sajuppillatsitsisarluni misissuinermit ataatsimit (sapaatit akunnerinik qaammatinilluunniit arlalinnik sivisussuseqartumit) sunniutit ataavartuunavianngillat suliat unitsinneqartussaanerat pissutigalugu. Sulialli qassiit kattullutik sunniutaat uumasunut sunniuteqarsinnaapput. Kalaallit Nunaanni sajuppillatsitsisarluni misissuinerit malittarisassiorneqarsimapput miluumasunut imarmiunut (pingaartumik arfernut) ajoqusiiniviit pinaveersaartikkumallugit, sumiiffinnilu pingaarutilinni sunniutit killilersorumallugit qilalukkanik qernertanik, arfivinnik aammalu aavernik illersuiviit qassiit toqqartorneqarsimallutik.

Silaannarmik seqqortaatit sajuppillatsitsisarluni misissuinermi atorneqartartut naqitsinerisa 5 meterit tikillugit ungasissusilimmi aalisakkat suaannik quperluusaannillu toqutsisinnaanerat uppernarsineqarsimavoq. Norgemi aarleqqutigineqarpoq sumiiffinni annertuumik sajuppillatsitsisarluni misissuiffiusuni aalisakkat kinguaassiaat ima toqorarneqartigisinnaasut allaat aalisakkat inersimasut amerliartornerannut sunniuteqarsinnaalluni. Taama amerlatigisunik aalisakkanik kinguaassiorfeqarnera Kalaallit Nunaata imartaani ilisimaneqanngilaq, aamma upernaakkut amerlanerpaasarput tamatumalu nalaani nalinginnaasumik sajuppillatsitsisarluni misissuisoqarneq ajorluni. Taamaammat Tunup imartaata ilaani aalisagaqarfiit sajuppillatsitsisarluni misissuinernit annerusumik sunnigaanissaat ilimanaateqanngitsutut inerniliunneqarpoq.

Misissueqqissaarluni qillerinerittaaq nipiliorfiusarput. Maskiinat sarpiillu qillerivimmik puttasumik nikitsaaliusartut (tassami sumiiffinni tamangajanni immap naqqanut qajannaakkanik qilleriviliorfigissallugu imaq itivallaartarpoq) assut nipiliortarput. Nipi miluumasunut imarmiunut ungasissumiittunut suunniuteqarsinnaasarmat nipiliorfik ingalatsertarpaat, pingaartumillu arferit misikkarissuuput. Taamaammat qilalukkat qernertat, arfiviit aarrillu najugannaamminnit pingaarutilinnit nujutsinneqaratarsinnaapput. Aamma aasap qaammataani arfiviit, tikaagulliusaat, tikaagulliit qipoqqaallu ataavartuunngikkaluamik nujutsinneqarsinnaapput.

Piniakkat piniarfinnaaniit nujutsinneqarsimappata miluumasunik imarmiunik piniarneq sunnerneqarsinnaavoq, tamannalu naliliiffiup kujasinnerusortaani Ittoqqortoormiit eqqaanni kiisalu Tasiilarmiut piniariartarfianni Kangerlussuup eqqaani pisinnaavoq.

Misissueqqissaarluni qillerinermi marraq perrassaatitut, qillikkap naqitsineranik aqutsinermut aammalu qillernerlukunik qilleriviup qaanut qalluinermi atorneqarpoq. Taanna imermik imerpallaateqarsimagaangami qillerinerup kingorna imaanut maqinneqarsinnaavoq, uuliamilli akullit avatangiisinut ajoqutaanerusartut ullumikkut nalinginnaasumik nunaliaallugit suliarineqartarput imaluunniit nakkutigisaasumik toqqortarineqartarlutik.

Kalaallit Nunaanni maannamut marraat perrassaatit imermik imerpallatat kisimik atorneqartarsimapput. 2010-imi Qeqertarsuup avataani qillerinermi marraq perrassaat 6000 tons kiisalu qillernerlukut 2261 m^3-inik annertussuseqartut maqinneqarput. Aamma Akuutissat avatangiisinut ulorianannginnerusut ″qorsummik″ ″sungaartumillu″ nalunaaqqutsikkat kisimik atorneqarsinnaaput (OSPAR-ip immikkoortiterinera takuuk.). ″Aappalaartumik″ ″qernertumillu″ nalunaaqqutsikkat akuerisaanngillat. Taamaattorli qillerinerup avatangiisinut ulorianannginnerulersinneqarnissaanut iluaqutaanissaat uppernarsarneqarsinnaappat ″aappalaartut″ (arrortikkuminaatsut) akuersissuteqarfigineqarsinnaapput. Malittarisassat taakku Norgemi qillerinermi akuutissat atorneqarnerinut malittarisassat assigaat. Oqaatigineqassaarli Norgemi marraq qillerinermi perrassaat uuliamik akulik aamma atorneqartarmat nunamut kingorna toqqortarineqarnissaa / suliarineqarnissaa taamalu imaani avatangiisinut aniatinneqannginnissaa piumasaqaatigalugu. Kalaallit Nunaanni 2010-ikkunni qillerinerup kingorna ajornarunnaarsimavoq.

Qillerinermi perrassaammik imermik akulimmik qillernerlukunillu aniatitsinermi maqitsiviup eqqaani marraap katersuunneratigut immallu iserissertinneqarneratigut immap naqqata uumasui sunnerneqarsinnaapput. Tunup avannaata imartaani marrarmik perrassaammik qillernerlunillu maqitsinerup sunniutai nalileruminaapput. Taamaattorli marraat perrassaatit avatangiisinut ulorianannginnerpaat atorneqarpata misissueqqissaarluni qillerinermit ataasiinnarmit maqitsinerit annikitsuinnarmik piffimmilu annikitsuinarmi sunniuteqarnissaat naatsorsuutigineqarput. Kisianni assersuutigalugu koraaleqarfiit nassaarineqaqqammersut assorsuaq sunnertiassapput.

Marrarnik perrassaatinik qillernerlukunillu aniatitsinermut taarsiullugu nunaliaassinikkut imaluunniit qillerinerup kingorna qillersimasamut maqitsinikkut sunniutit pinngitsoorneqarsinnaapput. Taamaaliornerli immini aamma avatangiisinut sunniuteqarfiusarpoq aniatitsinermut sanilliullugu oqimaalutartariaqartunik.

Kiisalu qillerinerit nukerujussuarmik pisariaqartitsiviusaramik gassinik kiassiartortitsisartunik annertoorujussuarmik aniatitsinermik kinguneqartarput. 2010-imi Qeqertarsuup avataani qillerinerit pingasut Kalaallit Nunaata aniatitsineranik 15%-imik qaffatsitsipput.

Misissueqqissaarluni qillerinerup nalaani avatangiisinut sunniutaaratarsinnaasoq annerpaat tassaavoq tissaluttoorneq (*blowout)*, uuliamik maqisoorujussuarmik nassataqartarpoq. Uuliammik maqisoornerup kingunerisinnaasai matuma kinguliani eqqartorneqassapput.

Ineriartortitsineq tunisassiornerlu

Misissueqqissaarnerup nalaani pisartut paarlattuannik uuliasiorfimmik ineriartortitsineq uuliamillu nioqqutissiorneq sivisoorsuarmik ingerlasarput (ukiut qulikkaat), suliallu qassiit avatangiisinut kingunerlorujussuarsinnaallutik. Sunniutit tamakku pilersaarusiorluarnikkut, *peqqissutsimut, isumannaallisaanermut avatangiisinullu* akuerisaasunik suleriaaaseqarnikkut, *periaatsinik pissarsiarineqarsinnaasunik pitsaanerpaanik* (BAT) atuinikkut kiisalu *Avatangiisit eqqarsaatigalugit suleriaatsinik pitsaanerpaanik* annertuumik pinaveersaartinneqarsinnaapput. Taamaattorli aniatitsinerit (soorlu nioqqutissiornermi imermik atorneqartumik), siuliani taaneqartunik iliuuseqaraluaraanniluunniit aniatitsiviusartut kattullutik sunniutaat pillugit ilisimasat amigaatigineqarput.

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

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

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

Atortulersuutit imminni inissisimanerat kiisalu taakku akornusersuinerat miluumasunut imarmiunut ima sunniuteqarsinnaapput allaat uumasut taakku neriniarfigisartakkaminnit nujoqqavissinnaallutik imaluunniit ingerlaartarfii allanngorsinnaallutik. Tunup avannaata imartaani pingaartumik qilalukkat qernertat, arfiviit aammalu aarrit tamatumani eqqartorneqarput. Tamatumalu saniatigut uumasut piniarneqarsinnaasut tamakku piniarneqarnerat ajornakusoornerulersinnaavoq.

Immap natermiui, soorlu koraleqarfiit 2017-imi nassaarineqartut, aamma immap naqqani atortulersuutinik inissiinermik innarlerneqarataannaapput.

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

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

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

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

Qilleriviup qalluiffiullu sunniutigisinnaasai assut nalileruminaannerat oqaatigisariaqarpoq tassami sumififissaat, qanoq annertutiginissaat, sivisutigisumik atuunnissaat aammalu qanoq ittuunissaat kiisalu teknikkikkut aaqqiissutit qanoq ittuunissaat ilisimaneqanngimmata.

Sumiiffimmi naliliiffiusumi uuliasiornerit sunniutaasa kingunerinut takussutissiaq naliliinerlu

Tabelimi tulliuttumi sumiiffimmi naliliiffiusumi uuliasiornerit sunniutaat pingaarnerpaat takussutissiorneqarput.

Uuliamik maqisoorneq

Uuliasiornermit avatangiisinut sunniuteqarsinnaasut annersaat tassaapput uuliamik maqisoornerujussuit. Tamakku pisarput tissaluttoornikkut *(blowouts)*, tassa qillerivik aqunneqarsinnaajunnaaraangat pisartut, imaluunniit uuliap toqqortarineqarnerani angallanneqarneraniluunnit ajotoornerit, soorlu uuliamik usisaassuit uumiarnerini.

Uuliamik maqisoornerujussuit ullumikkut akuttortissimaqaat atortorissaarutit isumannaallisaatillu pitsanngorsartuarneqarnerat pissutigalugu. Ajutoorsinnaanerli atuuttuaannarpoq, pingaartumik siusinnerusukkut uuliasiorfiusimanngitsuni, soorlu Kalaallit Nunaata imartaani ilulissat navianartorsitsivigisartagaanni ajutoorsinnaaneq qaninnerussaaq. AMAP (2007) naliliivoq Issittumi uuliamik maqisoortoqarsinnaanera uuliamik assartuinermi ilimanaateqarnerpaajusoq.

DMI kiisalu SINTEF Tunup avannaata imartaani uuliamik maqisoortoqarpat tissukarfissaat maqisoorfissat pingasut aallaavigalugit naatsorsorsimavaat (assiliartaliussaq 47). DMI-ip naatsorsugaasa ilaanni uulia maqisoorfimmiit 100 kilometerinik ungasissusilimmi sinerissamut apuuppoq. SINTEF-ip naatsorsugaasa ilaanni uulia sineriammut 100 kilometerit sinnerlugit isorartussusilimmut tippuppoq. Tassa sumiiffimmi naliliiviusumi siunissami uuliamik qalluivinniit uuliamik maqisoornerit sinerissamuttaaq apuuteratarsinnaapput.

Sinerissap imartaani uuliamik maqisoornerit avataani maqisoornerniit aseruinerujussuusartutut isigineqartarput. Kisianni Tunup avannaata imartaani taama naliliisarneq allanngortilaartariaqarpoq.

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

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

Tassami sikoqartarpoq uuliap nipinngaffigisiinnaasaanik arrortingaarnagillu sumorsuaq angallassisigisinnaasaanik. Aammali sikuunngitsumut sanilliullugu siku maqisoornerup siammarnissaanik killiliisinnaavoq. Immami sikuusumi uuliap qanoq pisarnera qanorlu nungusarnera pillugu ilisimasat killeqarput.

Sinerissap qanittuanni immap uuliaarluinermut annerpaamik navianartorsiortitaasarneranut pissutaasoq tassaavoq uuliap sumiiffiit assigiinngitsorpassuarnik amerlasoorpassuarnillu uumassusillit eqqorsinnaasarmagit, soorlu ikkannerit immap natermiuinik uumasullit aarrit inuussutigisaannik aammalu sumiiffiit timmiarpassuallit. Uuali kangerliumanerni kangerlunnilu uneralersinnaavoq taavalu immap qaaniit ammut naqqata tungaanut uuliap akui toqunartoqaqisut unerarsinnaallutik. Aamma uulia marrarmut imaluunniit sissamut ujarattuumut unerarsinnaavoq taamalu kigaatsumik avatangiisinut seererusaarsinnaalersarluni sivisoqisumik sunniuteqalersinnaalluni, soorlu timmissanut sineriassiortartuusunut. Tassalu Prince William Soundimi taama pisoqarsimammat 1989-imi maqisoornerup kingorna suli tassa sumiiffinni taama ittuni uuliaqarpoq. Sumiiffimmi naliliiviusumi sinerissat ilarpassui Prince William Sounditut pissuseqarput. Kiisalu sumiiffiup naliliiffiup kujasinnerusortaa tamaanimiunit piniarfiullunilu aalisarfiuvoq, suliallu taakku uuliaarluernermit sunnigaasinnaapput.

Imaannarmi uuliap arrortarnera uuliaarluernerup avatangiisinut sunniutaanik annikinnerulersitsisarpoq. Tunup avannaata imartaani sumiiffimmi naliliiffiusumi imartaqarpoq sinerissamut ungasikkaluarlutik taamaattoq navianartorsiortinneqarataanaasunik. Soorlu, appaliarsuit Ittoqqortoormiit eqqaanni erniorsuusut amerlaqalutik nunaviup avammut atanerani katersuuttarput pingaartumillu nunaviup avammut atanerata itiseriarnerani ukiakkut katersuuttarlutik. Sarfat aporaaffiii, nunaviup avammut atanerata ikkaleriarnerani sarfat nillikaasut aammalu sikut saatsersut sinaat, upernaakkut uumasuararpassuit pinngorarfigisartagaat, aammalu planktonit naasuusaasut uumasuaraasullu amerlaqalutik immap qatsinnerusortaanni pinngorarfigisartagaat uuliaarluinermut misikkarilluinnarsinnaapput pingaartumik 2010-imi *Deepwater Horizon*-ip ajutoorneranisut maqisoorneq immap naqqaniit aallaaveqarsimappat.

Uuliaarluernerli qaleraleqassusermut sunniuteqarunnangilaq, qalerallillu tassaapput sumiiffiup naliliiviusup kujasinnerusortaani aalisakkani iluanaarniutigineqarsinnaasut, kisiannili aalisarneq sunnigaasinnaavoq sumiiffiup aalisarfigeqqusaajunnaarsinnaanera pissutigalugu.

Timmissat immap qaani uuliaarluinermut misikkareqaat, Tunullu avannaata imartaani misikkarissunik timmiaqarfippassuaqarpoq. Assersuutigalugu appat appaliarsuillu erniorfissuaqarput, upernaakkut mitit katersuuttartorsuupput kiisalu naajavaarsuit amerlajunnaartut katersuuttarlutik. Aamma ukiassalernerani mitit assigiinngitsut arlallit sinerissami isallutik katersuuttarput. Aamma appaliarsuit imaannarmi ukiakkut isasut misikkarissuupput.

Miluumasut imarmiut immap qaani uuliarluernermit sunnigaasinnaapput. Sumiiffimmi naliliiffiusumi aarrit navianartorsiortinneqarataannaapput neriniarfiit pingaarutillit ikittuinnaasut amerlaqalutik katersuuffigisarmatigit. Aarluit (taamalu arferit aamma allat) 1989-imi *Exxon Valdez*-ip ajutoornerata kingorna paasineqarput uuliarluernerup kingorna uuliap aalarnerinik najuussuinermikkut misikkarissuusut, uuliamillu maqisoortoqarpat taamaalisoqarataanaavoq (matuma kingulianiittoq takuuk).

Nannut navianartorsiortinneqarsinnaasorujussuupput meqquminnik aluttuillutik uuliaajaasarnertik pillugu, taamaalillutillu uuliamik iiorakkaminnit toqunartoqalersinnaallutik.

Immami sikulimi uuliaarluertoqarpat uulia qularnangitsumik sikup ikersisimanerini puttaallu ataanni katersuutissaaq, taamalu timmissanut miluumasunullu imarmiunut immamik ammaannartumik isumalluuteqartunut sunniuteqarsinnaassalluni, aammali eqalukkat kinguaassaat sikup ataani katersuuttartut aamma sunnigaassapput. Miluumasut imarmiut ammanersanut amerlanngitsunut allatut ajornartumik anersaariartortariaqartassapput, taakkunanilu uuliaqarpat uuliap aalarnerinik najuussueratarsinnaapput.

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

Mexicop kangerliumarnangani *Deepwater Horizon*-imi ajutoornermit uuliaarluernerujussuaq immap naqqanit itisoorsuarmit aallaaveqarpoq (1500 meterit missaannit). Tamatuma kingunerisaanik immap ikera annertoorujussuaq uuliaarlernersaqalerpoq. Uulia tamaaneerusaaginnarpoq sumorsuarlu siammarluni. Sumiiffik neqeroorfiusussaq Tunup avannaata imartaaniittoq nunaviup avammut ataneraniippoq

530 meterit tikillugit itissuseqarluni, taamaammat immap naqqaniit uuliamik maqisoqalissagaluarpat ajutoornersuarmi pisutulli pisoqarnissaa ilimanaateqannginneruvoq. Taamaakkumaanngitsutulli oqartoqarsinnaanngilaq tassami 1979-imi *Ixtoc*-imi maqisoornersuarmi 50 meteriinnarnik itissusilimmi taama pisoqarsimammat.

Sumiiffiit uuliaarluernermut sunnertiasut

Nunap assingini assiliartaliussani 76 aamma 77-imi ittuni sumiiffiit qassiit uumassuseqarnikkut pingaaruteqartut tikkuarneqarput. Nunap assingi taakku GIS atorlugu misissueqqissaarnernik tunngaveqarput, tassanilu tamatuma uumasui uumasoqarfiuneranullu tunngasut allat (aakkarnersuaqarfiit, ikkanneqarfiit allallu) nunap assinginut immikkoortunut qaleriiaarlugit iliorarneqarput misissoqqissaarneqarlutillu. Tamatuma kignoran nunap assingit taakku sumiiffinnik uuliaarluernermut akornusersuinermullu misikkarilluinnartunik toqqartuinermi atorneqarput (assiliartaliussaq 78). Toqqartukkat taakku sumiiffinnik assigiinngitsunik illersuiffiusunik (sumiiffinnik uumasunut pingaarutilinnik) toqqartukkanik allannguinissamut siunnersuuteqarfiupput, kiisalu sumiiffinnik uuliaqarneranik gasseqarneranillu misissueqqissaarfiusariaqanngitsutut pisuussutinik uumaatsunik suliaqarnermi avatangiisit pillugit Damarkimi Avatangiisinik Nukissiutinillu Misissuisoqarfiup Pinngortitaleriffiullu suleqataaffiini allannguinernik nassataqarlutik.

Uuliaarluernermik akiuineq

Atortorissaarutit periaatsillui pitsaanerpaat (BAT & BEP), isumannaallisaanermi piumasaqaasit tunngavigissaarlunilu malittarisassaqartitsinerit atorneqarnerisigut uuliaarluerneq pinngitsoortinneqassaaq. Uuliaarluernerit pingasuitsigut akiorneqarsinnaapput: katersuineq, akuutissat atorlugit siammartitsineq aammalu ikuallaaneq. Katersuinerit Amerikami 1989-imi 2010-imi uuliaarluernerujussuarni iluatsingaarfiusimanngillat imarlu suliffiginiagaq sikuuppat katersuinerit ajornakusuussallutik.

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 (*Environment & Oil Spill Response*, EOS). Aammali uuliap annikitsuaranngorlugu imermi siammarneratigut isumaminik nungujartortinneqarnissaa sukkanerulersinneqarsinnaalluni.

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

2017-imi sumiiffimmi naliliiviusumi uumasuaqqat uuliamik arrortitsisinnaassusiat misissorneqarpoq. Nunaviup avammut atarngata itiseriarnerani immap ikerani annikitsunnguamik uumasuaqqat arrortitsinnaassuseqarput, kisiannili nunaviup avammut atanerata nalaani aamma immap naqqata marraani uumasuaqqat arrortitsisinnaassusiat annikeqaaq. Nunaviup avammut atanerata itiseriarnganiluunniit uumasuaqqat uuliamik arrortitsisinnaasut killeqarput imaq naammattumik inuussutissaqanngimmat uumasuaqqat uuliamik arrortitsiniarnerminni nukissarisinnaasaannik. Imaq aatsaat inuussutissaqarneruppat uumasuaqqat arrortitsinerat sukkanerulersinnaavoq.

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 (*Uuliaarluernerup sunniutaanik minnerpaatitsiniutinik naliliinerit*, SIMA).

Sumiiffiit killilernissaat pillugit Danmarkimi Avatangiisinik Nukissiutinillu Misissuisoqarfiup Pinngortitaleriviullu kaammattuutaat

Paasisat katersukkat nutaat kiisalu periusissiorfiusumik avatangiisinik naliliinermi matumani nassuiarneqartut atorlugit uppernarsarneqarpoq:

a. Avannaata imartaata ilarujussua uumasunit nungutaaqqajaasutut nunatsinni nunallu tamalaat akornanni naliligaasunit qassiinit najorneqartartoq. Pingaartumik issittup avannarpasissormiunut Tunup avannaata imartaa najugannaajuvoq pingaarutilik (takukkit tabel 9 aamma 10 kiisalu Kapitali 3-imi nassuiaatit). Silap pissusia allanngoriartoqimmat, pingaartumillu ukiumiit ukiumut allanngorartaleqimmat, Tunup avannaata imartaa uumasunut taakkununnga uumaffittut pingaaruteqaleraluttuinnassangatinneqarpoq sikuijuitsup sikuisa tamaannaqquullutik ukiuni qulikkaani suli amerlaqisuni aniajuarnissaat naatsorsuutigineqarmat.

b. Tamaani annertuumik uuliamik maqisoorneq timmissat imarmiut miluumasullu imarmiut ilaasa ukiorpassuarni toqoraatigissavaat. Maqisoorneq taama ittoq sinerissamut tipippat (Nunami eqqissisitami aammalu ungasinnerusumi) *Exxon Valdez*-p Alaskami 1989-mi maqisoorneranit misilittakkat takutippaat sunniutit ukiuni qulikkaani qassiini atuussinnaasu (Kapitali 7 aamma 8, Tabel 19).

c. Sumiiffiup naliliiviup avannarpasinnerusortaa ukioq tamaat saatsersunik sikoqartarpoq kujasinnerusortaani minnerpaamik ukiukkut upernaakkullu saatsersunik sikoqartarluni. Nunarsuup avannarpasinnerusortaani sikuusarneranik siumut eqqoriaanerit naapertorlugit maannamut pisarneratulli ukiorpassuarni suli tamanna Sikuijuitsumiit sikunik aniaffigineqartuassasoq. Taamaakkaluartorli imartami annertuumi saatsersunik sikulimmi qerisartumilu uuliaarluernermik pitsaasumik saliisinnaassuseq uuliasiortunit suli ineriartortinneqarsimanngilaq (Kapitali 8). Kaperlattarnera tamatumalu avinngarusimanera pissutigalugit uuliaarluernerup akiorniarnera suli ajornakusoornerulissaaq. Tamatumalu saniatigut 2017-imi misissuinerup takutippaa uuliap isumaminik nungujartortarnera killeqaqisoq (Kapitali 8). Tamaani uuliaarluernerup qanoq pinissaanut uuliap qanoq ittuussusia silallu qanoq innera apeqqutaassapput, nillernerali pissutigalugu nungujartornera, arroriartornera siammariartorneralu kigaatsuinnarmik ingerlassallutik. Tamatuma malitsigisaanik uulia sumiiffimmit naliliiviusumiit tissukassaaq ilimanarluinnarlunilu kujammut Kalaallit Nunaata kujammut sineriaa atuassagaa. Uulia nunamut tipippat isumaminik nungujartornera ukiunik qulikkaanik qassiinik sivisussuseqarsinnaavoq.

Danmarkimi Nukissiutinik Avatangiisinillu Misissuisoqarfik Pinngortitaleriffillu uulia gassilu pillugit periusissamut nutaamut siunnersuuteqarmata kaammattuutigineqartut ilagaat Tunup avannaata imartaani (sumiiffinnilu qassiini) avannarpasissutsip 80°-ip avannaani avatangiisit mianeriumallugit piffissami periusissiorfiusumi uuliaqarneranik gasseqarneranillu misissueqqissaartoqassanngitsoq (Mosbech et al. 2019). Kaammattuummi tassani tunngavigineqarput:

- Tamaani uumasut assigiinngissitaarnerat, nunarsuatsinnut pingaaruteqartoq.
- Uumassusileqarfiup uuliaarluernermut immallu iluatigut nipiliornermut misikkarinnerujussua.
- Misissueqqissaarnerup nalaani, imaanilu uuliasiorfissamik suliaqarnerup uuliamillu tunisassiorfiliornerup nalaani immap iluani nipiliorneq annikillisinniarlugu atortorissaarutinik misilittagaqartoqannginnera.
- Imaani ingerlaartuartunik sikulimmi kaperlattartumilu uuliaarluernermik akiuiniutinik atortorissaarutinik misilittagaqartoqannginnera.

Ilisimasat nutaat nalunaarusiami matumani nassuiarneqartut kaammattuutip naliliivigeqqinnissaanik pissutissaqalersitsipput. Maanna inerniliunneqartoq tassaalerpoq sumiiffik naliliiffiusoq uumasorpassuaqarluni assut pingaaruteqartuusoq, aammalu sumiiffimmut ukiup ilaani sikuusartumut sikuusanngitsumulluunniit sanilliulluni uuliamik maqisoortoqarpat sunnigaanerujussuusussaassasoq. Taamaammat Danmarkimi Nukissiutinik Avatangiisinillu Misissuisoqarfik Pinngortitaleriffillu maanna kaammattuuteqarput piffissami periusissiorfiusumi nutaami (2020-24) sumiiffik naliliiffiusoq uuliaqarneranik misissueqqissaarnermut ammaanneqassanngitsoq.

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1 Introduction

This document comprises an updated version of the strategic environmental impact assessment (SEIA) of expected hydrocarbon activities in the Greenland part of the Greenland Sea issued in 2012. The update is based primarily on the new information obtained through an intensive research activity during the *Strategic Environmental Study Program for Northeast Greenland,* carried out in the years 2016-2019.

This was designed to define the ecosystem and obtain new knowledge that could be used to minimise the impact of oil exploration in the area, through improved planning and regulation and development of an oil spill response. The results will also be used for coastal zone mapping of areas sensitive to oil spill. The results will moreover be valuable in a broader context for management of this region of Greenland.

Oil companies with exclusive licenses for exploration and exploitation for oil and gas in Greenland are obliged to contribute to obtaining an understanding of environmental conditions. This funding is managed by the Greenland Minerals Authority. Agreement on the study program was reached between the licensees, Greenland Minerals Authority (GMA) and the Environmental Agency for Mineral Resources (EAMRA). The advisers to the EAMRA, the Greenland Institute of Natural Resources and DCE – the National Centre for Environment and Energy at Aarhus University, conducted the projects in consultation with a number of national and international partners.

The program as a whole was designed to provide answers to three key questions that support planning and regulation of oil activities in the area, and contains over 20 different research projects involving a range of different activities performed on sea, land and in the air.

The three key questions were:

1. How to conduct and regulate increased seismic activities in the Greenland Sea so that significant impacts from underwater noise on marine mammal populations are avoided or minimized?
2. How to regulate discharge of drilling mud and chemicals from exploration drilling in the Greenland Sea, so it is certain that significant impacts are avoided, and the best solution is selected based on specific information on toxicity and degradation in the high Arctic environment?
3. How to minimize the environmental impacts if an oil spill occurs based on:
   a) Planning of exploration activities so the most sensitive areas and periods are avoided.
   b) Planning of oil spill preparedness and response so efficient and environmentally beneficial response options for the Greenland Sea are available and can be selected operationally using a Net Environmental Benefit Analysis (NEBA).

These key questions were then addressed by eleven interlinked themes with a number of project proposals. The study plan was presented to the licence holders of the five licence blocks, and most of the proposed studies were subsequently funded by these companies. The *Strategic Environmental Study Program for Northeast Greenland* studies included:

- A ship-based integrated survey of oceanography and ecology in the Greenland Sea in August/September 2017 (Hansen et al. 2019b, Møller et al. 2019, Jørgensen et al. 2019, Bouchard 2020).

- Studies of benthic communities (Hansen et al. 2019b, Wegeberg 2020b).
- A study of tidal and subtidal macroalgal communities in 2017 and 2018 (Wegeberg et al. 2019).
- Seabird studies: an aerial survey of seabirds offshore Northeast Greenland simultaneously with the ship-based survey in August/September 2017, studies of ecology and distribution of ivory and Sabine's gulls in 2017, 2018 and 2019 (Boertmann et al. 2019a, b, Frederiksen et al. 2019).
- Marine mammal studies: aerial surveys winter and summer 2017 and 2018 and deployment of passive acoustic monitors (PAM) in 2016 and 2017, effect studies of seismic noise on narwhals and satellite tracking of bowhead whales, harp seals, ringed seals and polar bears (Hansen et al. 2019a, Heide-Jørgensen et al. 2019a, b, Laidre et al. 2019, Rosing-Asvid & Dietz 2018, Rosing-Asvid & Zinglersen 2018, Videsen et al. 2019, Williams et al. 2017).
- Effects of oil compounds on *Calanus hyperboreus*, on bivalves and other benthic organisms (Agersted et al. 2018, Gustavson et al. in prep.).
- Effects of dispersed oil on macroalgae (Wegeberg et al. 2020a, in prep.).
- Degradation of oil in water and sediment of the Greenland Sea (Johnsen et al. 2019).
- In situ burning: environmental impacts of residues and burning in ice (Fritt-Rasmussen et al. in prep. a, b).
- Development of an oil spill sensitivity atlas covering Northeast and Southeast Greenland (in preparation).
- Analysis of hunting habits in Ittoqqortoormiit and Tasiilaq (Flora et al. 2019).

The results of these studies presented in the chapters and text boxes in this report and in the above mentioned references have considerably improved the knowledge base on both ecological and oil spill issues in the assessment area.

The updated version of the SEIA report is funded by the Government of Greenland (the Mineral Licence and Safety Authority and the Environmental Agency for Mineral Resource Activities) and prepared by the Danish Centre for Environment and Energy (DCE) and the Greenland Institute of Natural Resources (GINR).

It is important to stress that a SEIA does not replace the need for site-specific Environmental Impact Assessments (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. An SEIA forms part of the basis for relevant authorities' decisions, and may identify general restrictive or mitigative measures and monitoring requirements that must be addressed by the companies applying for oil licences. However, the information described in the SEIA will be highly relevant for the preparation of specific EIAs.

Finally, 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 and coastal waters between 68° N and 82° N (from Kangerlussuaq Fjord northwards to Nordostrundingen) are the focus of this report, as it is the region which may potentially be affected by exploration and exploitation activities, particularly from accidental oil spills (Figure 1). This area will be referred to as 'the assessment area'. However, the oil spill trajectory models developed by DMI and SINTEF indicate that oil may drift further, outside the boundaries of this area, for example into Norwegian and Icelandic Exclusive Economic Zones (Nielsen et al. 2008, Johansen 2008).

The assessment area extends over waters of the Sermersooq Municipality and the National Park of North and East Greenland. There is only one town in the area: Ittoqqortoormiit/Scoresbysund with an airport located 40 km northwest of the town (Nerlerit Inaat/Constable Pynt). The total number of people living here is approx. 360. The National Park is a high Arctic environment, almost without anthropogenic impacts. There are a few permanently manned sites: the weather station Danmarkshavn and the military outposts Daneborg and Station Nord. Moreover, the old airport at Mestersvig is guarded by military personnel and there is a research station at Zackenberg which is currently manned from May to September.

To the south, the assessment area borders the former municipality of Tasiilaq (today included in Sermersooq Municipality). The inhabited sites in Tasiilaq are far from the assessment area but hunters may occasionally travel as far as the southern part of the Blosseville Kyst in the southern part of the assessment area.

1.2 Impact assessment methodology

The assessment includes activities associated with the full life cycle of an oil field, i.e. from exploration to decommissioning, see Chapters 7 and 8.

Exploration activities are expected to take place in the short summer window when the sea ice cover is relatively low; that is from July through September or mid-October. Production activities, if initiated, are likely to take place throughout the year.

The potential impact on important ecological elements of activities during the various phases of the life cycle of a hydrocarbon licence area are summarised in a series of tables in Chapters 7 and 8 (Tables 17-19).

Potential impacts listed in these tables are assessed under three headings: displacement, sublethal effects and direct mortality. Displacement indicates spatial movement of animals away from an impact, and is classified as none, short-term, long-term or permanent. For sessile or planktonic organisms, displacement is not relevant, and this is indicated with a dash (-). Sublethal effects include all notable fitness-related impacts, except those that cause immediate mortality of adult individuals. This category thus includes impacts that decrease fertility or cause mortality of juvenile life stages. Sublethal 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 2010a), the extensive literature from the *Exxon Valdez* oil spill in Alaska in 1989 (e.g. Shikenaga 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 (Anonymous 2003) – have been drawn upon. Se also Chapter 7 for a detailed account of the effects of the two spills *Exxon Valdez* and *Deepwater Horizon*.

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. Much uncertainty in the assessment is inevitable and this is conveyed with phrases such as “most likely” or “most probably”.

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

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

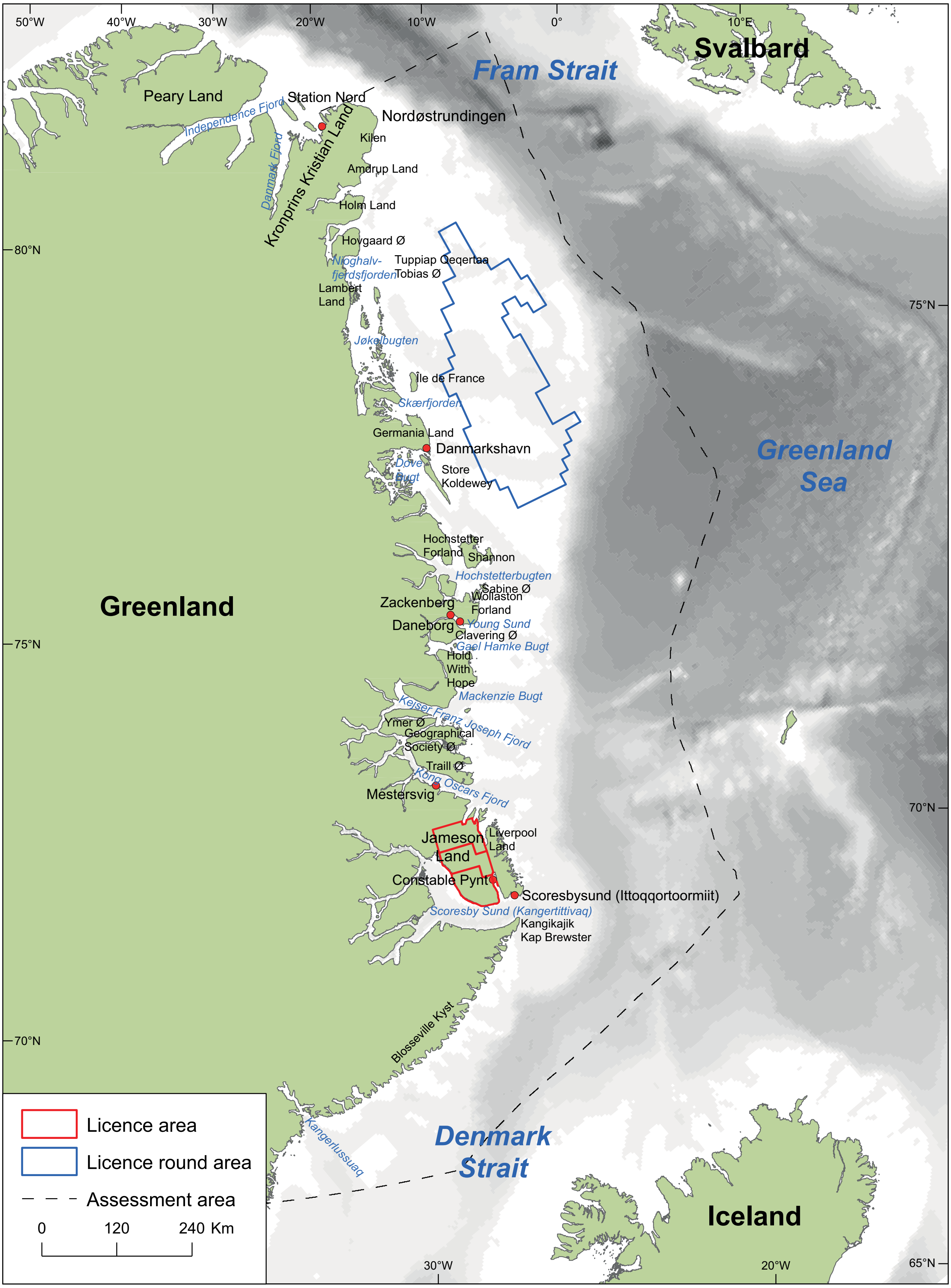


Figure 1. The assessment area with the most important place names shown. Red dots indicate inhabited sites: Towns (only one: Ittoqqortoormiit/Scoresbysund), military outposts, weather and research stations etc. See also text. There are currently no offshore hydrocarbon licences in the area. The perimeter of the offshore blocks available in the licencing round in 2012 is shown in blue and the three active onshore hydrocarbon licence blocks in Jameson Land are shown in red.

2 The physical environment

Christian Mohn (AU), Eva Friis Møller (AU), Jørgen L.S. Hansen (AU) & David Boertmann (AU)

The assessment area is situated mainly within the high Arctic climate zone, which means that the average July temperature does not exceed 5 °C. It is also far north of the Polar Circle, so continuous daylight is present during summer and there is a period of continuous darkness in the winter. The offshore part is the northwestern part of the Greenland Sea south of the Fram Strait between 74° N and 80° N in latitude and west of Svalbard between 24° W and 0° W in longitude (Figure 1). A significant feature of the physical marine environment of the shelf is the presence of sea ice and icebergs throughout the year.

2.1 Weather

The climate of the assessment area is Arctic, and most of it classified as high Arctic, which means that the average July temperature do not exceed 5 °C. Summer is therefore generally cool and winter very cold. This also implies that on land, there is continuous permafrost, and at sea, there is sea ice in a large part of the year. According to Pedersen et al. (2011), winds in winter are generally northerly and wind speed of gale force or stronger is frequent. During summer, southerly winds are almost as frequent as northerly winds, and strong winds are less frequent than in winter. Fog is widespread and occurs frequently in summer (May-August). Icing caused by freezing rain, sea spray and fog occurs primarily November to May, occasionally also in summer, and is another feature inhibiting human activities at sea.

2.2 Oceanography

The shelves off Northeast Greenland are 'outflow shelves' (*sensu* Carmack and Wassmann 2006), i.e. regions where the dominant flow is of cold, nutrient-poor water from the Arctic Ocean into the North Atlantic. Such regions are generally less productive than 'inflow shelves' such as the Barents Sea. The ice-free period in high Arctic areas around Northeast Greenland is generally 2–3 months, but in polynyas it may be > 6 months. Large areas off Northeast Greenland are dominated by heavy drift ice throughout most summers.

The following sections on oceanography are largely based on the information obtained during the survey in August and September 2017, which was a part of the *Strategic Environmental Study Program for Northeast Greenland*. The surveys covered the northern part of the assessment area, including the licensing round area (Figure 1).

2.2.1 Water masses

The different water masses of the Northeast Greenland shelf and in the deeper northern Greenland Sea during August/September 2017 are highlighted in Figure 2. The classification of water masses follows the water mass analysis by Rudels et al. (2002). Near-surface waters (upper 100 m, Figure 3a) were dominated by Polar Surface Water (PSW) of Arctic origin and mainly associated with the East Greenland Current. The core of the PSW was largely confined to the Northeast Greenland shelf between 50 and 100 m water depth and was characterized by salinities in the range of 31 – 33.5‰ and temperatures <–1 °C. Its upper part at depths < 50 m was less saline (S < 31‰) and significantly warmer (T range -1 to +2 °C) due to sea ice melting in warmer Atlantic Water (Rudels et al. 2002).

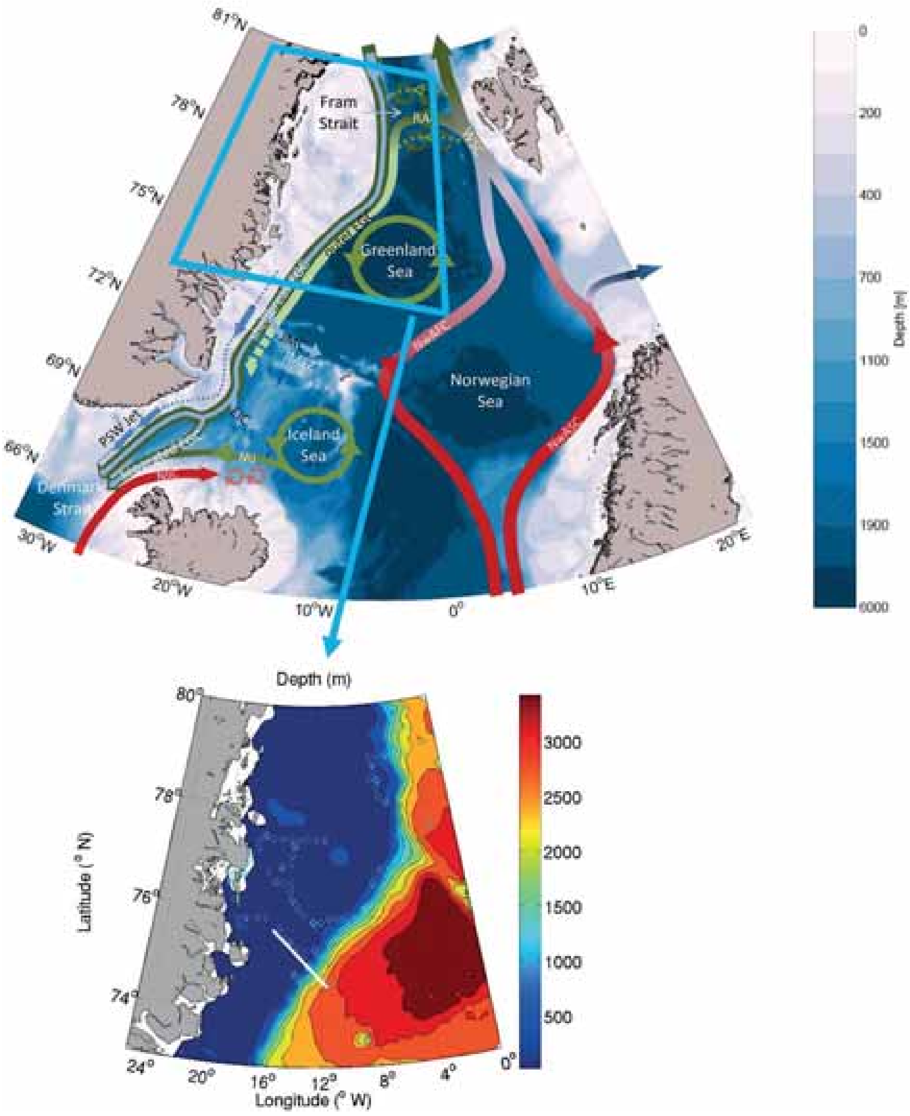


Figure 2. Top: Schematic representation of the warm to cold water conversion in the Greenland Sea (from Håvik et al. 2017). Bottom: Bathymetry of the assessment area based on the General Bathymetric Chart of the Oceans (GEBCO) 1 minute dataset interpolated on a 12 km grid. Symbols in cyan indicate locations of CTD stations during the Aug/Sep 2017 field survey. The white line on lower map shows the location of the transect presented in Figure 5.

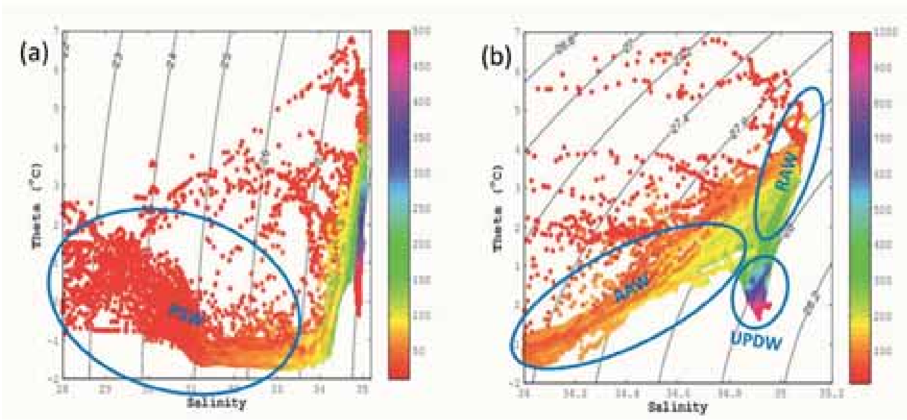


Figure 3. T-S diagram of all water masses of the East Greenland Current and surrounding waters between 74° and 80° N west of the Greenwich meridian based on CTD measurements conducted in Aug/Sep 2017. (a) All stations, (b) only stations at water depths > 100 m. The location of CTD stations are shown in Figure 2.

The Arctic Atlantic Water (AAW) is a water mass of Arctic origin with contributions from Atlantic waters. It was found in the salinity and temperature range $\Delta S = 34 - 34.8$ and $\Delta T = -1 - +2$ °C respectively (Figure 3b). The warmest and most saline water is Return Atlantic Water or recirculating Atlantic Water (RAW, Figure 3b). RAW was centred along the Northeast Greenland shelfbreak with salinities > 35 and temperatures of up to 4 °C. RAW originates in the northward flowing

West Spitsbergen Current and crosses the northern Greenland Sea at around 78 °N. It continues to flow southward as part of the East Greenland Current system. The most prominent observed deep water mass is upper Polar Deep Water (uPDW) with salinities < 35 and temperatures < 1 °C (Figure 3b).

2.2.2 Currents

The Greenland Sea is important in the global thermohaline circulation as a region where the ocean loses heat to the atmosphere. The Greenland Sea is therefore an area with a pronounced transformation of warmer northward flowing currents in the eastern Greenland Sea to colder and fresher waters in the western Greenland Sea (Figure 2). This causes a change in the buoyancy of the surface water, and it sinks. The less dense portion of these water masses can flow south and across the Greenland-Scotland Ridge (overflow water) into the North Atlantic, where it contributes considerably to the North Atlantic Deep Water. The importance of this process for the global thermohaline circulation ('the cold heart of the oceans') has drawn a great deal of attention to the Greenland Sea and to the water masses and the mechanisms that create the overflow water (Olsen et al. 2008b and references therein). Warmer northward flowing currents are of Atlantic origin and include the Norwegian Atlantic Frontal Current, the Norwegian Atlantic Slope Current and the West Spitsbergen Current (Håvik et al. 2017). Water from the West Spitsbergen Current flows westward in the Northern Greenland Sea and forms the outer East Greenland Current (EGC). Another important feature of the circulation in the Greenland Sea is the Greenland Sea eddy centred in the western Greenland Sea at 75 °N. The EGC is the most prominent circulation feature in the Greenland Sea. The EGC flows southward along the eastern coast of Greenland from the Fram Strait (79 °N) to Cape Farewell (60 °N). The EGC is strongest and most energetic along the continental shelfbreak. Observations of surface currents from satellite altimetry (remote sensing measurements of [small variations in] sea level to accurately determine surface currents) showed surface current speeds of up to 30 cm / s during the cruise in 2017 (Figure 4). Another distinctive circulation feature observed during the cruise was a cyclonic, northward flowing current along the coast of East Greenland between 75 °N and 78 °N.

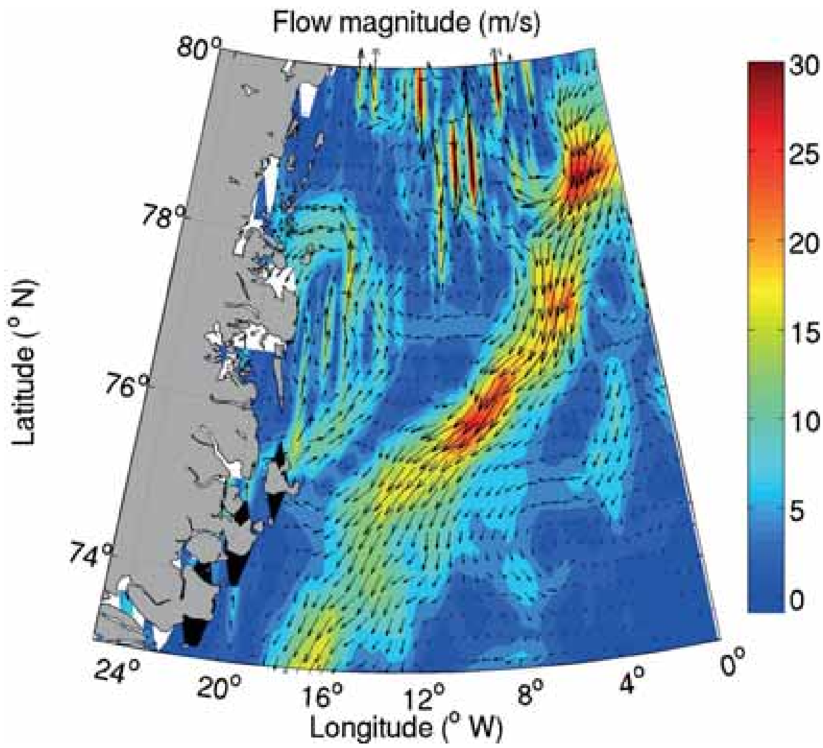


Figure 4. Surface currents derived from daily AVISO satellite altimetry averaged over the period of the cruise in August/ September 2017.

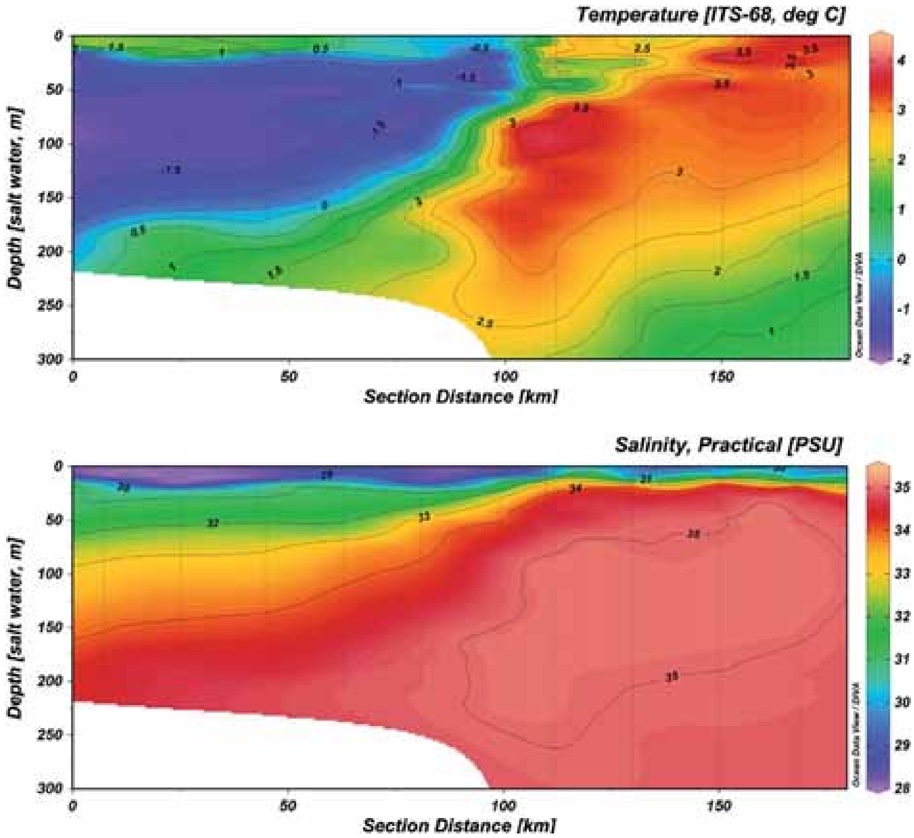


Figure 5. Temperature (top) and salinity (bottom) distribution along a transect crossing the East Greenland shelf break (for location of transect see Figure 2) highlighting the sharp water mass boundary between the colder and less saline waters of the East Greenland Current and warmer and saline waters of Atlantic origin.

2.2.3 Frontal systems

Water mass boundaries between colder and less saline East Greenland Current waters and warmer and more saline waters from the Atlantic create dynamical frontal systems along the East Greenland shelfbreak (Figure 5 and Figure 6). Such fronts were clearly visible during the cruise creating steep gradients in different water mass properties (temperature, salinity). At such water mass boundaries as well as along ice edges (including marginal ice zones) upwelling events are possible, where nutrient-rich water is forced towards shallower water depths. Another important factor driving up- and down-welling are tidal currents and internal waves. It is not known, based on the measurements from the August/September 2017 survey, whether such tidally driven upwelling events occur off Northeast Greenland, but it is very likely.

2.2.4 Long-term variability

Additional data from the TOPAZ reanalysis system at the Copernicus web site (Link) was used to analyse principal patterns of long-term variability for the period 1991 to 2017 (27 years) in the study area and beyond. August/September depth averages of potential temperature and salinity were calculated for the top 200 m of the water column for each year. In addition, mixed layer depth (MLD) defined as a change in density anomaly σ of 0.05 kg·m^{-3} was extracted from the TOPAZ model data set. The spatial resolution of the TOPAZ data is 12.5 × 12.5 km, but was re-gridded to a 0.2 × 0.2 degree grid. Mean August/September values and variability of all parameters were lowest on the East Greenland shelf except for some near-coastal areas (Figure 6). The magnitude of all parameters increased with increasing distance from the coast towards open ocean regions. The temperature and salinity variability was highest along the shelfbreak and most likely associated with inter-annual variations of the EGC. In contrast, MLD variability was highest in the open

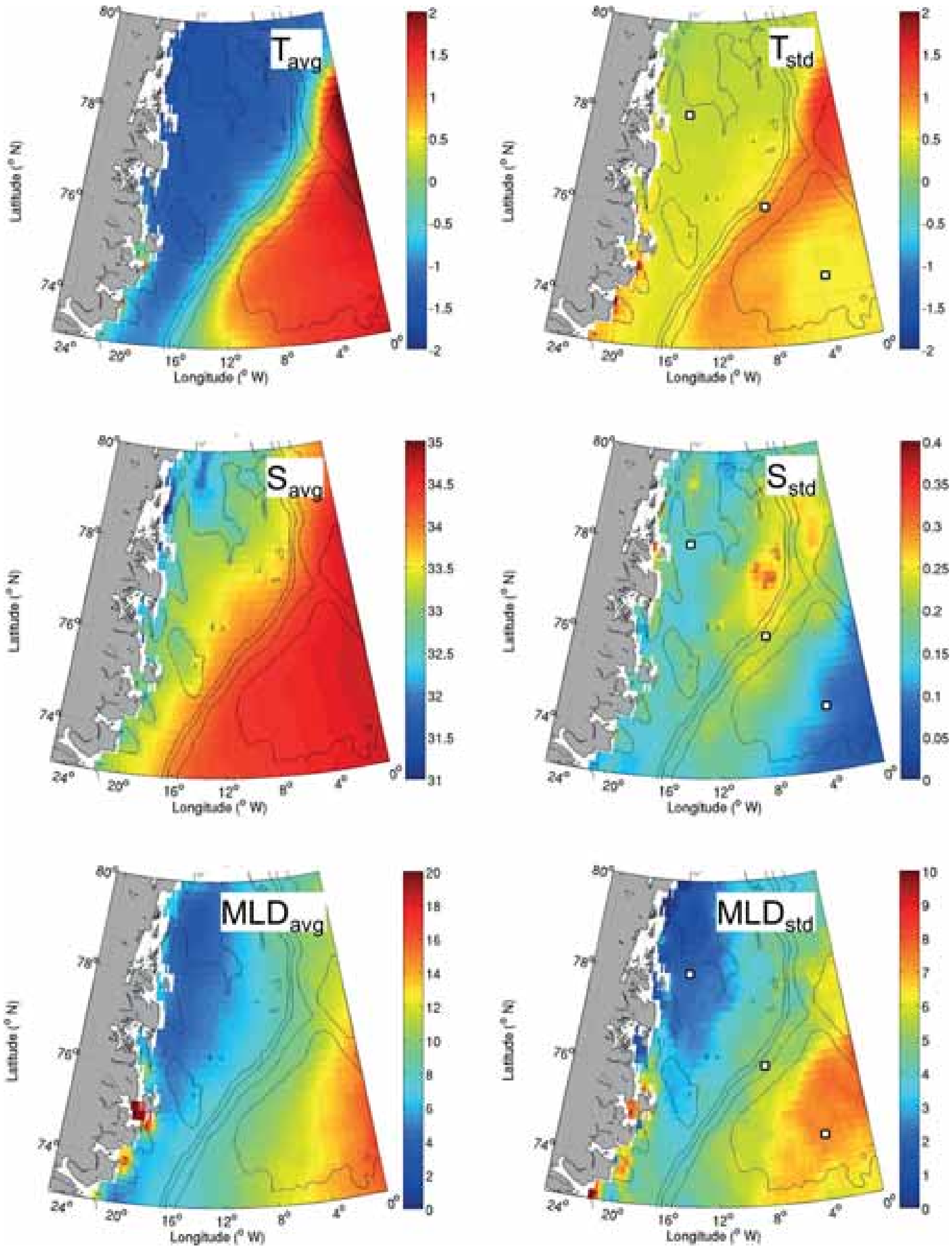


Figure 6. Mean (avg) and standard deviation (std) of potential temperature T (°C), salinity S and mixed layer depth MLD (m). Only August and September data in the upper 200 m of the water column from the period 1991 to 2017 were considered. White squares indicate locations of time series presented in Figure 7. Black contour lines indicate depth contours 200 m, 500 m, 1000 m, 2000 m, 3000 m from the East Greenland coast to the deep sea. Data source: TOPAZ reanalysis from http://marine.copernicus.eu/.

Greenland Sea. Changes of individual parameters in each year with reference to the 27-year mean at three different locations are presented in Figure 7. The dominant pattern in all variables was an extended period of mostly negative anomalies between 1996 and 2010 (Figure 6). Temperatures, salinities and mixed layer depths were significantly lower than the long-term average in the East Greenland Current and Greenland Sea for most of the time during this period. Since 2012, the trend in these two regions is largely opposite showing warmer and saltier waters in the top 200 m. On the East Greenland shelf, changes are generally smaller and less consistent over longer periods than in the open waters farther east. In the study period (August/September 2017), the general trend of the previous years (higher T, S and MLD values than the long-term mean) was resuming.

2.3 Ice conditions

In the assessment area, several types of ice occur (Buch 2007): Two types of sea ice – the *fast ice* anchored at the coast and immobile, and the dynamic *drift ice* (or pack ice) consisting of floes of varying size and density. In addition, icebergs originating from calving glaciers are frequent along the coast in some areas.

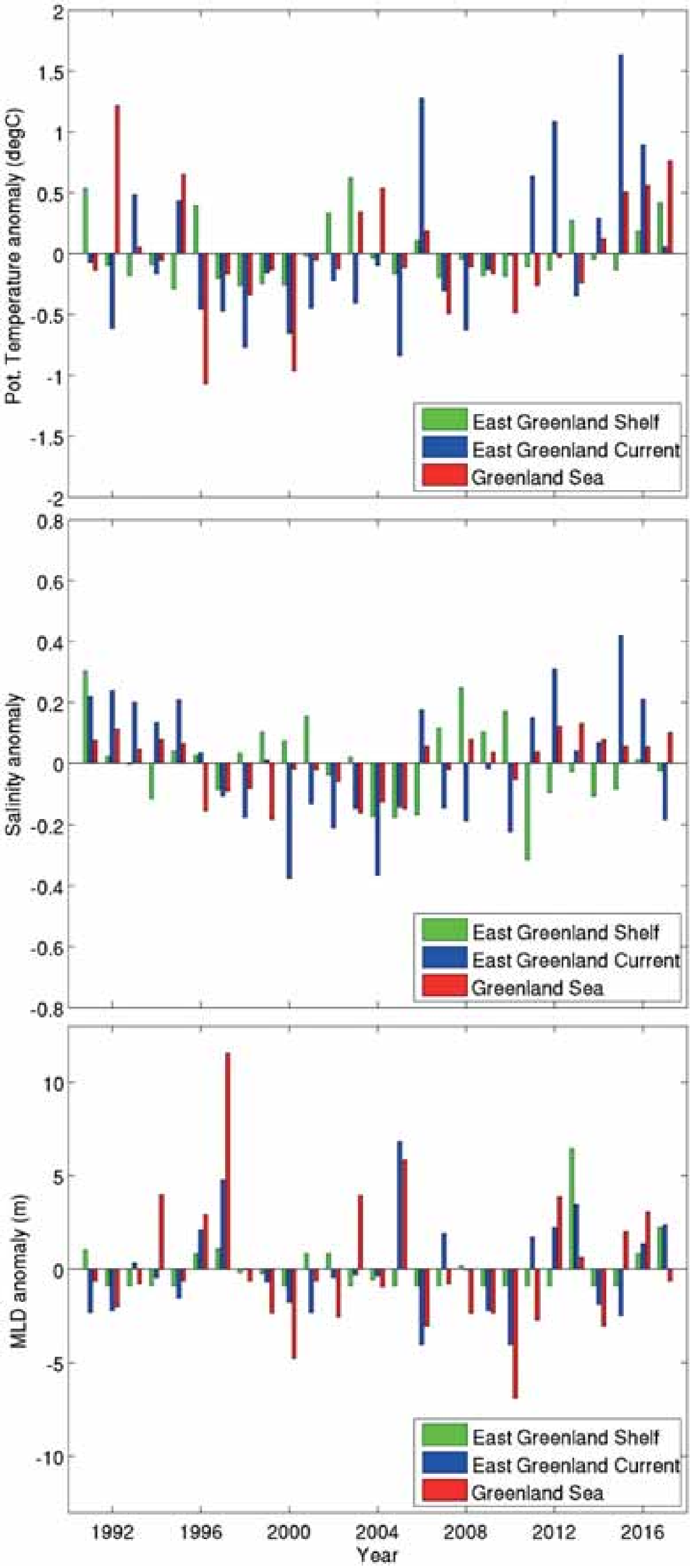


Figure 7. Time series of changes in potential temperature (top), salinity (bottom) and mixed layer depth (bottom) in each year relative to the 27-year mean at three different locations as indicated in Figure 6. Only August and September data in the upper 200 m of the water column from the period 1991 to 2017 were considered. Data source: TOPAZ reanalysis from http://marine.copernicus.eu/.

In addition to the summary below, see further descriptions of the sea ice from the studies carried out in relation to the previous licence round: Hansen et al. (2008), Hvidegaard et al. (2008), Pedersen et al. (2011), Dowdeswell et al. (without year).

2.3.1 The drift ice

Sea ice is an important element of the marine system of the assessment area. It occurs throughout the area, with a maximum extension in March and a minimum in September (Figures 8-10). In March, most of the assessment area is usually covered by sea ice, while in September the ice is restricted to the northern part.

The drift ice consists of several types of ice of varying age (first year (or annual), second year, multiyear). It is transported by the East Greenland Current along the coast and is usually very dense and difficult to navigate, except for the summer months August and September.

In recent decades the sea ice cover of the northern hemisphere has been reduced in extent, in duration, in thickness and in composition – for example the fraction of multiyear ice has decreased (Figure 11; see Chapter 6.4) (Perovich et al. 2019): This is also reflected in the composition of the sea ice in the assessment area; during the past decade, some summers have had very light ice conditions.

2.3.2 The fast ice

The fast ice covers the fjords and a shelf along the outer coast. The fjord ice disappears usually during June and July, and also the ice shelves along the outer coasts melt. However, in some areas a stationary or semi-permanent shelf made up from fast ice and consolidated drift ice is present throughout the summer. The most prominent fast ice area is found between Germania Land and Hovgaard Ø (i.e. south of the Northeast Water) called the Norske Øer Barrier (Schneider & Budéus 1997). This ice area usually persists throughout the summer but have in recent decades proved less stable (Sneed and Hamilton 2016, Dowdeswell et al. without year).

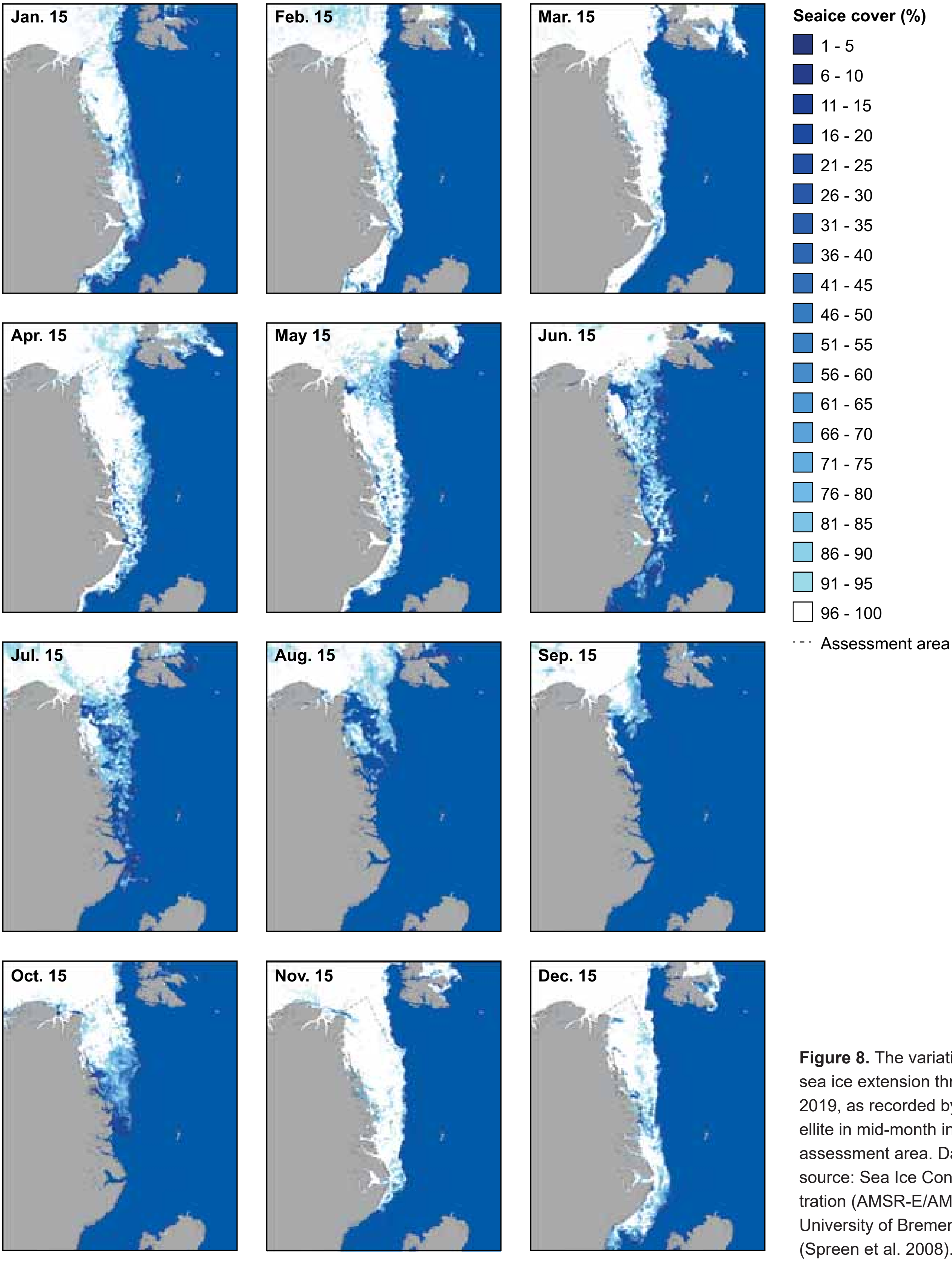


Figure 8. The variation in sea ice extension through 2019, as recorded by satellite in mid-month in the assessment area. Data source: Sea Ice Concentration (AMSR-E/AMSR2), University of Bremen (Spreen et al. 2008).

2.3.3 Icebergs

Icebergs differ from sea ice since they originate from glaciers on land, they are deep-drafted and with appreciable heights above sea level and pose a hazard to navigation and offshore activity. In Northeast Greenland the most prolific iceberg producers are the glaciers named Nioghalvfjerdsbræ, Zachariae Isstrøm and Storstrømmen. The two former glaciers (located between 78° 00′ N

Figure 9. Arctic sea ice extent for September 16 2019 was 4.21 million km2 compared to the median extent for that date 1981-2010 indicated by the orange line. Data source: National Snow and Ice Data Center (link).

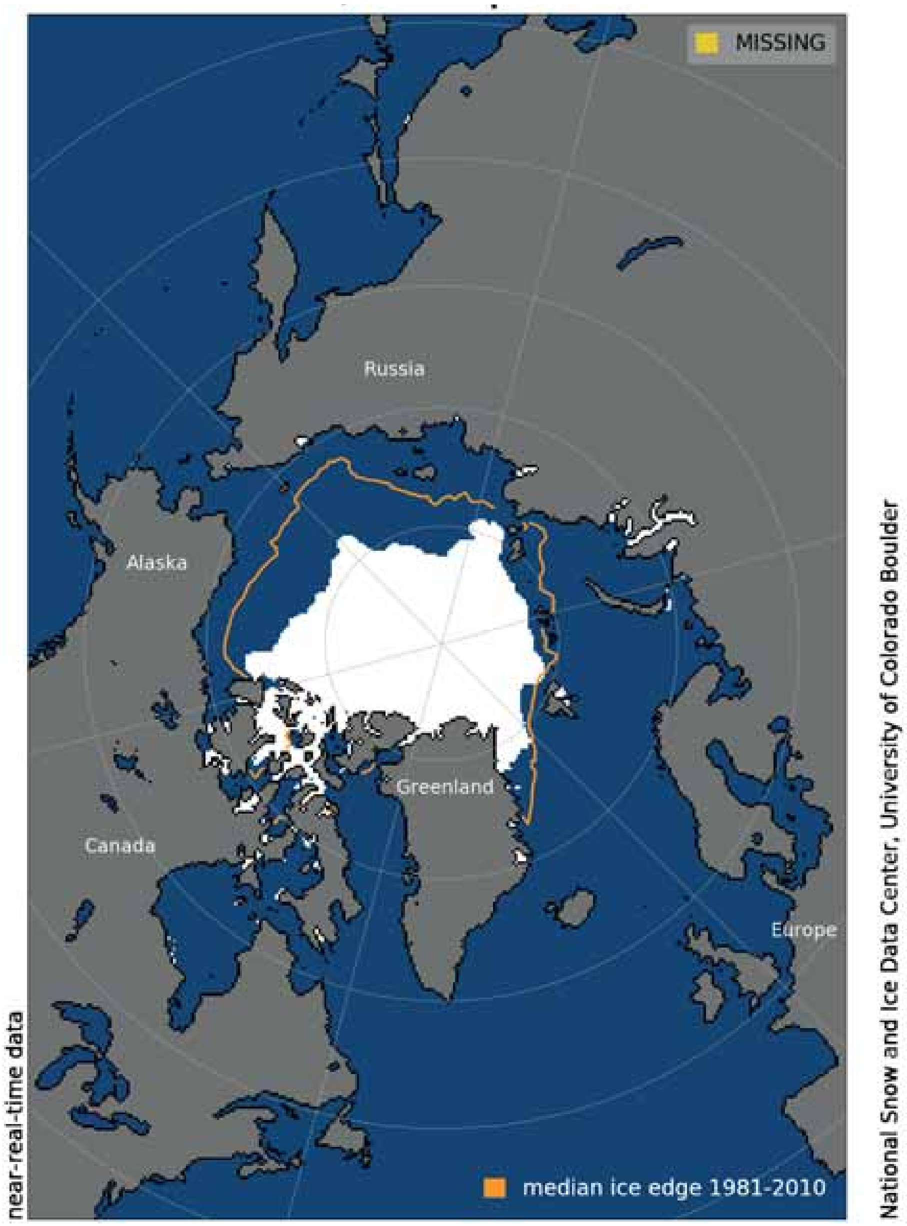
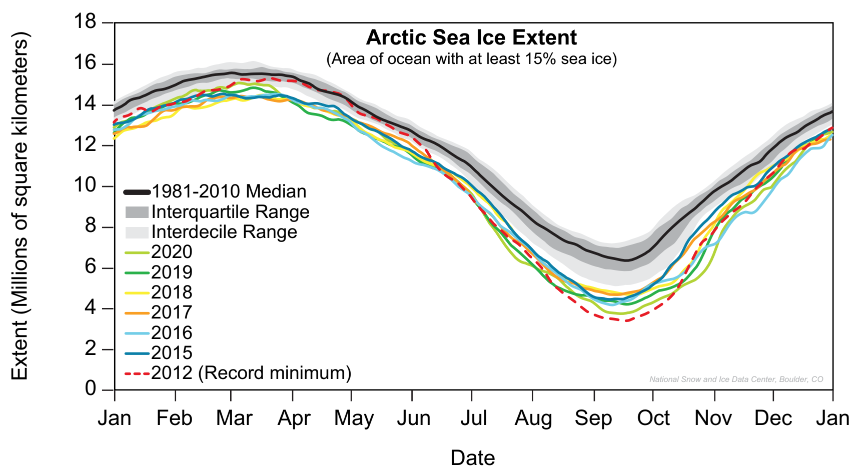
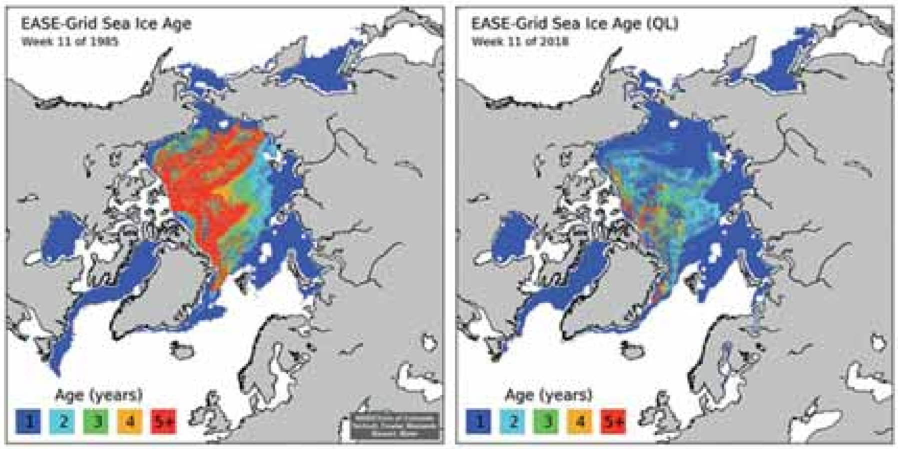


Figure 10. The graph shows Arctic sea ice extent as of September 16 2019 along with daily ice extent data for four previous years and the record low year 2012, compared to the median for 1981-2010. Data source: National Snow and Ice Data Center (link).



and 79° 30′ N) produce mainly large tabular icebergs – similar to those seen in the Antarctic – which are often trapped in the shorefast sea ice and only released during certain break-out years when many icebergs can start drifting (Dowdeswell et al. without year).

Figure 11. Sea ice coverage map for March 1985 and March 2018, with distribution of different age classes. The fraction of the oldest ice have decreased 95% (from Perovich et al. 2019).



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

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

2.3.4 Polynyas, shear zone and MIZ

Polynyas are more or less ice-free areas in otherwise ice-covered waters. They are predictable in time and space and are of a high ecological significance, especially in winter and early spring as primary production commences earlier, and marine mammals and seabirds have access to open waters and foraging opportunities. The most significant polynyas of the assessment area are the Northeast Water (NEW) off Kronprins Christian Land, the waters off Wollaston Forland (now termed the Sirius Water Polynya (Pedersen et al. 2010)) and the mouth of the Scoresby Sund (Figure 12). There are also some much smaller and less frequent open polynyas along the coast. Moreover, a shear zone may occur (with open cracks and leads) between the land-fast ice and the drift ice.

The zone between the dense drift ice and the open ocean is the Marginal Ice Zone (MIZ) which is also very important from an ecological perspective. The extension of the MIZ varies with wind and wave conditions.

2.4 Bathymetry and seabed properties

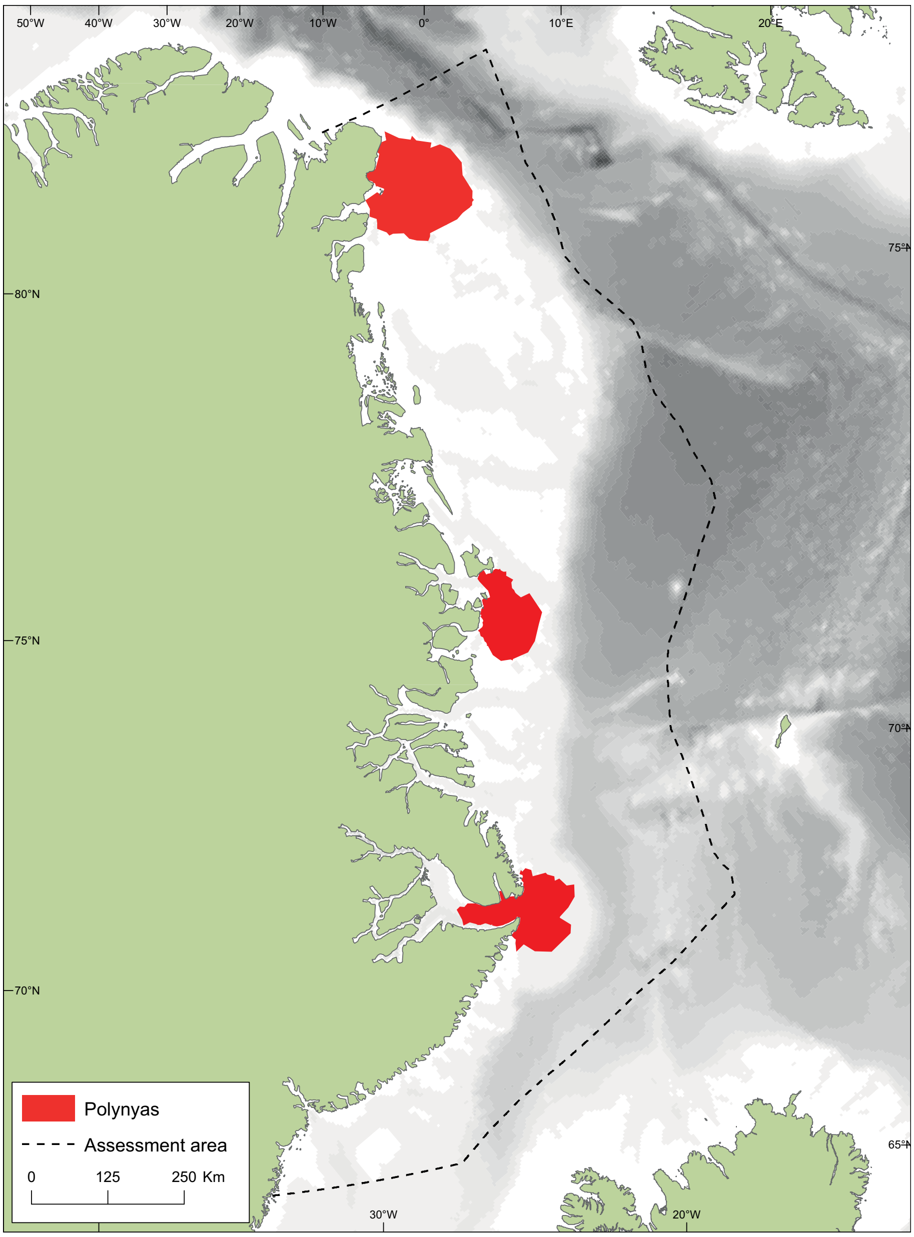
2.4.1 Bathymetry

The bathymetry of the assessment area is characterized by a wide continental shelf, with waters less than 250 m in depth (but approx. 500 m in some troughs); in the northern and central part of the assessment area the shelf reaches more than 300 km offshore. The shelf becomes gradually narrower towards the south and is approx. 90 km wide off Scoresby Sund. The shelf and the open Greenland Sea are separated by a steep continental slope, where water depths increase to >2500 m within only a few tens of kilometres. The waters in the northern and central Greenland Sea are very deep, in some areas greater than 3000 m, except for the two seamounts Eggvingrunden and Vesterisgrunden.

2.4.2 Seabed properties

The *Strategic Environmental Study Program for Northeast Greenland* carried out in the assessment area in 2017 also included studies of seabed properties. Sed-

Figure 12. The most prominent polynyas in the assessment area.



iment was collected from the benthos samples and from specific sediment samples. In addition, a number of samples from 2016 were made available by another study. These were supplemented by video recordings.

All stations sampled for fauna in 2017 consisted of soft sediments composed of fine mud with little differences among stations. The average water content (in 11 samples) was 25% and the organic matter content (ignition loss) was about 2.5%. Almost similar water contents were found in the samples from 2016 with an average of 26.6 ± 7% and a corresponding average ignition loss of 2.8% ± 0.5%.

In most areas, the video recordings show striking featureless clay bottoms which, however, were almost completely covered with smaller stones and gravel. The video recordings were contrasted to the sampled sediment in the van Veen grabs where there were relatively few stones in the sieved material (Figure 13). This clearly indicates sorting of the sediment with stones on top. These observations are interpreted as being a result of erosion of the sediment surface: fine sediment is removed, leaving the stones on the sediment surface.

Figure 13. Mud bottom at station 27 covered by stones (gravel) measuring 2-7 cm on the sediment surface. Very few stones were found deeper in the sediment. To the right some hexactinellid sponges of the genus *Asconema*, probably the species *foliatum*.

At a station where the water depth was 117 m, video recordings showed marks or craters of several meters in depth. These were identified as resulting from scouring from icebergs. Another observation was that station 49 differed from the other shelf stations in that there were no stones on top of the sediment and no clear sign of erosion or bioturbation. This was evident from the edges of the iceberg scour marks, which were standing sharp in the mud (Figure 14). Thus erosion must have been very limited, at least during the time elapsed since the iceberg scouring event.

Sediments from the bottom deeper than 800 m (on the shelfbreak) were more brownish and with large amounts of foraminifera shells. From stations 74 and 76B where the largest gardens of bamboo corals *Keratoisis* sp. were observed (see Chapter 3.4), the sediment contained large quantities of the skeletons of this coral species. The skeletons in the sediment seemed to be connected to living branches of the corals, and they probably function as an anchor of the colonies. At the same stations the sediment was rich in needle-like silica spines which were also attached to sponges above the sediment.

The sediments were also analysed for microbial capacity of oil degrading and for content of PAHs (see Chapter 6.1).

Figure 14. Seabed scoured by iceberg; note the sharp edges, indicating very little erosion, and note also the numerous brittle stars.

2.5 The coasts

The coasts of the assessment area are very diverse. Rocky shores made up from bedrock, basalts or sedimentary rocks are frequent – in some parts are tall and steep – but also many talus slopes occur. In some areas, extensive sedimentary coasts are found, for example at Hochstetter Forland, Shannon and Germania Land; Kilen in the utmost north also has a low sedimentary coast. At Nordostrundingen and in Antarctic Bugt glaciers reach the sea without calving, while calving glaciers (releasing icebergs to the sea) are found here and there, the most significant being Zachariae Isstrøm and Nioghhalvfjerdsbræ (see above).

3 The biological environment

3.1 Primary productivity

Thomas Juul-Pedersen (GINR), Eva Friis Møller (AU) & Signe Lemcke (AU)

Generally, the primary production in the assessment area is low. However, locally there are areas with enhanced production, first of all in the Northeast Water Polynya and probably also in the other polynyas (although this have not been studied). The 2017 studies showed that nitrate depletion occurred on the shelf in late summer, but there was a relatively high production above and outside the shelfbreak. Previous studies have also shown high production in the Marginal Ice Zone (MIZ).

3.1.1 Primary productivity in the Arctic - background information

Marine primary producers create organic compounds from aqueous carbon dioxide through the process of photosynthesis using light as the energy source. Primary producers are therefore the foundation of the marine food web and the source of energy of all higher trophic organisms.

Arctic seas generally have a brief and intense phytoplankton bloom immediately after ice break-up, characterised by high (transient) biomass and a grazing food web dominated by large copepods, but relatively low total primary production integrated over depth and season. However, this general picture is modified by the presence of large polynyas, where early ice break-up and availability of nutrients from upwelling lead to locally very high production.

Biogeochemistry and phytoplankton

Four different types of primary producers contribute to the total primary production: phytoplankton, ice algae embedded in fast or drift ice, benthic microalgae and macrophytes. In high latitude waters experiencing seasonal or year-round ice-free conditions, phytoplankton remain the major primary producers (e.g. Carmack & Wassmann 2006), while ice algae, macrophytes and benthic microalgae may contribute significantly depending on ice conditions and water depths. The relative importance of the four sources is likely to vary geographically with depth and extent of ice cover. In Lancaster Sound in high Arctic Canada, Welch et al. (1992) estimated that phytoplankton contributed 90%, ice algae 10% and benthic algae 1% of the total primary production. Similarly, Søreide et al. (2006) found that the primary carbon source for pelagic grazers in marginal ice zones of the Barents and Greenland seas was phytoplankton, but that the contribution from ice algae was locally important. Ice algae are also expected to be relatively unimportant producers in polynyas (Michel et al. 2002) (see Chapter 3.5 on sea ice flora and fauna).

Phytoplankton production is mainly regulated by environmental factors such as sea ice and light conditions, nutrient replenishment and stratification of the water column (e.g. Tremblay & Gagnon 2009). While light conditions may set the seasonal boundaries for the primary production, inorganic nutrient availability and replenishment generally determines the magnitude of production in high latitude systems experiencing seasonal or year-round ice-free conditions.

In addition to the magnitude of total primary production, it is important to know the strength of the benthic-pelagic coupling, or in other words how much of the produced organic carbon is recycled through the microbial loop, how much remains available to pelagic consumers, and how much is 'lost' through sinking to the bottom, thus becoming food for benthic fauna. Several studies have attempted to quantify the various pathways of organic carbon through planktonic ecosystems in the Arctic, but general conclusions have been difficult to achieve. This is partly because primary production varies considerably among the different Arctic regions, due to differences in hydrography and thus physical forcing.

3.1.2 Primary production in the assessment area

The assessment area is highly heterogeneous in terms of ice cover and thus primary productivity. Large parts of the area are dominated by heavy drift ice throughout most summers, leading to reduced light conditions in the water column and, thus, low productivity; in addition, the ice is causing great logistical challenges for scientific studies. Therefore, previous studies have concentrated on three areas where the open-water season is longer and productivity is higher: the Northeast Water Polynya in the north of the assessment area, the extensive fjord systems along the Greenland coast, and the marginal ice zone in the Greenland Sea, close to the eastern edge of the assessment area.

In the following sections, we review published studies of primary productivity in the assessment area, supplemented by a series of maps of satellite-derived estimates of surface chlorophyll concentration. Lastly, as a part of the *Strategic Environmental Study Program for Northeast Greenland*, an interdisciplinary survey with R/V Dana was conducted in August/September 2017 in the assessment area. In total, 82 stations were sampled between 2° W and 20° W and 74.5° N and 79° N, primarily at stations at 100-400 m depth on the shelf, but also at deeper stations at the shelfbreak and off shelf.

3.1.3 The Northeast Greenland shelf area

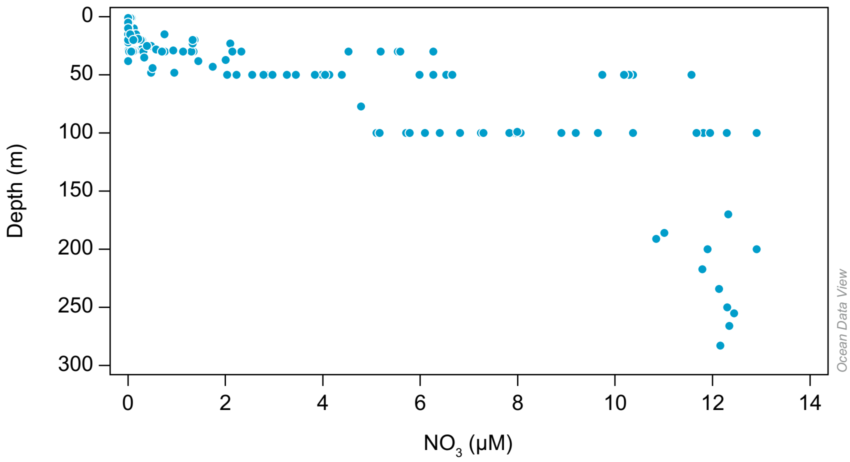
This chapter presents the most recent findings related to phytoplankton from the assessment area collected during the interdisciplinary survey in August/September 2017 which covered the northern parts of the assessment area, including the licensing round area (Figure 1).

Nutrients

Replenishment of inorganic nutrients is essential for sustaining phytoplankton production, i.e. new production. Inorganic nutrient stocks and cycling along with advection of nutrients, stratification and mixing of the water column are principal factors controlling the nutrient replenishment (e.g. Tremblay & Gagnon 2009). While nitrogen, silicate, phosphate and ammonia are considered important, nitrogen and silicate are often singled out as the two main nutrients limiting phytoplankton production in high latitude systems. While silicate is essential to two important microplankton groups, i.e. diatoms and dinoflagellates, nitrogen remain vital to all groups.

A general trend observed throughout the study area was low nutrient concentrations in the surface waters (< 20 m), particularly for nitrate (Figure 15). Depleted nitrate levels in the surface layer, which also denotes the most favourable light conditions for phytoplankton productivity, is likely the major factor controlling phytoplankton production in late summer/autumn. While low nitrate levels (at 0-50 m) were observed at the shelf stations, silicate levels remained relatively high (Figure 16). The highest nitrate concentrations were recorded along the shelfbreak corresponding with deeper mixing of the water column.

Figure 15. Nitrate (NO_3) concentrations (µM) in relation to sampling depth for all stations 0 to 300 m.



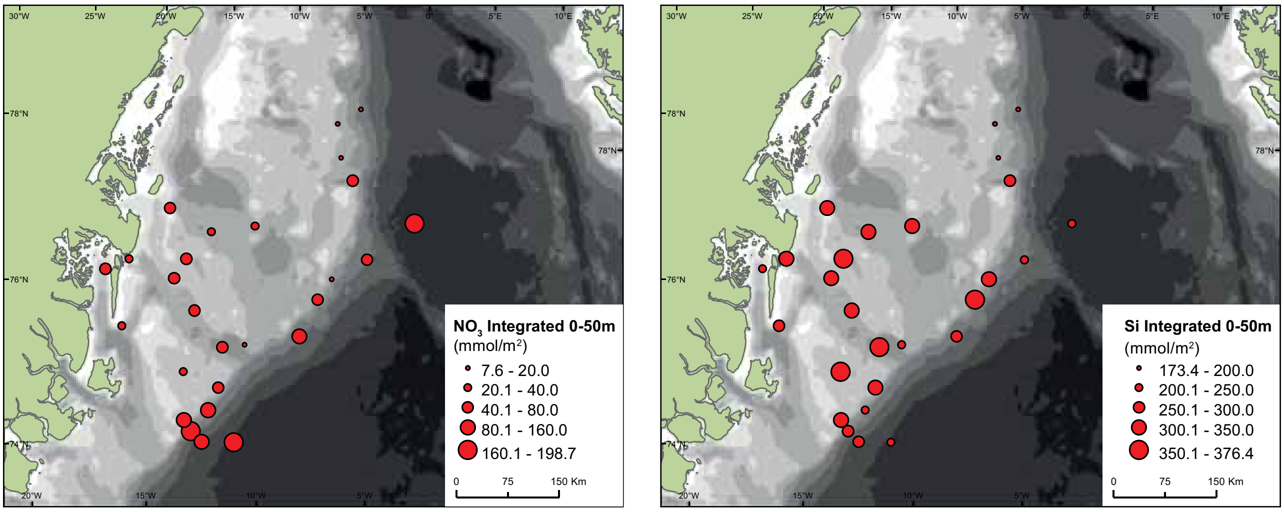


Figure 16. Integrated nitrate (left) and silicate (right) concentrations (mmol m^{-2}) for the 0-50 m depth strata at all sampling stations.

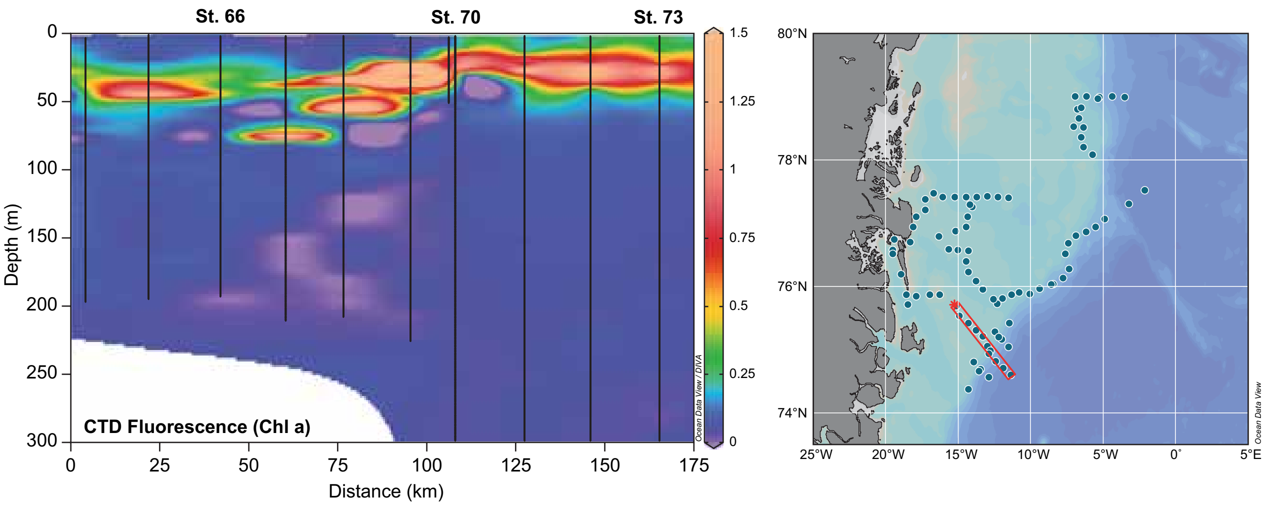


Figure 17. Fluorescence (relative chlorophyll *a* concentration) along a transect crossing the East Greenland shelf break.

Phytoplankton

The biomass of phytoplankton is often depicted as the concentration of chlorophyll *a*, the main photosynthetic pigment in planktonic algae. In contrast, productivity of phytoplankton is often described as the amount of carbon produced through photosynthesis (e.g. measured by the ^{14}C incorporation technique).

Fluorescence (relative chlorophyll *a* concentration) profiles showed maximum phytoplankton biomass between 30 and 50 m depth late in the productive season (Figure 17). Deeper chlorophyll *a* maxima (up to 50 m) were occasionally found along the outer shelf and on individual stations at the inner shelf. Integrated phytoplankton biomass and production (0-50 m) revealed the highest values at or outside the East Greenland shelfbreak. The lower values on the shelf was likely linked to nitrate limitation of the phytoplankton production. High values at the shelfbreak correspond with the previously described boundary between the colder waters of the East Greenland Current and warmer waters of Atlantic origin resulting in elevated mixing of the water column sustaining a higher nutrient replenishment to the surface water (see Chapter 2.2 on oceanography).

Primary production late in the productive season revealed low production on the shelf, while higher production rates were observed at or outside the shelfbreak (Figure 18). The deep layer of chlorophyll *a* maxima, characterized by low productivity across the shelf, may represent a stressed phytoplankton biomass that is settling (i.e. sinking) towards the bottom. Fractionated pigment analysis revealed a higher proportion of larger phytoplankton, i.e. chlorophyll *a* >10 µm, compared to the smaller phytoplankton biomass (i.e. <10 µm) at the shelfbreak, while on the shelf and outside the shelfbreak the larger phytoplankton contributed less (Figure 18). Small phytoplankton species can usually maintain a higher nutrient uptake per body volume as their surface area-to-volume ratio is larger. Thus, low nutrient concentrations on the shelf and outside the shelfbreak favours small phytoplankton species. This is of particular interest for the energy transfer to the higher trophic levels, as the large filter feeding copepods *Calanus* spp. are limited to the larger food particles. The shelfbreak in the assessment area, therefore, seems to comprise an abundant food supply for copepods during this late summer study, which is of importance for energy supply to higher trophic levels such as fish, benthos, marine mammals and seabirds.

Figure 19 shows a model (Copernicus) output of the primary production in the assessment area. The enhanced production on the shelfbreak and in the polynyas is visible in July, but the model have not 'caught' the early production in the polynyas.

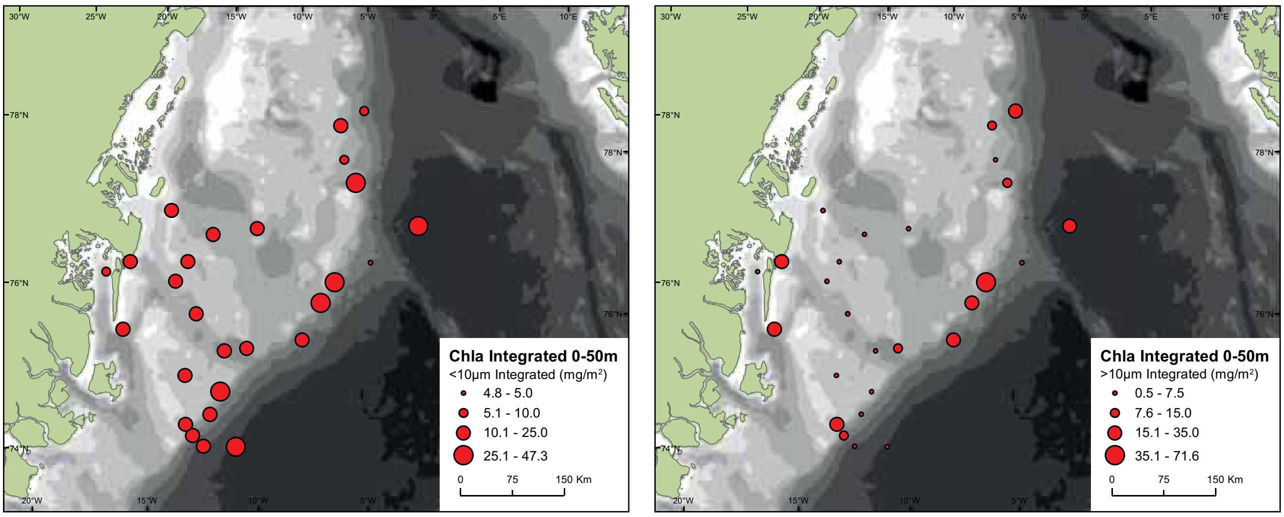
3.1.4 The Greenland Sea and the marginal ice zone (MIZ)

A study of phytoplankton species composition in the southern part of the assessment area and further south in the Denmark Strait region showed little spatial variability among taxa with abundances dominated by diatoms in offshore waters during September (Krawczyk et al. 2015). Species composition of diatoms was different between the shelf area dominated by the cold East Greenland Current and the Mid-Denmark Strait influenced by the warmer Atlantic waters (Krawczyk et al. 2015).

The marginal ice zone (MIZ), which is often located close to the eastern edge of the assessment area, is relatively well studied. Gradinger & Baumann (1991) found that phytoplankton biomass was very low and dominated by flagellates in the drift ice, but much higher and dominated by diatoms and the prymnesiophyte *Phaeocystis pouchetii* in the marginal ice zone (cf. Hirche et al. 1991). Based on several cruises in the open Greenland Sea, Richardson et al. (2005) found that primary production peaked in May and was dominated by diatoms, and that flagellates including *Phaeocystis* were more important later in summer. Production was highest, with evidence for recurring blooms throughout the summer, along the ice edge, where diatom dominance was also most pronounced. A subsurface peak in phytoplankton biomass was found at most stations and an estimated overall mean production was 81 g C m^{-2} yr^{-1}.

3.1.5 Coastal areas

The coastline of the assessment area is highly indented with many large fjord systems. Only one of these, Young Sund at ~74° N, has been subject to extensive scientific studies (Rysgaard et al. 2007). This fjord system is covered by sea ice around 9 month of the year (Middelbo et al. 2018). Although primary production by ice algae is considered negligible (Rysgaard & Nielsen 2006), an intense under-ice phytoplankton bloom in early summer precedes the pelagic production during ice-free conditions (Holding et al. 2019). The pelagic primary production remains consistently low during the ice-free period (50-200 mg C m^{-2} d^{-1}; Holding et al. 2019). Still, pelagic primary production dominates the production across the entire Young Sund system during the ice-free period with benthic production contributing approx. 26% of the pelagic production (Attard et al. 2016). Turbid surface waters caused by the freshwater runoff significantly reduces the light availability in the water col-



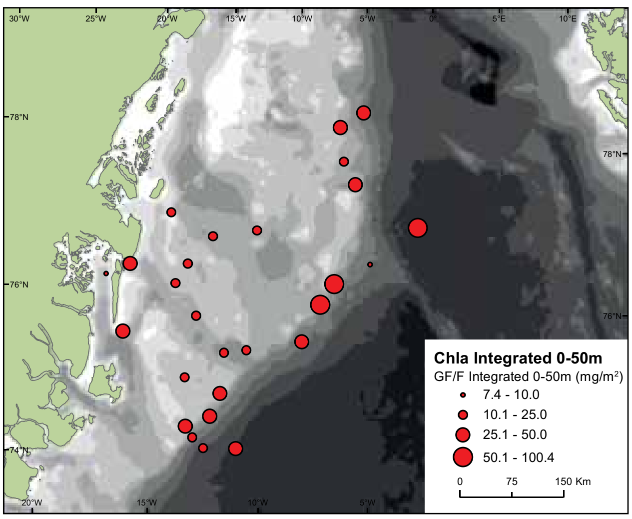
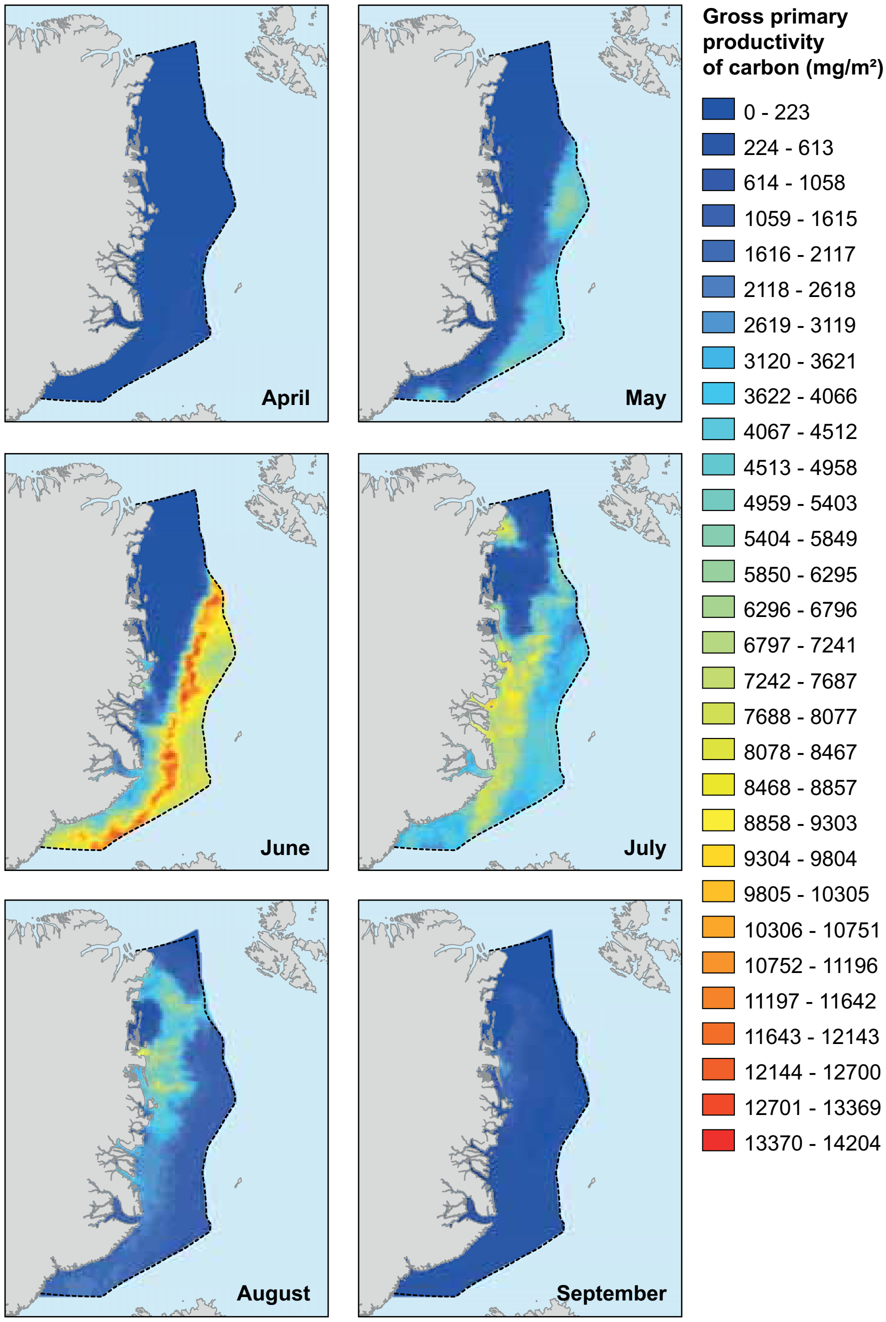


Figure 18. Integrated chlorophyll a concentration: A) plankton smaller than 10 µm (mg chl a m^{-2}), B) larger than 10 µm (mg chl a m^{-2}) and C) primary production (mg C m^{-2} d^{-1}) for the 0-50 m depth strata at all sampling stations.

Figure 19. Modelled primary production in the assessment area in the period April to September. Data source: the Arctic Ocean Biochemestry Analysis and Forecast page of Copernicus Marine Environment Monitoring Service (Link).



umn and restricts phytoplankton to the surface waters away from the nutrients below, in the inner part of the fjord system (Figure 20). The less turbid waters in the outer part of the fjord means that phytoplankton here are able to utilise the nutrients deeper in the water column. In autumn, prior to ice formation, the decreasing incoming solar radiation and low solar angle force the phytoplankton higher in the water column (Figure 20). The local primary production in Young Sund remain insufficient to sustain the bacterial carbon demand of the fjord system, thus organic carbon from terrestrial runoff and to a lesser degree from coastal inflow water constitutes significant carbon sources to the fjord (Rysgaard & Nielsen 2006, Paulsen et al. 2017).

The species composition of the phytoplankton community along the Young Sund system varies significantly corresponding to temperature and salinity gradients caused by freshwater runoff from land-terminating glaciers and remains significantly different from the communities observed in the offshore areas of the assessment area (Krawczyk et al. 2015).

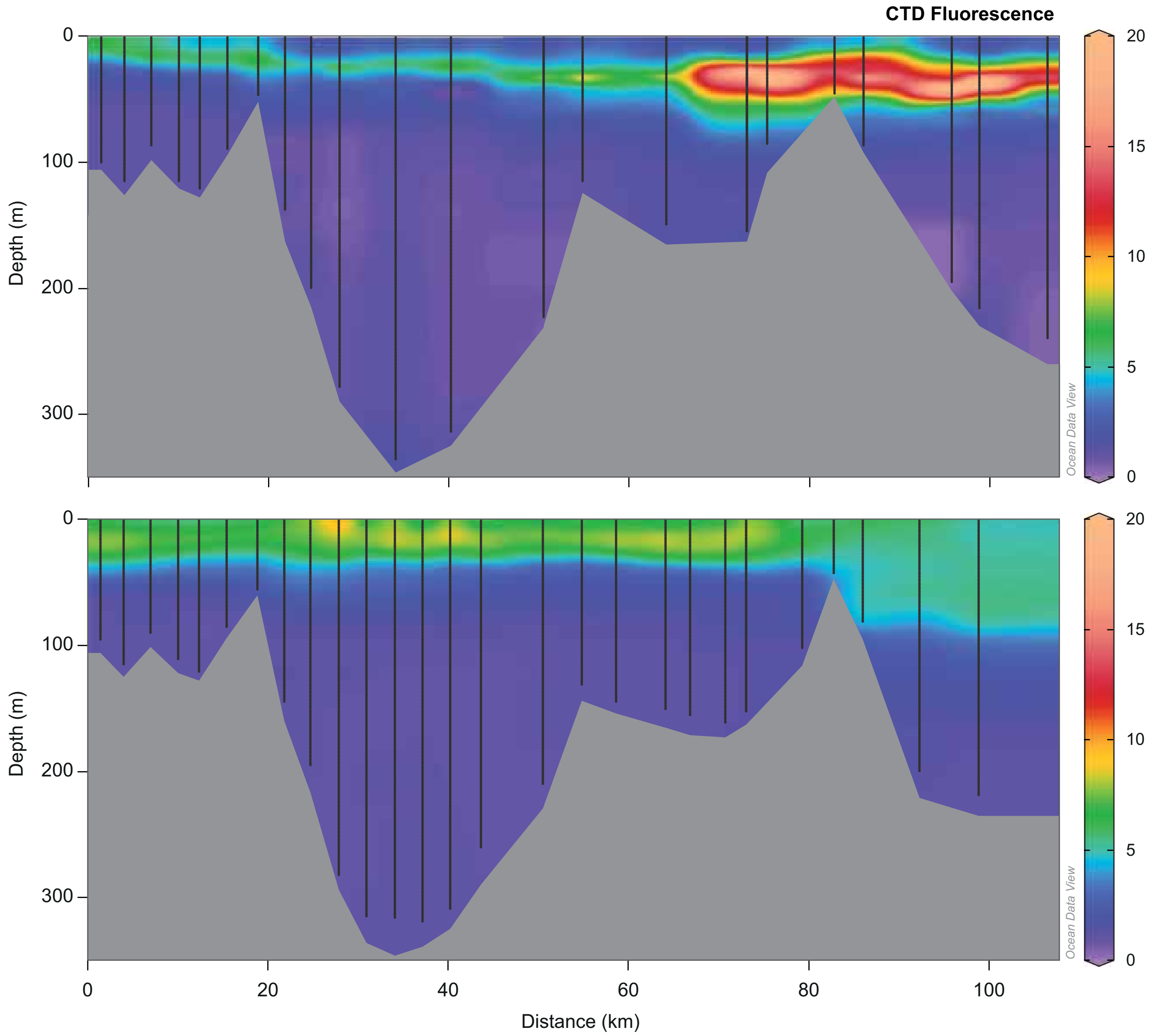


Figure 20. Fluorescence (relative chlorophyll a concentration) along a length transect of the Young Sund fjord system in August and October, 2014 (modified from Holding et al. 2019).

3.1.6 The Northeast Water Polynya (NEW)

This large (~45,000 km²) and important polynya is very remote, and access is difficult. Consequently, the only major study of physical and biological processes remains the extensive summer cruises in 1992 and 1993 (Hirche & Deming 1997). It is likely that conditions have changed substantially in the last decades due to, e.g., decreasing summer ice cover in the Greenland Sea and Fram Strait but the description here is necessarily based mainly on the 1992/93 studies. The most open part of the polynya, with high primary production dominated by diatoms, was generally located around the northern limit of the assessment area, whereas the southern part was characterised by higher ice cover, no surface stratification, lower primary production and dominance by flagellates, all typical of a non-bloom situation (Pesant et al. 1996). Stable isotope analyses indicated that benthic-pelagic coupling in NEW was strong, i.e. that a large fraction of primary production was exported to the benthic community rather than being consumed by pelagic organisms (Hobson et al. 1995). However, detailed studies of production and grazing of both large and small phytoplankton indicated that a large part of late-season production was advected out of the polynya to neighbouring ice-covered areas, where it subsidised local heterotrophic planktonic and benthic communities (Pesant et al. 1998, 2000). Food web dynamics in NEW seem largely to be regulated by advective processes, and horizontal exchanges are important relative to vertical and internal flows. The microbial components form an almost closed loop, recycling dissolved organic matter with little connection to the rest of the food web and weak seasonal variations (Berreville et al. 2008). In this regard, NEW differs from the North Water Polynya (NOW) off Northwest Greenland, probably due to differences in their seasonal longevity, i.e. the longer-lived NOW Polynya having more time to develop complex trophic interactions.

3.1.7 Important areas for primary production

The information on primary production is generally too sparse to identify localised important and / or critical areas except for the special productive zones like polynyas, the marginal ice zone, and the fronts in association with the transition zone between different water masses as above the shelfbreak.

3.2 Zooplankton

Eva Friis Møller (AU)

3.2.1 Zooplankton in the Arctic

Zooplankton has an important role in marine food webs (Figure 21) since it provides the principal pathway to transfer energy from primary producers (phytoplankton) to consumers at higher trophic levels, e.g. fish and their larvae, marine mammals and seabirds.

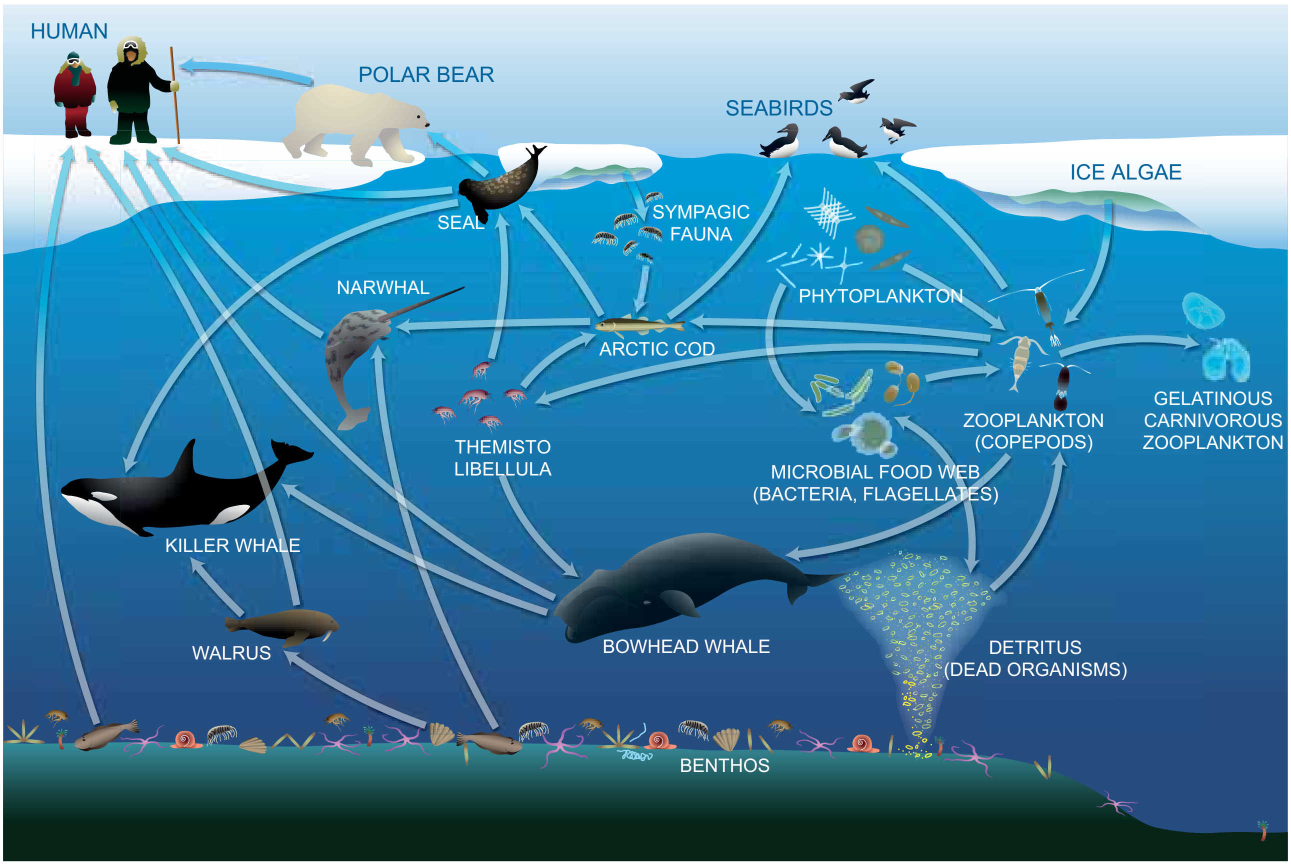


Figure 21. An overview of the interactions in the marine Arctic environment (from Darnis et al. (2012), printed with permission).

Most of the higher trophic levels in the Arctic marine ecosystem rely on the lipids that are accumulated in the large lipid rich copepods of the genus *Calanus* (Falk-Petersen et al. 2007). The little auk and the bowhead whale, for instance, are specialized feeders on the large copepods (Laidre et al. 2010, Møller et al. 2018). In larvae of the Greenland halibut and sandeel from the West Greenland shelf, copepods were the main prey during the main productive season (Simonsen et al. 2006). Lipids from *Calanus* can be transferred through the food web and be incorporated into the lipids of consumers through several trophic levels. For instance, lipids originating from *Calanus* can be found in the blubber of white and sperm whales, which feed on fish and squid (Simonsen et al. 2006).

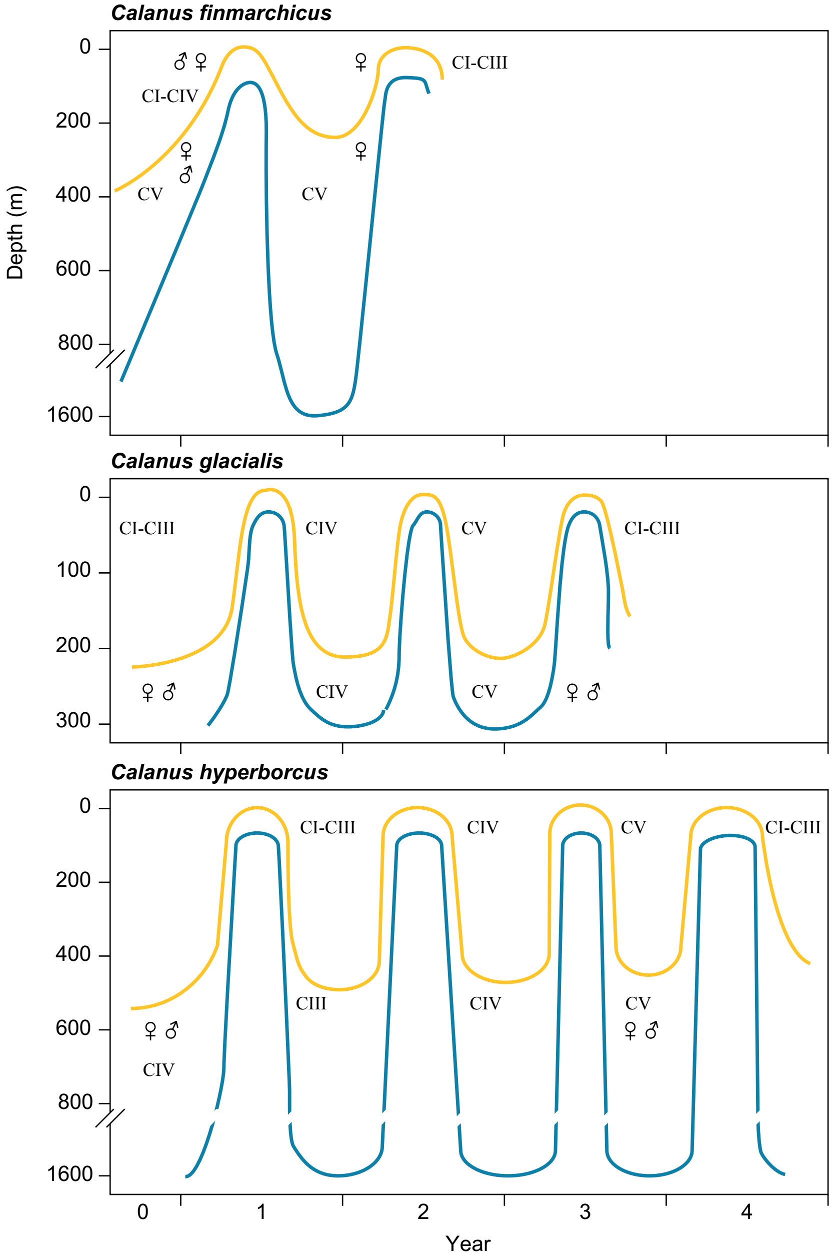
Three *Calanus* species exist in the Arctic: *C. finmarchicus*, *C. glacialis*, and *C. hyperboreus*. The first is primarily associated with North Atlantic waters, while the two latter are considered Arctic species (Falk-Petersen et al. 2007). While the three species share the same general life cycle and morphology, there are important differences, particularly in size and phenology (Swalethorp et al. 2011). *Metridia longa* is another large important copepods species; it is often found to perform large daily vertical migrations, and to be active also in the winter period supported by its omnivorous diet (Ashjian et al. 2003). Other smaller species, such as *Oithona similis*, *Pseudocalanus* spp., and *Microcalanus pygmaeus*, are often found in large numbers. They exhibit a shorter generation time and often reproduce for a longer period of the year, suggesting that their importance in ecosystem productivity could be greater than implied by their biomass alone (Møller et al. 2006, Svensen et al. 2011). The boreal *C. finmarchicus* is expanding and to some extent replacing its Arctic relatives *C. glacialis* and *C. hyperboreus* (Møller & Nielsen 2019).

Although copepods are typically predominant in Arctic marine systems, there is a broad assemblage of other holoplanktonic groups. Larvaceans (Appendicularians), for example, have been shown to be abundant in Arctic seas. These soft-bodied filter feeders are capable of much higher ingestion rates, faster growth and reproduction than crustaceans, allowing them to respond more rapidly to shifts in primary production. During times when larvaceans are abundant, the efficiency with which primary production is exported to the benthos may be greatly increased (Hopcroft et al. 2005). Other important and common predatory groups are chaetognaths, amphipods, ctenophores and cnidarians. Arctic chaetognaths may represent considerable biomass, have long life cycles (e.g. 2 years) and are thought to be important in controlling *Calanus* populations (Bandara et al. 2016). Hyperiid amphipods (e.g. the genus *Parathemisto* – also known as *Themisto*) can also be abundant in Arctic waters (Hirche et al. 1994b, Auel & Hagen 2002), with 2- to 3-year life cycles, and a similar potential to graze a notable proportion of the *Calanus* population (Auel & Werner 2003). In turn, polar cod, seabirds and marine mammals are often feeding on pelagic amphipods. Thus, hyperiid amphipods also play a key role in the Arctic pelagic food web (Figure 21) as a major link from mesozooplankton secondary production to higher trophic levels. Additionally, euphausiids (krill) can be numerous and constitute important food for seals, whales and seabirds.

Phenology of zooplankton

One important aspect of the life cycle of the dominant zooplankton genus *Calanus* is their seasonal vertical migration (Figure 22). All three *Calanus* species can store large amounts of lipid based on their grazing in the surface waters during spring and summer (Lee et al. 2006, Falk-Petersen et al. 2007). These reserves are used to fuel hibernation at depth (Falk-Petersen et al. 2007), but their different phenology means that they reach their maximum abundance in

Figure 22. Generalized seasonal migration and stage development of *Calanus finmarchicus*, *C. glacialis* and *C. hyperboreus*; upper and lower lines delineate the general depth of the population (from Falk-Petersen et al. (2009).



the surface waters and lipid content at different time of the year (Swalethorp et al. 2011). When the large *Calanus* leave the surface waters, the small copepods and protozooplankton dominate the grazing on primary producers (Levinsen & Nielsen 2002, Møller et al. 2006). Generally, a great deal of the biological activity, e.g. reproduction and growth of fish and breeding seasons of some seabirds, are synchronized with the life cycle of *Calanus* (Varpe & Fiksen 2010, Møller et al. 2018).

Predictability of zooplankton

Generally, high biological activity in the surface waters can be expected in connection with hydrodynamic discontinuities, i.e. spring blooms, fronts, upwelling areas or at the marginal ice zone (Kiørboe 1998). However, the large variations in physical forcing such as extent of sea ice cover, light and stratification in the Arctic makes general predictions of the timing and productivity of zooplankton difficult (Daase et al. 2013). Still, a long period of ice cover, i.e. a short open water period, seems to result in a dominance of *Calanus* (Rysgaard et al. 1999) as this genus is able to survive long period with low food availability and can control plankton biomass throughout the short productive season. In contrast, in areas where there is a longer open water period, e.g. in Disko Bugt in western Greenland (Levinsen & Nielsen 2002) and the central Greenland Sea (Møller et al. 2006), the smaller species and juvenile stages of copepods dominate the copepod biomass in the surface waters during the late summer. This is possible because *Calanus* leave the surface waters as early as midsummer to start their winter hibernation. It is critical to understand the control interactions of seasonal vertical migration of zooplankton to be able to extrapolate from one Arctic region to another as well as to predict implications of a changing climate (Baumgartner & Tarrant 2017).

The reduction of the sea ice cover (Stroeve et al. 2011) potentially has an impact on stratification and light conditions and consequently on the timing and succession of the lower trophic levels of the food web. Moreover, the influx of Atlantic water masses to the Arctic Ocean has increased during the last decades, but it remains unclear how flux variability affects the pelagic ecosystem. Indications from the North Atlantic show changes in the distribution of species, in the seasonal timing of peak abundances, and poleward movement of temperate species (Beaugrand et al. 2002). Unfortunately, plankton data from the Arctic are scattered in space and time. Hence, the level of information regarding ecological variability in the Arctic seas may limit the ability to detect ecological changes related to climate variability.

3.2.2 Zooplankton in the assessment area

As a part of the *Strategic Environmental Study Program for Northeast Greenland*, an interdisciplinary survey with R/V Dana was conducted in August/September 2017 in the northern part of the assessment area. In total, 82 stations were sampled between 2° W and 20° W and 74.5° N and 79° N, primarily at stations at 100-400 m on the shelf but also at deeper station at the shelfbreak and off shelf. The overall picture on the zooplankton obtained during the dedicated survey agreed with earlier observations in the adjacent sea areas as described below.

The Northeast Greenland Shelf area

The biology in the area was clearly associated with the physical-chemical environment (Chapter 2). Depleted nitrate levels in the surface layer, which also has the most favourable light conditions, likely was a major factor controlling phytoplankton production. Integrated phytoplankton biomass and production within the 0-50 m depth strata across the study area revealed the highest values at or outside the East Greenland shelfbreak (Chapter 3.1).

Likewise, the mesozooplankton biomass and community composition was clearly associated with the oceanography and bathymetry of the area. The biomass was highest along the shelfbreak area, and species composition reflected the origin of the water (Figure 23). Copepods dominated the biomass (on average 97±10% of the integrated biomass) and most of those were *Calanus* spp. (average 69±15% of the integrated biomass). Other abundant copepods species were *Pseudocalanus* spp., *Microcalanus* spp., *Oithona similis*, *Oncaea borealis* and *Metridia longa*. The North Atlantic *Calanus finmarchicus* were present at all stations but most abundant at the stations off the shelf in the Greenland Sea in the southernmost part of the 2017 survey area. The Arctic *Calanus* species *C. glacialis* and *C. hyberboreus*, on the other hand, showed the opposite pattern, and were not found at all in the upper 50 m in the Greenland Sea samples off the shelf (Figure 24). On the shelf area, a large part of the dominant *Calanus* were still present in the surface water in August, where they are important for visual predators and predators feeding from the surface e.g. seabirds like the little auk (Figure 23).

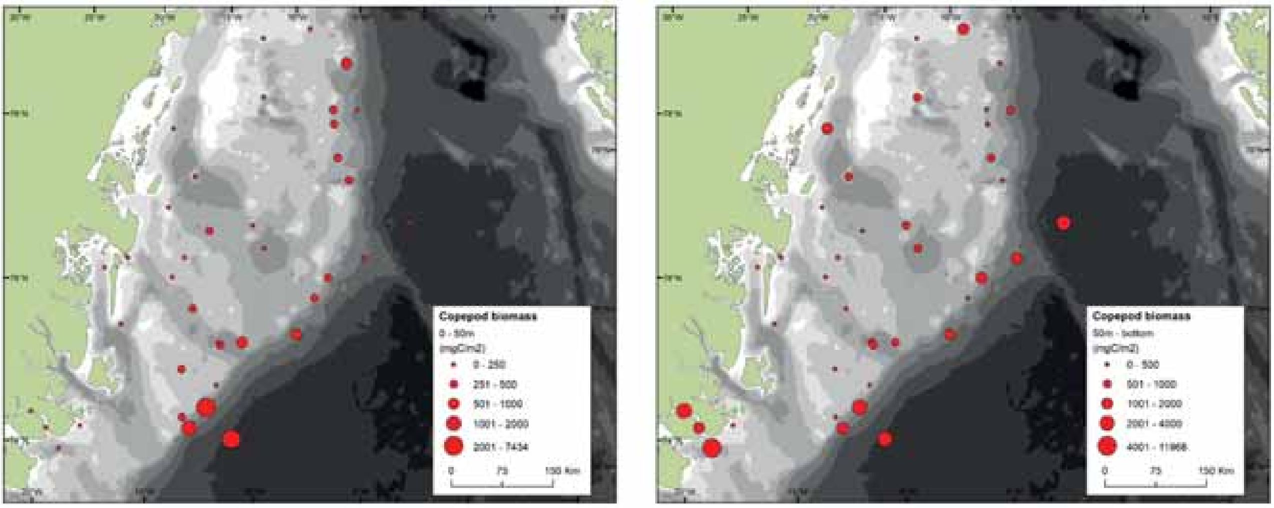


Figure 23. The biomass of copepods in August/September 2017 in the upper 50 m of the water column (map to the left) and from 50 m to the bottom (right) although never deeper than 1000 m, sampled by a Multinet.

Macrozooplankton, like the mesozooplankton, had elevated biomass in the shelfbreak area, but also at some stations nearshore and in fjords (Figure 25). They were dominated by krill (*Meganyctiphanes norvegica*, *Thysanoëssa inermis*, *Thysanoëssa longicaudata*), amphipods (*Themisto libellula*, *T. abyssorum*) and Chaetognatha. Acoustic measurements gave a high-resolution distribution of the density of organisms along the cruise track, and confirmed the pattern identified by net sampling.

The eastern part of the Greenland Sea

The distribution of zooplankton was investigated during summer 1983 in the marginal ice zone of the west Greenland Sea. Nutrient levels, especially inorganic nitrogen, were extremely low, and probably limited the growth of phytoplankton during this period. Generally, zooplankton biomass was similar to other polar regions and species distributions indicate the origin of the two major water masses in this area (Smith et al. 1985). Other studies have indicat-

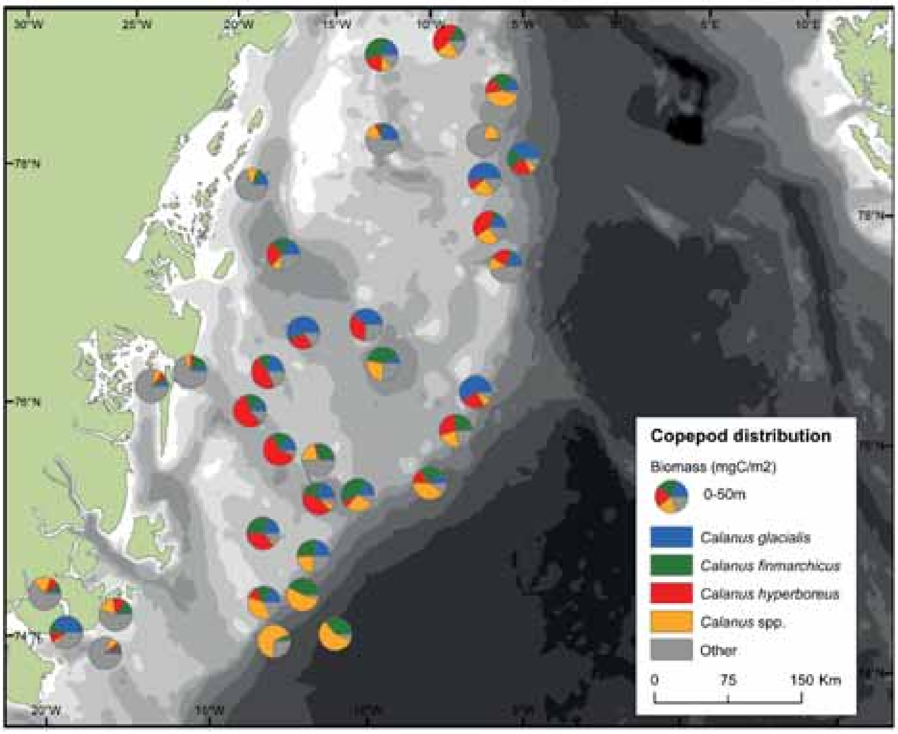
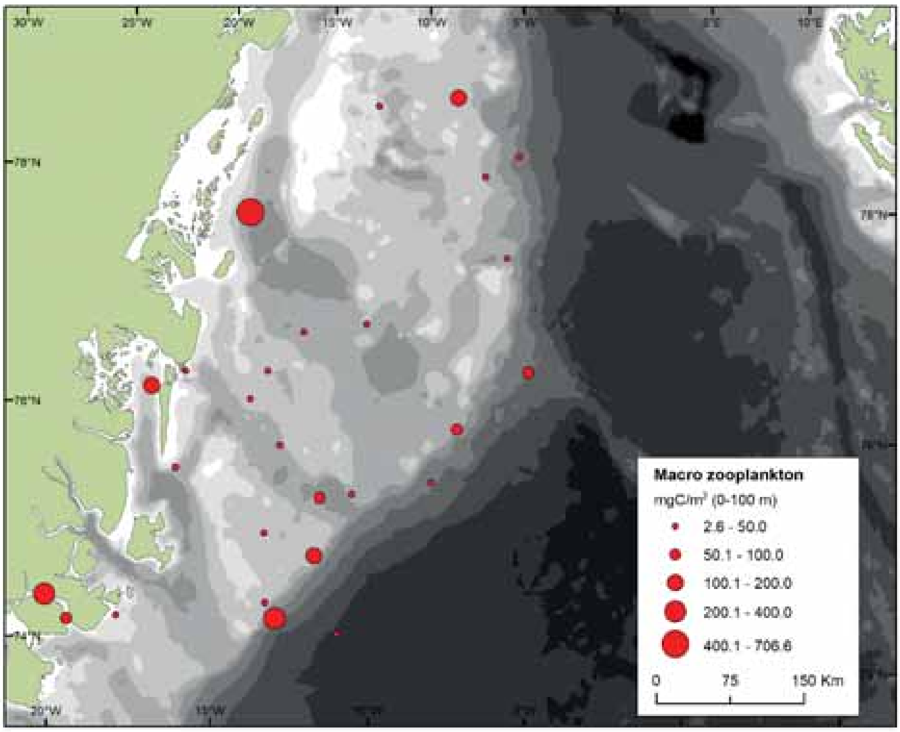


Figure 24. The species composition of the copepod community in the upper 50 m of the water column in August/September 2017.

Figure 25. The biomass of macrozooplankton in in the upper 100 m of the water column sampled by the MIK-net (mid-water ring net) in August/September 2017.



ed that the zooplankton community on the East Greenland shelf and slope is composed of Arctic species transported south by the East Greenland Current (EGC) and a variety of Atlantic species injected into the area via the Return Atlantic Current (Hirche et al. 1994b). Furthermore, it was shown that zooplankton distribution was influenced by the Greenland Sea Gyre (the large gyre in central Greenland Sea).

Coastal areas

In Young Sund the zooplankton community is dominated by the three *Calanus* species, *C. glacialis*, *C. hyperboreus* and *C. finmarchicus*. When they disappear from the surface water smaller species dominate but the total biomass is low (Rysgaard & Glud 2007, Middelbo et al. 2017). Freshwater enters the fjord as surface runoff, including from land-terminating glaciers, and this affects the pelagic community. In 2014, four stations were investigated from June to October along the freshwater gradient from the inner fjord to the Greenland Sea (Middelbo et al. 2017, 2018, Paulsen et al. 2017). The inner station consistently had lower biomass of chlorophyll *a*, compared to the outer station, and smaller phytoplankton were much more abundant at the inner station compared to the outer station. Copepod grazing rates were low on these small cells, which resulted in low copepod grazing at the freshwater-affected site in the inner fjord: While daily grazing impact by copepods was about half of the daily primary production during July and August in the outer region of the fjord, grazing impact was always less than 10% of the daily primary production in the inner fjord, and in the late part of the open water season at all stations. These findings suggest that meltwater-driven stratification results in dominance of small phytoplankton cells, which directly impacts secondary producers and reduces transfer to higher trophic levels. The fjord has experienced changes in both sea ice coverage and freshwater content between 2003 and 2015. The copepod species composition shows inter-annual variation but no major trends, indicating a relative resilient pelagic community, although the data does not allow for evaluation of any changes in the zooplankton phenology (Middelbo et al. 2018).

Northeast Water Polynya (NEW)

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

Zooplankton biomass in the ice-covered parts was dominated by copepods making up 84% of biomass of all taxa, followed by chaetognaths (Hirche & Kwasniewski 1997). The large *Calanus* species, i.e. *Calanus glacialis*, *C. hyperboreus* and *C. finmarchicus*, made up to 91% of the copepod biomass, which was in accordance with earlier investigations in the area (Hirche et al. 1994b, Hirche & Kwasniewski 1997). These species are commonly associated with polar water on Arctic shelves (*C. glacialis*), Arctic water in the Greenland Sea (*C. hyperboreus*) and Atlantic water in the North Atlantic Current (*C. finmarchicus*).

In the NEW, *C. glacialis* inhabited areas of low current speeds on Belgica and Ob Bank, *C. hyperboreus* dominated shelf slopes and trough stations, while *C. finmarchicus* was most abundant in the Return Atlantic Current along the shelf slope and at the eastern Belgica Trough (Hirche & Kwasniewski 1997).

However, biomass was low in the NEW and only 10% of the phytoplankton carbon was grazed, which was in agreement with earlier studies (Hirche et al. 1994b). The meso- and macroplankton appeared to be only minor contributors to the overall carbon flow within the polynya system. It was suggested that a large portion of the organic matter is not utilised in the water column, but is exported to the benthos where it supports a rich community. High sedimentation rates were reported from Belgica Bank and benthic distribution patterns in the NEW usually reflected pelagic regimes (Piepenburg et al. 1997). Further evidence of a high benthic biomass is given by the presence of benthos-feeding marine mammals and seabirds, such as walruses and eider ducks (Hirche et al. 1994a). Other studies confirmed the low standing stock of mesozooplankton in the NEW and it was suggested that this might be a typical feature for this region (Ashjian et al. 1995).

3.2.3 Important areas for zooplankton

In Arctic marine habitats, the most severe ecological consequences of massive anthropogenic impacts (such as oils spills) can be expected in seasons when the pelagic food web has high activity (i.e. spring and summer). On a horizontal scale, the most important areas are the fronts in association with the transition zone between different water masses, as for example over the shelfbreak in the assessment area. Later in the season, when the biological activity can be concentrated at the pycnocline or at the seabed, for example where *Calanus* accumulate in winter, a subsea spill may cause more damage (cf. the *Deepwater Horizon* spill).

3.3 Benthic flora

Susse Wegeberg (AU) & Ole Geertz-Hansen (GINR)

The occurrence of macroalgae in the assessment area is determined by light, substrate and ice, and if conditions are favourable kelp can be found to 40 m depths, and red algae even deeper. Kelp forests were found as far north as the survey in 2017 covered (76° 45′ N). Below the tidal zone, the macroalgae vegetation can be very rich in the shape of kelp forests and seaweed meadows.

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 (Bertness et al. 1999, Lippert et al. 2001) but may be more important as a source of particulate organic material fuelling the benthic communities locally and also on larger depth outside the photic zone (Renaud et al. 2015, Fredriksen 2003). In addition, an increased dependence on kelp carbon has been measured, especially during the dark winter period when phytoplankton is absent (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 sustain a relatively lower production or may appear as barren grounds. Therefore, establishing a robust baseline on littoral- and sublittoral communities is essential to identify important areas and areas sensitive to oil spill.

3.3.1 Benthic vegetation communities in the assessment area

Investigation of the marine benthic flora in the assessment area was scarce until a new study was conducted in 2016 and 2017 in the southern and central parts of the assessment area, along the coast from Tasiilaq to Danmarkshavn (Wegeberg et al. 2019). The investigations included underwater video recordings from approx. 5 to 50 m depth at more than 200 sites as well as samples collected by divers at 13 sites (Box 3.1). Prior to the 2016-17 surveys, mainly qualitative floristic studies have been conducted (Table 1): Lund (1959a, b) investigated macroalgal samples collected in the region between the Scoresby Sund and Kejser Franz Josephs Fjord. Even earlier, however, marine macroalgae were collected at different expeditions to the area during the 19th century, and identified and described by Rosenvinge (1893, 1898, 1910, 1933). More recently, few studies of the macroalgal flora were conducted at the northeast coast of Greenland: A study at Mestersvig (Birklund et al. 2006), which included collections and identifications of macroalgae supplements the floristic overview, and studies of marine macroalgal biomass and production in Young Sund have been performed by Borum et al. (2002), Roberts et al. (2002) and Krause-Jensen et al. (2007) (Table 1). These sporadic studies confirmed presence of macroalgae communities and that the benthic flora was divers, but the extend of the communities, e.g., kelp forests, along the Northeast Greenland shoreline was completely unknown. Hence, further studies were needed to evaluate potential effects of for example oil spills.

Table 1. List of macroalgal studies on the Greenland east coast before the 2016-17 studies (see Box 3.1).

Latitude (°N)	Reference	Site
82	Lund 1951	Jørgen Brønlund Fjord
76	Rosenvinge 1910	Danmarkshavn and adjacent areas
74	Borum et al. 2004; Krause-Jensen et al. 2007	Young Sund
74	Lund 1959	Kejser Franz Joseph Fjord, Dusén Fjord
72	Lund 1959	Ella Ø
72	Birkelund et al. 2006	Mestersvig
70	Lund 1959	Scoresby Sund and adjacent areas
69	Rosenvinge 1933	Kap Dalton
68	Rosenvinge 1933	Kangerlussuaq

Marine macroalgae are found along shorelines with hard and stable substratum, such as stones, boulders and rocky coasts. The vegetation is distinctly divided in zones, most pronounced in areas with high tidal amplitudes. In Greenland, the vegetation in the littoral zone –which is alternately immersed and emersed – is characterized by fucoid species (of the genus *Fucus* and *Ascophyllum nodosum*; Høgslund et al. 2014). However, in the assessment area no marine vegetation was observed above low water level (Box 3.1), probably due to the low air temperatures in the high Arctic, although the perennial species from the littoral zone do tolerate freezing (Becker et al. 2009).

The majority of the macroalgal species grows below the low water mark. The submerged vegetation is restricted to depths with sufficient light. The depth of the photic zone may vary considerably along the coast due to local outfall of turbid melt water from the glaciers or due to variation in ice cover. In the Arctic, the length of the ice-free period is an important controlling factor of the light reaching the sea floor, and the depth range of the kelp belt increases from north towards south along Greenland's west coast in parallel with the increase in the ice-free period (Krause-Jensen et al. 2011). In Northwest Greenland, a relatively rich macroalgal flora can be found down to water depths of about 15-20 m (Krause-Jensen et al. 2011), and as deep as 60 m in the Disko Bugt area (Krause-Jensen et al. 2019). On the east coast, kelp species have been observed up to depths of 40 m at 76° N (unpublished data) and red algae species may penetrate even deeper.

The marked seasonal changes in the light regime, consolidated by cover of sea ice during 9-10 months of the year in, e.g., Young Sund (74° N) and the low temperatures, call for efficient adaptive strategies (Bertness et al. 1999, Borum et al. 2002). The seasonal physiological performance of Arctic macroalgae is strongly linked to life-strategies of individual species or ecotypes as observed for *Laminaria solidungula* and *Saccharina latissima*, respectively, in the assessment area. Particularly *L. solidungula*, and to a lesser extent *S. latissima*, can possess up to several blade (lamina) generations (Lund 1959a,b, Borum et al. 2002, Box 3.1), whereas in temperate regions the lamina of *S. latissima* from the proceeding year's growth is lost successively due to erosion along with development of the new lamina. As discussed by Borum et al. (2002), maintenance of old lamina, and thereby accumulation of surface area of an individual, enhances light and inorganic carbon harvesting, implying that the old tissue is still photosynthetically active and contributing to a positive carbon balance of the individual. They found that the photosynthetic capacity of the lamina from the preceding year was similar to that of the current year. The ability to sustain a photosynthetic performance, comparable to that of macroalgae in temperate regions, might be explained by low light compensation points facilitated by relatively low respiration rates during periods of poor light conditions, and indicates an adaptation to constant low temperatures and long periods of low light intensities (Borum et al. 2002). Furthermore, a fast response in photosynthetic performance to changing light conditions is considered to be part of a physiological strategy in a highly variable environment as in, e.g., the littoral zone. It also ensures optimal harvest of light when available (Becker et al. 2009, Krause-Jensen et al. 2007).

The sea ice is a complex driver on the macroalgal vegetation (Box 3.1). The mechanical scouring of floating ice floes prevents especially perennial fucoid species from establishing in the littoral, which is the zone mostly influenced by the ice dynamics. At such exposed ice scoured localities, communities of opportunistic macroalgae, like species of the filamentous green algae *Ulothrix* and *Urospora*, develop quickly during the summer months due to the avail-

Box 3.1

Submerged vegetation communities along the coast of Northeast Greenland

Susse Wegeberg (AU), Jannie Fries Linnebjerg (AU), Jozef Wiktor (IO PAN) & Ole Geertz-Hansen (GINR)

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

In August/September 2016 and 2017, a ship-based survey was carried out to document occurrence, composition and coverage of the benthic macroalgae in the Northeast Greenland (NEG) assessment area. In 2016, the survey covered the stretch from Ittoqqortoormiit (70° N) to just north of Danmarkshavn (76° N), and in 2017 the stretch from just south of Tasiilaq (65° N) to Ittoqqortoormiit. In total, the survey covered more than 1700 km and a range of app. 12 degrees latitude and resulted in underwater video recordings from 286 sites (Figure 1). The underwater video recordings were obtained along transect perpendicular to the coast at app. 5-50 m's depth to describe vegetation composition, coverage and depth distribution. In addition, at a limited number of sites (Figure 1), a total of 45 samples covering an area of 0.1 m^2 were collected by SCUBA divers from 5 and 10 m's depth. Associated fauna was sampled by everting a net (mesh size 1 mm) over the vegetation sampled. These samples were analysed for species, biomass, fauna abundance and kelp growth rate. At each site, visual observations of tidal vegetation (presence/absence) were obtained and documented by photos.

The results of this study together with data from the limited previous investigations along the Greenland east coast have been used to update our knowledge and establish a baseline on the benthic submerged vegetation communities in the assessment area.

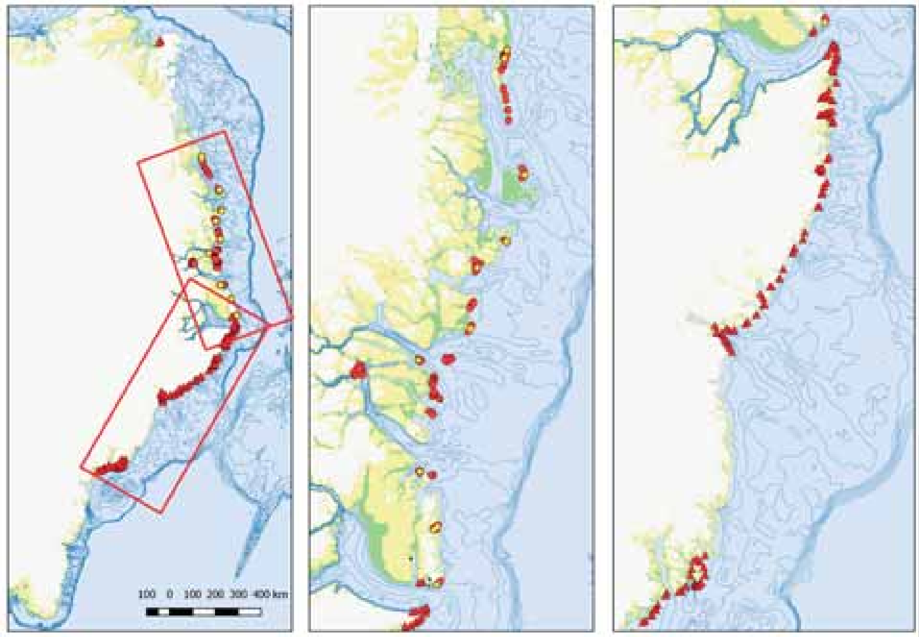


Figure 1. The study area along the Greenland northeast coast is shown on the map to the left. The map in the middle show the area studied in 2016 and the map to the right the area studied in 2017. Red triangles show where underwater transects were performed and yellow dots were samples were collected by divers.

Figure 2. Intertidal vegetation of *Fucus distichus* at the abandoned settlement, Kangerlussuaq.

The seaweed communities along the coast of Northeast Greenland

Littoral vegetation

In general, no littoral communities were observed north of Kangerlussuaq. However, at the Kangerlussuaq abandoned settlement, tidal *Fucus distichus* communities occurred (Figure 2), which is in accordance with observations by Rosenvinge (1933). In Tasiilaq, also *F. vesiculosus* was observed. Here, *Ascophyllum nodosum* have earlier been registered as abundant (Kruuse 1912), although not in this study, but that may be due to limited access to and exploration of the coastline.

Seaweed meadows

In the northern leg of the study (north of Ittoqqortoormiit), a distinct vegetation community was observed in the depth range of app. (5) 8–20 m (typically around 10 m depth), and which is here referred to as seaweed meadows. These seaweed meadows were characterised by a cover of low macroalgal vegetation dominated by *Fucus distichus* and *Chaetopteris plumosa* inter-mixed with *Punctaria glacialis*. *P. glacialis* is considered a high Arctic species by Rosenvinge (1910), and has so far only rarely been observed in Greenland (Pedersen 2009). This macroalgal vegetation type was only observed along the coastline between app. 71° N and 73° N (Figure 3), but similar vegetation may have been described from the Inglefield Inlet at Qaannaaq (77° N) in Northwest Greenland (Wilce 1963), although without the element of *P. glacialis*.

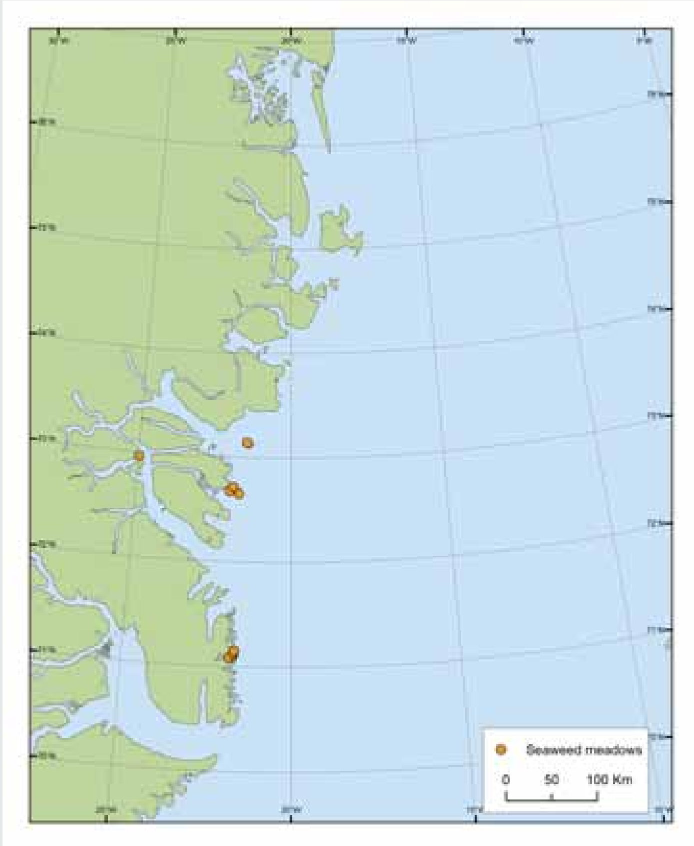


Figure 3. Observations of seaweed meadows i.e. widespread low macroalgal vegetation dominated by *Fucus distichus* and *Chaetopteris plumosa* inter-mixed with *Punctaria glacialis*.

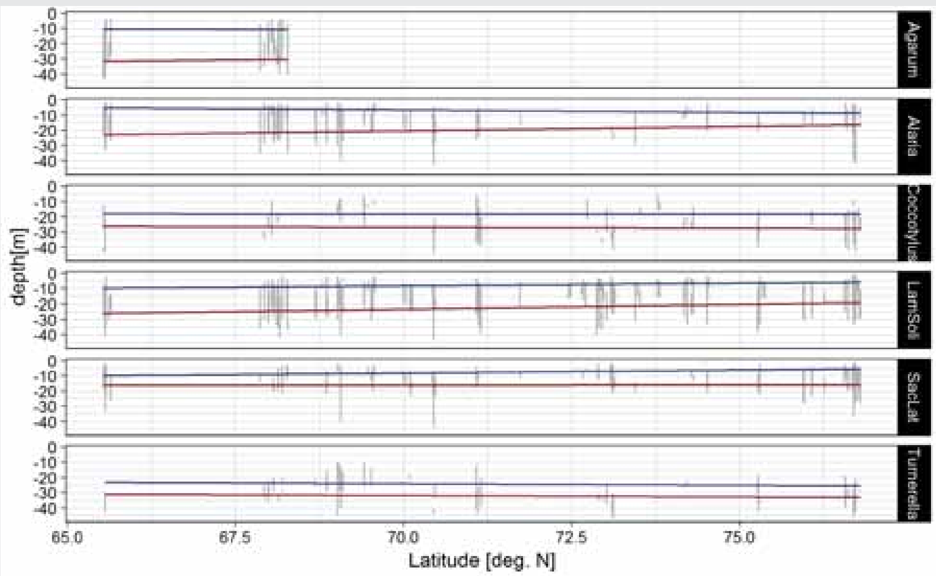
Kelp forests

The kelp forest along the east coast of Greenland is characteristic in particularly two ways:

1) A characteristic component of the east coast kelp forest is *Laminaria solidungula*, a species not common in West Greenland, and usually occurring there as smaller plants. In the present study, this species formed the kelp forest, especially at the northernmost localities, together with *Alaria esculenta*. *L. solidungula* had up to three generations of lamina, which is also described by Rosenvinge (1910) for the east coast. Each lamina section represents the production of one year, as the species grows from a meristem located between stipe and lamina, pushing up the older lamina. Three lamina as observed in August 2016 hence represents growth from the years of 2014, 2015 and 2016, and from the weight of these generation blades, growth rate was calculated.

2) The absence of *Agarum clathratum* from Kangerlussuaq fjord (68° N) and northwards (Figure 4) is also characteristic for the kelp forests along the Northeast Greenland coast. The species is a characteristic component of the kelp forest and actually the dominant species at more sheltered locations and at greater depths around Tasiilaq and at the Greenland south and west coasts (unpubl.).

In addition, *Saccharina latissma* is a characteristic element of the kelp forest along the Greenland east coast. As a note, no specimens, which unequivocally can be assigned to *S. longicruris* were observed, and hence all sugar kelp specimens were assigned to *S. latissima*.



Deep red algae community

A characteristic deep red algal community consisted of *Coccothylus truncatus* and *Turnerella pennyi*, often together with coralline red algal species. *T. pennyi*, in this study, is the holder of the depth record being registered at 45–47 m depth at, e.g., Borg Island (73° N) (Figure 4).

Figure 4. Depth range of dominant species along the latitudinal gradient investigated in this study. The blue and red lines represent the linear regression of minimum and maximum of the depth range respectively. The species are from top to bottom *Agarum clathratum*, *Alaria esculenta*, *Coccothylus truncatus*, *Laminaria solidungula*, *Saccharina latissima* and *Turnerella pennyi*.

No change in depth limits within latitudes

There is no obvious trend in decreasing depth range with increasing latitude, which may have been expected due to increase in length of season with suboptimal light conditions (Figure 4).

At sites, the seaweed vegetation penetrated down to more than 40 m depth. The species depth distribution in the kelp forests generally followed a pattern where *Alaria esculenta* and *Saccharina latissima* dominated the more shallow subtidal zone until app. 25 m, and wheras *Laminaria solidungula* together with *Agarum clathratum*, when present, dominated the deeper part of the kelp forest until > 30 m. However, the species intermixed and in some sites, *A. esculenta* and *S. latissima* penetrated to deeper waters (Figure 4).

A. esculenta belongs generally to the more shallow subtidal zone, which may be related to light conditions, and also to exposure to more dynamic water movements (a more efficient supply of nutrients) (Wegeberg 2007). Such environmental parameters cannot, in this study, be separated, as sea ice influence both the local light conditions and the wave dynamics by calming the sea surface (see also later).

The depth penetration of kelp found in the study area are a little less than found in the Disko area in West Greenland, where the depth record in the North Atlantic was recorded at 50 m (Krause-Jensen et al. 2019). Local conditions influencing, e.g. light penetration, such as turbid waters from river and glacier outlets, may influence depth range as also observed in this study (Figure 4).

No change in biomass and production within latitudes

At eight sites, quantitative samples were taken by SCUBA divers. The samples were not randomly taken, but represent areas where macroalgal vegetation was representative. It was a semi-quantitative approach to elucidate a north-south gradient. The biomasses of neither flora nor fauna showed correlation with latitude within the investigated area (Figure 5 and 6).

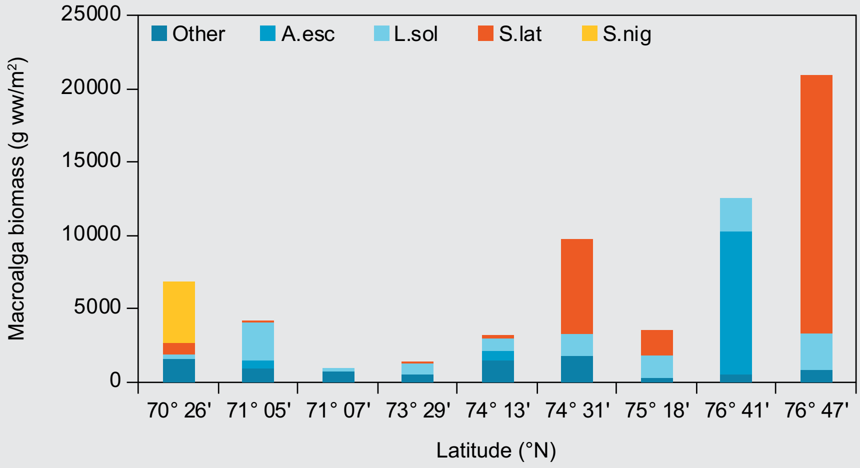


Figure 5. Total macroalgal biomass in wet weight per 0.1 m^2 divided into dominating species, *Alaria esculenta* (A.esc), *Laminaria solidungula* (L.sol), *Saccharina latissima* (S.lat), *S. nigripes* (J.Agardh) Lontin & G.W.Saunders (S.nig) and other species from samples at different latitudes along the northeast Greenland coast.

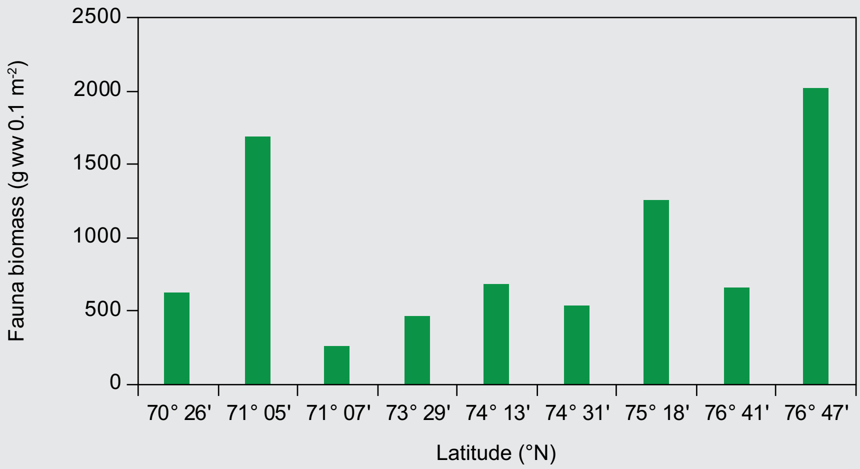


Figure 6. Total fauna biomass associated and collected with the macroalgal samples at different latitudes along the northeast Greenland coast.

The relatively high biomass at the higher latitudes may be explained by the large and potentially old plants, which constitutes a generally undisturbed kelp forest, although the production could be expected to be relatively low due to, e.g. suboptimal light conditions through a large part of the year. However, no correlation between growth rate and latitude was observed in, e.g. *Laminaria solidungula* (Figure 7). The growth rate of *L. solidungula* was higher than what have been found for *Saccharina latissima* in Young Sound (74° N) (Borum et al. 2002).

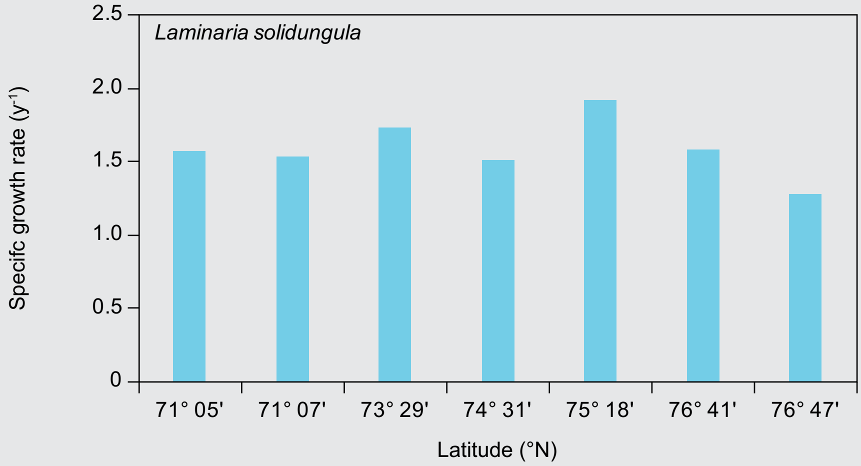


Figure 7. Growth rate *of Laminaria solidungula* at 10 m's depth based on the weight of each blade segment produced per year from different latitudes along the northeast Greenland coast.

Ice, a complex and important driver?

Ice may occur along the Northeast coast of Greenland in several conditions; as stable sea ice, as dynamic drift ice formed locally or from the Polar Sea; as glacier ice (ice bergs and floes); and as an ice foot, a brim of ice attached to the coastline. These ice types may impact the tidal and subtidal vegetation in different ways (Figure 8). Glacier ice may scour on the seabed and shoreline and prevent vegetation to establish. Moreover, melting glacier ice may release fine particles into the water column and reduce water transparency and hence light penetration (AMAP 2017). Sea ice, when drifting as floes, may have similar scouring effects on the shoreline. On the contrary, when the sea ice is stable it protects the coast from wave exposure and also ice scouring, although it may have a shading effect depending on the overlay of snow (Glud et al. 2007). An ice foot may protect littoral vegetation from other ice scouring and also exposure to low air temperature. However, when released, unless just thawed, it may cause scouring.

Hence, ice seems a complex and important driver on both littoral and sublittoral vegetation and communities. Future analyses of the data set will reveal whether the impact from ice can be explained and predicted.

Potential environmental impact of oil spills reaching the coast

So far, our mapping of the macroalgal vegetation along the coastline of Northeast Greenland has revealed unknown and unexpected occurrences of dense kelp forests and also seaweed meadows. Seaweed meadows, understood and defined as subtidal *Fucus distichus* beds intermixed with particularly *Chaetopteris plumosa*, but also *Punctaria glacialis*, a species considered high Arctic and rarely registered before this study, was characteristic and identified at nine sites, solely within the assessment area. This habitat type is hence considered unique for the assessment area on the east coast of Greenland. On the other hand, no intertidal vegetation was observed in the assessment area.

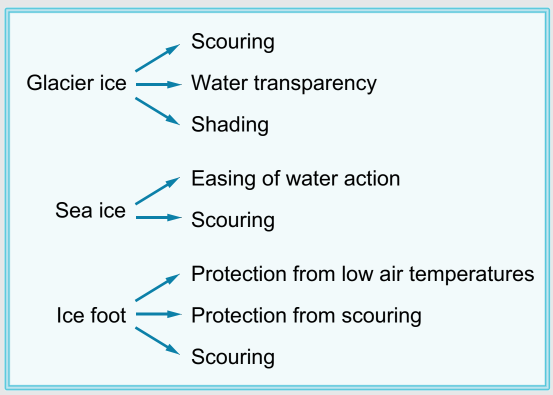


Figure 8. Different ice types and how they may influence on littoral and sublittoral vegetation and communities.

able substratum and life history microstages that are not detached by ice. This scenario is described by Lund (1959b) for the Scoresby Sund and Kejser Franz Joseph Fjord areas, and also observed by the studies in 2016 and 2017 in the same area (Figure 26). However, the littoral vegetation may survive being frozen into an ice foot, provided the ice foot melts without being disrupted. The macroalgal vegetation then remains intact as observed in more sheltered localities by Lund (1959b) and the authors (Box 3.1, Figure 27).

Substratum characteristics are also important for the distribution and abundance of macroalgal vegetation: only hard and stable substratum can serve as base for a rich community of marine, benthic macroalgae. However, at the 2016-17 survey it was observed that despite the presence of stable substratum, macroalgae may be absent. A possible explanation may be that melt water from the numerous glaciers along the coast is causing re-suspension of particles resulting in reduced water transparency (Figure 27).

Climate change will probably affect the macroalgal vegetation by a longer season with open water, and thereby a longer season for growth as well as reduced impact from ice scouring and shading. However, lowered salinity and increasing water turbidity, as a result of an increase in freshwater runoff, could also deprive growth conditions in some areas (Borum et al. 2002, Rysgaard et al. 2007). A northward range expansion of species is another likely scenario with oceanic warming (Müller et al. 2009).

In this respect, the northward expansion of, e.g., fucoid species, such as *Ascophyllum nodosum*, and the kelp species *Agarum clathratum*, may be expected. However, natural barriers for species expansion must be considered. For instance, the Blosseville Kyst may be such a barrier – it is very exposed, it has steep cliffs but relatively low depths with sandy bottom, and may also have particularly complex ice conditions due to assemblages of ice in gyres along this coast (Figure 27 and 28). All these conditions are unfavourable for establishment of macroalgal vegetation, although kelp and red algal vegetation do occur to approx. 20-25 m depth (unpublished data).

3.3.2 Important areas for benthic flora

The present knowledge on macroalgae diversity and community shows a heterogeneous subtidal distribution and abundance linked with a highly variable physical environment in the assessment area (Box 3.1). The rich kelp forests

Figure 26. The coast along Liverpool Land (67°N): wave exposure and possible ice scouring prevent establishment of fucoid species, but a fringe of green filamentous algae can be observed.

are widespread, while seaweed meadows are more restricted in distribution and apparently unique for Greenland. The latter was for example found at several sites in and off Vega Sund. Both vegetation types are important to be considered through a thorough Spill Impact Mitigation Analysis (SIMA) in case an oil spill should be combatted in the assessment area.

Figure 27. The Blosseville Kyst: steep cliffs impacted by ice, but with relatively low water depth.

3.4 Benthic fauna

Jørgen L.S. Hansen (AU)

The seabed communities of macrofauna in the assessment area are characterised by a high biodiversity of long-living crustaceans, echinoderms, molluscs etc., but compared to West Greenland, biomass and abundances are low. The seabed communities are important food resources for seabirds and marine mammals such as eider, bearded seal and walrus. During the 2017 surveys a very sensitive seabed community was discovered on the shelfbreak, where deep-sea corals and sponges were abundant.

3.4.1 Benthic fauna in the Arctic

The benthic macrofauna communities play a key role in the functioning of the marine ecosystem and contribute with the majority of species, adding to the overall marine biodiversity. In shallow waters, where the productive surface layer is in direct contact with the seabed, the macrofauna can sometimes control the pelagic ecosystem production by filtering off the phytoplankton. In deeper waters where there is no primary production, the fauna communities is fuelled almost entirely on the so called allochtoneous organic material, which is organic matter transported to the ecosystem from outside (as opposed to autochtoneous material originating from within the ecosystem).

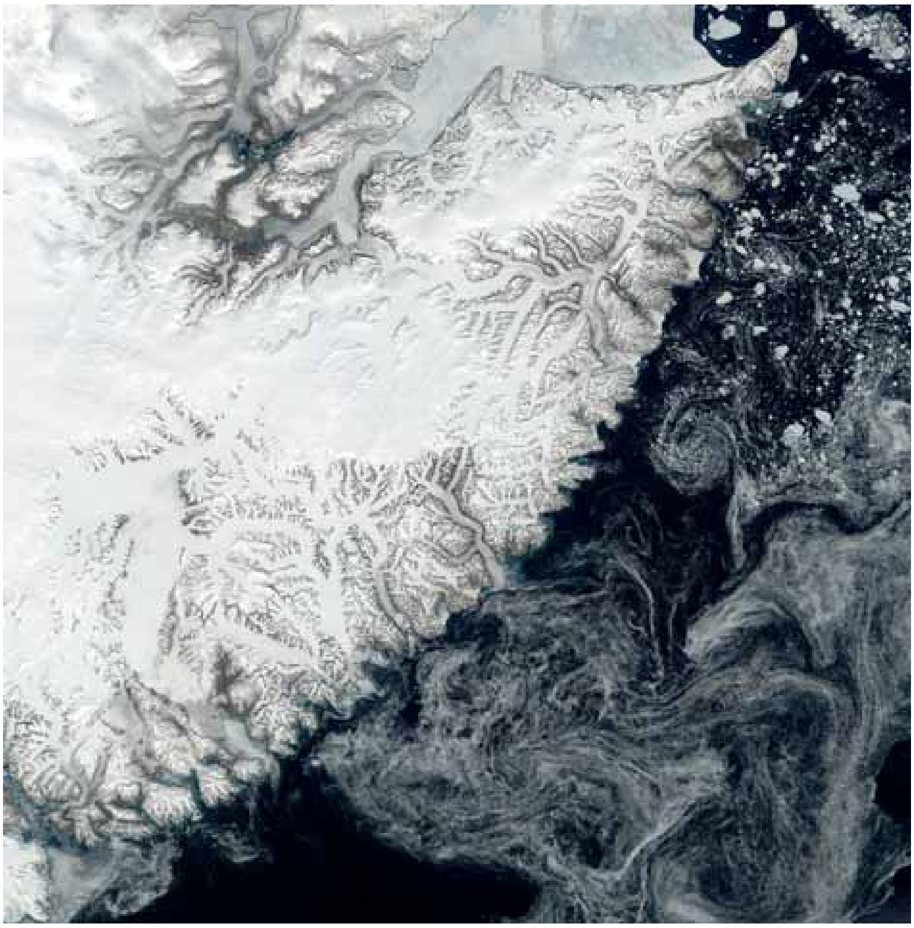


Figure 28. Ice conditions at the Blosseville Kyst 12 June 2016: gyres are gathering ice along the coastline. Data source: NASA Worldview application (Link).

This input of organic material originates from primary production in the illuminated surface layers of the ocean and subsequently sinks to the bottom. Here, the material is taken up by the benthic fauna community and enters the benthic food chain eventually sustaining higher trophic levels such as fish, mammals and birds if water depths allow them to dive to the bottom.

Furthermore, the low temperature reduces the energy requirements of benthic species, allowing a relatively high biomass to exist despite the low primary production (Sejr & Christensen 2007). In areas with low temperatures and a stable environment with no physical disturbance of the seabed, benthic species with long life span are favoured, allowing accumulation of a large biomass over decades in spite of low annual production. Food availability is one of the major driving forces influencing biomass and composition of benthic assemblages in the Arctic.

From an ecosystem point of view, the benthos is of importance because it harbours a significant proportion of the biodiversity. It is not unusual that up to 200 different macrofauna species are found per m^2. Moreover, benthos plays an important role in the food web. It is well established that especially bivalves are an important food source for walruses, bearded seals and eiders (Hobson et al. 2002, Born et al. 2003, Lovvorn et al. 2003). Undoubtedly, the benthos is equally important for bottom-living fish and shrimp, but this effect has not yet been studied in the Greenland Sea assessment area.

The overall biomass and richness of the seabed fauna is related to the input of organic matter and, therefore, to the distribution of primary production in the water column above. This linkage, between pelagic primary production and benthic secondary production, may be so close that even small-scale hydrographic features such as productive frontal areas may be evident in the benthos community in terms of enhanced standing biomasses (Josefson & Conley 1997, Josefson & Hansen 2003). However, water depth also plays an important role in the amount of the sedimentary input to the benthos because there is a respiratory loss during the descent of the organic matter through the water column. This means that the deeper the water column is, the less organic matter input, and the lower its degradability. Therefore, due to a combination of high productivity and relative shallowness, bottoms of continental shelfs generally receives high sedimentary input which sustain a rich benthic fauna community.

The majority of benthic species have a life span of 5 to 10 years. In Arctic areas, however, the life span of large species such as sea urchins and bivalves may exceed 50 years and for corals even more. Due to the long life span, changes in the benthic community often occur over several years and if the community is disturbed, it may take decades for the system to recover.

3.4.2 Benthic fauna and its role in the assessment area

The sea ice limits accessibility of the area for scientific exploration of the shelf bottom and to date, only a few studies have documented the benthos of the Northeast Greenland Shelf. A number of Polarstern R/V cruises (ARK VII, VIII, IX and X) have covered parts of the area with benthic sampling: Mayer & Piepenburg (1996) and Schnack (1998) conducted a study across the shelf-break at about the 75° N; otherwise, most other studies have covered the area north of 78° N (Brandt et al. 1995, Piepenburg 2005, Piepenburg & Schmid 1996a, 1996b, Schack 1998). The area between 75° and 78° N, covered by the 2017-survey under the *Strategic Environmental Study Program for Northeast Greenland* was largely unexplored before (Figure 29).

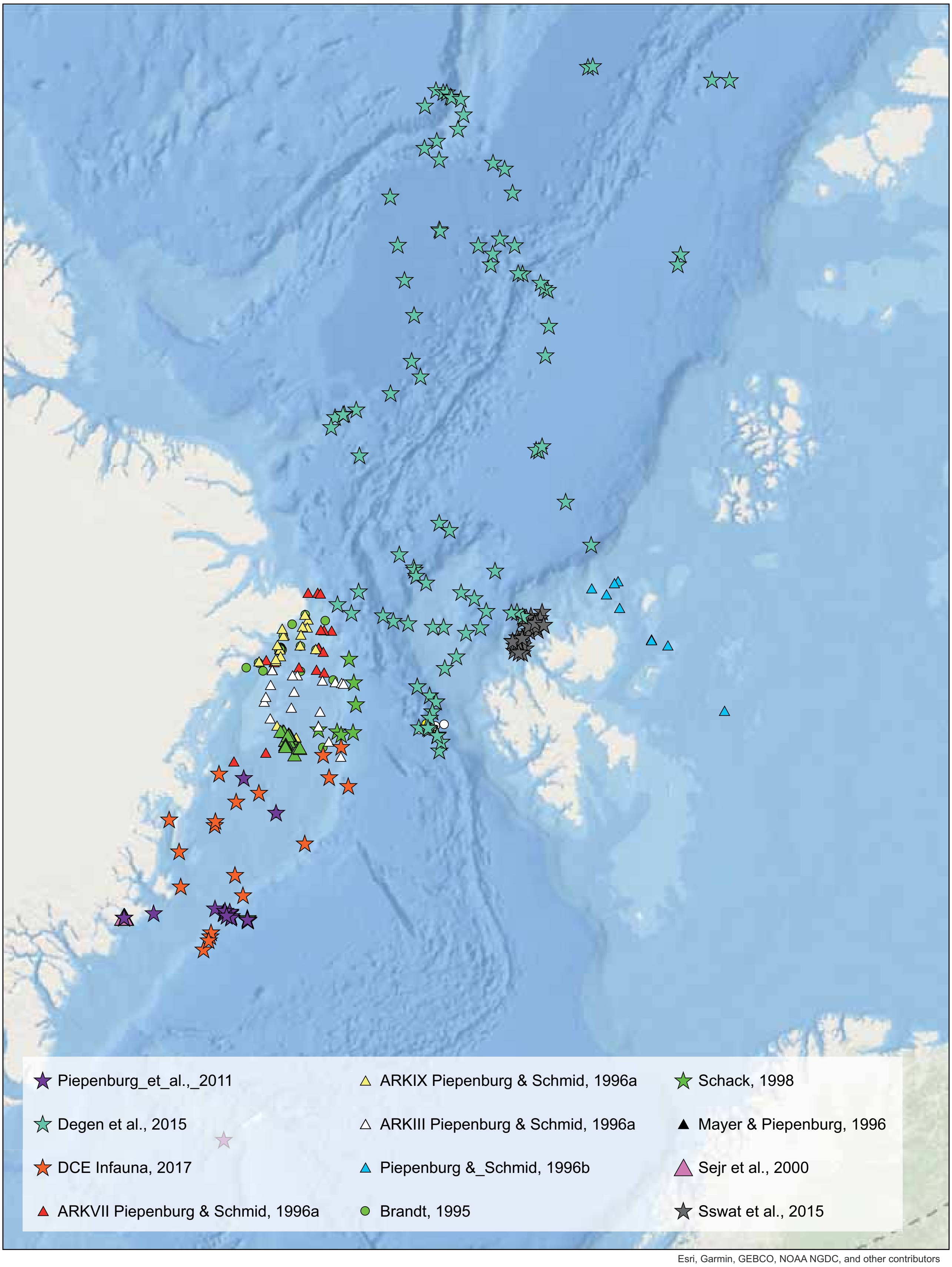


Figure 29. Locations of Strategic Environmental Study Program for Northeast Greenland sampling stations 2017 (red stars) together with sampling stations visited by previous expeditions on the Northeast Greenland shelf and adjacent areas.

The assessment area covers a wide range of physical habitats extending from the tidal zone to almost 3000 m depth. It ranges from the innermost parts of the large fjord systems strongly influenced by glacial run-off to the open ocean with shelf areas, shelf slope and deep-sea plains.

Primary production in the assessment area is generally controlled by sea ice that limits light availability. As a consequence, annual primary production is low and confined to a short period in summer (see 3.1). Food is an important constraint on benthic growth and reproduction, and patterns of macrobenthic biomass often reflect the variations in primary production in the overlaying water column. For example, benthic biomass is higher underneath polynyas (Piepenburg et al. 1997) and it may also have associated effects on the higher trophic levels of the area, such as the walrus population, which is probably limited by food availability (Born et al. in prep.).

Another example on how food availability governs benthic biomass is the depth zonation found in Young Sund in East Greenland where a high biomass of bivalves is found at a depth of 20 m to 40 m, which corresponds with the depth of the chlorophyll maximum in summer (Sejr & Christensen 2007). In addition to food supply, level of disturbance is also an important factor influencing benthic biomass and distribution. Typical sources of disturbance are sedimentation of inorganic particles (from rivers or glaciers) or grounding sea ice and scouring icebergs. Hence, benthic biomass is likely to be lower in the inner parts of the fjords or on shallow banks where larger ice floes ground or icebergs hit the seabed. Thorson (1933, 1934) reported a benthic biomass in the range 200-500 g wet weight per m^2 from East Greenland fjords.

So far, investigations concerning benthic communities, their distribution and functions, have focused on the Northeast Water Polynya at the northern limit of the assessment area, where multidisciplinary studies including the macrobenthos have been conducted (Piepenburg & Schmid 1996, Weslawski et al. 1997). Benthic life has also been studied along the East Greenland continental margin at two down-slope transects at 75° N (200-2700 m depth), at 79° N (200-2000 m depth) during 1994/1995 (Mayer & Piepenburg 1996, Schnack 1998), and in the western Fram Strait (78°-80° N, 4°30′-14° W) in summer 1985 (Piepenburg 1988) (Figure 30A). In these studies, seabed imaging was applied to describe benthic communities living on the sediment surface (epibenthos) (Piepenburg et al. 1997). A few studies have also used Agassiz trawls to estimate benthic diversity (Mayer & Piepenburg 1996) and up to 80 species were found (Figure 30B). These were mainly crustaceans, echinoderms, molluscs and polychaetes and their presence was sediment and depth dependent (Figure 30C). Multivariate analyses of megabenthic species distribution revealed a distinct depth zonation (Piepenburg et al. 1997). Shallow shelf banks (<150 m), characterised by coarse sediments, numerous stones and boulders as well as by negative bottom-water temperatures, housed a rich epifauna (30 to 340 individuals per m^2, Figure 30B). It was strongly dominated (80-98% by number) by the brittle stars, *Ophiocten sericeum* and *Ophiura robusta* (Piepenburg et al. 1997).

On the East Greenland continental slope at 75° N, a total of 91 different epibenthic species were identified, and up to 50 species at some locations (Figure 30D). Using classification and ordination analyses, three faunal zones were distinguished which correspond to different depth regions of the continental margin: shelfbreak (190- 370 m), upper slope (760- 800 m) and lower slope (1400-2800 m), which differed clearly in species composition (Figure 30E). See Box 3.2 on the deep-water corals found in 2017.

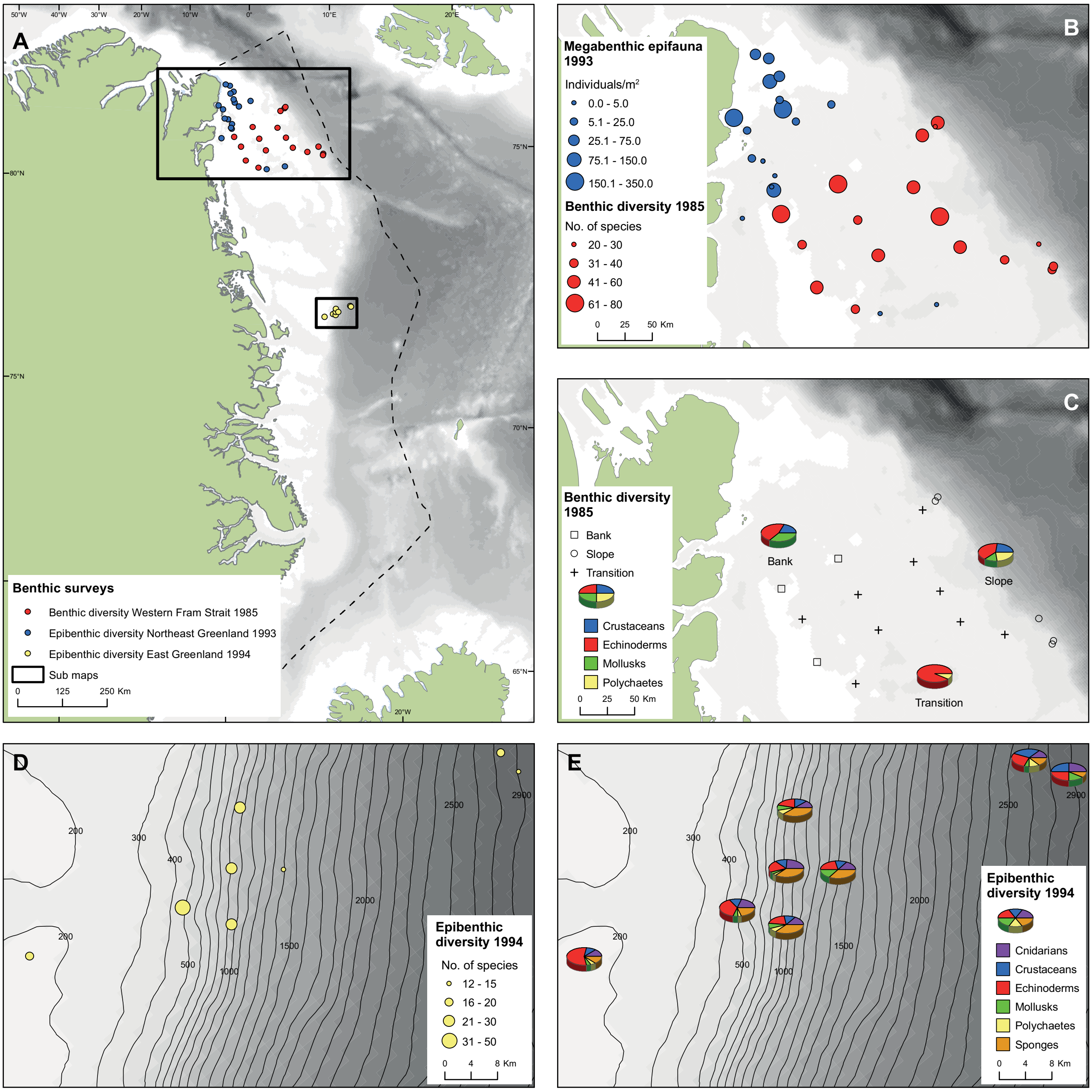


Figure 30. Benthic fauna studies in two areas of the assessment area (Piepenburg 1988, Schnack 1998). A) Sampling stations, B) Densities and species richness in northern area, C) Diversity of different taxonomical groups in different habitats in northern area, D) Species richness in the southern area, E) Diversity of different taxonomical groups in southern area. See also text.

The Young Sund fjord in the central part of the assessment area is another region where macrobenthic fauna and other aspects of this ecosystem have been investigated in past years (Rysgaard & Glud 2007). In addition, a long-term marine monitoring program was initiated there in 2003. Based on the findings from these studies our current knowledge regarding macrobenthos distribution and role in the ecosystem is summarised as follows: In the shallow coastal zone bivalves are a dominant component of the benthos. At depths between 5 and 20 m the genus *Astarte* is often found at abundances of 100-300 individuals per m². In the tidal zone, sea ice often destroys flora and fauna, and the effect of ice can extend down to 5 m. In addition, in fjords with a large input of fresh water, a low-saline surface layer can also influence the benthos of the upper 0-5 m. At depths from 10 to 50 m, large species such as *Mya truncata, Hiatella arctica* and *Serripes groenlandicus* can be found at abundances of 50-100 individuals per m² (Figure 31). Below 50 m in depths, total biomass drops significantly and the bivalves are replaced by polychaetes (Sejr et al. 2000). As in many other Arctic regions, brittle stars are the most dominant group with a biomass in the range of 400-600 mg C m^{-2} (Piepenburg 2000, Piepenburg &

Box 3.2

Cold water corals and epibenthic megafauna on the Northeast Greenland continental shelf slopes

Jørgen L.S. Hansen (AU), Mikael K. Sejr (AU), Tore H. Holm-Hansen (AU) & Ole Norden Andersen AU)

Among the wealth of species recorded during the NEG 2017 cruise, findings of the giant sea pen, *Umbellula encrinus* (Linne 1753), and the soft cold water coral *Keratoisis* sp. are of special interests as these species indicate undisturbed conditions of the seabed. Furthermore *Keratoisis* form a type of biogenic habitat which is presently endangered worldwide. A search of the scientific literature indicate that the present findings are the first of this genus on the NEG continental shelf area. *Keratoisis*, also known as bamboo corals, were observed both from semi-quantitative video recordings (Figure 1), as well as from 0.1 m^2 quantitative grab samples. The distribution of the *Keratoisis* populations was scattered in patches or "gardens" on the steep slope of the continental shelf at about 1100 m depth, but only with significant coverage on one station (St. 74; 74° 26′ N, 13° 40′ W). Video observations showed that the individual patches with up to 100% coverage had sizes of >100 m^2 of the seafloor. Within these patches, the more or less unbranched erect stems of *Keratoisis* formed stands of 1-2 m high colonies. Furthermore the densest stands seemed to be associated with a local elevation of the seafloor. This is interpreted as a result of locally enhanced sediment deposition within the stands. This hypothesis is consistent with observations from the grab samples, showing that the living branches of *Keratoisis* above the sediment surface were directly interconnected with dead branches below in the sediment. It is therefore possible that there exists a self-organizing habitat formation process where growth of the coral colonies are balanced by sediment deposition within the coral gardens and that this process (over centuries?) grow small hill or dune like structures of deposited sediment covering old and dead parts of the bamboo corals.

The bamboo corals had a rich associated epifauna of sponges, fish, crustaceans, and echinoderms which altogether, contrasted the rather poor epifauna community surrounding seabed on the shelf and shelf slopes. The video showed that the *Keratoisis* polyps were actively filtering and particulate organic matter (marine snow) was present in the bottom near currents. The patches of *Keratoisis* are local biodiversity hotspots, and although the total community biomass associated with these coral gardens was not quantified, it was evident from the videos that the bamboo coral and associated epifauna constituted a biomass hotspot as well. Aggregation of biomass can be due to both attraction of organism to the reef habitat (reef effects) or biomass could have been produced on the reef by filtrating organisms taking up suspended particulate organic matter from the bottom near currents.

The erect braches of *Keratoisis* were extremely fragile and broke easily when hit by the sampling equipment. This together with the slow growth of the coral emphasis that these location were undisturbed. Counting of year rings of the central stem of *U. encrinus* in this and other studies (Neves et al. 2018) suggest that the largest specimens were about 75 years old. *Keratoisis* also grow very slowly with an annual length growth of about 7 mm (Andrews et al. 2009). The longest unbroken piece recovered from the grab samples was 60 cm corresponding to about 90 years of growth. However, the *Keratoisis* gardens on the video had longer skeletons, and the fact that the branches were inter-connected with older and dead parts of the skeleton below in the sediment indicate that these habitats and communities were considerable older.

The gardens of Bamboo corals on the NEG continental slope indicate that these locations presently are preserved in pristine and undisturbed conditions and therefore have special interest for conservation of the seafloor biodiversity. The NEG 2017 survey furthermore showed that these biogenic habitats are very vulnerable to physical disturbance and their recoverability upon disturbance may be extremely low due to the very slow growth rate of the bamboo coral. However, the distribution range of bamboo corals along the wider continental slope of the east Greenland shelf needs to be documented further to add perspective to the present records.

Figure 1. Gardens of cold water corals *Keratoisis sp*. at 1100 m depth on the eastern margins of the NEG continental Shelf. Note tentacles on the polyps are open and actively filtering. The hexactinellid sponge below is an *Asconema*, probably the species *foliatum*.

Schmid 1996). Generally, the benthic fauna consists of both Boreal/Arctic species and of proper Arctic species (Piepenburg & Schmid 1996).

The 2017 studies

The studies carried out in 2017 in the northern part of the assessment area as a part of the *Strategic Environmental Study Program for Northeast Greenland* established a baseline for Northeast Greenland shelf area benthos and provided data that may further be used to assess the sensitivity of the benthic ecosystem to disturbance from human activities and environmental changes (Hansen et al. 2019). The survey sampled on 21 stations (Figure 29) on the shelf and shelfbreak at depths from 66 to 1460 m. Both sampling and video recording were applied. This survey provided much new information on the benthic communities off Northeast Greenland: Densities of arthropods and annelids were generally low with about 600 individuals m^{-2} as an average for the area, and the corresponding biomass was even lower with an average biomass of 1.8 g m^{-2}. Compared to the West Greenland shelf areas, from where there exists corresponding and comparable data, the biomass of the infauna was about 10 times lower and the abundance about 4 times lower in the assessment area. The differences in the benthic fauna communities between the western and eastern shelfs are in agreement with the differences in productivity of the two shelf ecosystems. Species densities in the samples (0.1 m^2 sample) was also lower, about two thirds of comparable species densities on the West Greenland shelfs. However, Shannon diversity index showed about the same values of the two shelfs and species accumulation plots of arthropods and annelids suggest that the total species pools of the systems could be approximately the same sizes, or even larger, at the Northeast Greenland shelf.

Qualitative sampling of benthic epibenthic megafaunal communities included observations of an iconic giant >2 m sea pen *Umbellula encrinus* both from bottom trawling and underwater video. Furthermore, dense gardens of cold-water corals *Keratoisis* sp. were observed on the continental slopes. Based on counts of year rings the population of *Umbellula encrinus* was determined to be >30 years old, and literature values of growth rates of *Keratoisis* suggests that these populations were considerably older. These epifaunal communities document the pristine conditions of the Northeast Greenland Shelf and emphasise the extreme vulnerability of these communities to disturbance (Box 3.2).

Figure 31. Photo of the seafloor in Young Sund showing the diverse infaunal and epifaunal community (at approximately 30 m depth).

3.4.3 Important areas for benthic fauna

As feeding grounds for seabirds and marine mammals, the coastal region at depths from 0 to approx. 75 m is of particular importance, since this is the region where the benthos can be expected to play a significant role as a source of food for fish, seabirds and mammals. Furthermore, this depth range is most likely to be affected by potential oil spills.

Deeper areas may also be impacted by exploration activities, as drill cuttings and mud may be released here and structures placed there, which is why improved knowledge of the seabed communities is essential to regulate such activities.

The coral gardens located on the shelfbreak in 2017 (Box 3.2) is an extremely vulnerable habitat as these corals will be destroyed by activities (such as trawling) affecting the seabed where they occur.

Furthermore, the populations of the sea pen are vulnerable to all kinds of disturbance on the seabed. These occur more scattered on the soft seabed. From the video recordings of the benthos and the seabed, no sign of bottom trawling was observed. However, effects from physical disturbance may be more prominent in areas with less intense ice cover.

The distribution of the sea pen and the vulnerable coral gardens need to be mapped before any activities (including trawl fisheries) on the seabed are initiated off Northeast Greenland.

3.5 Ice flora and fauna

Susse Wegeberg (AU), David Boertmann (AU) & Thomas Juul-Pedersen (GINR)

The information on sea ice communities in the assessment area is limited. In other areas the primary production in and below the sea ice vary considerably depending on sea ice diversity and longevity. The sea ice is an important feeding and spawning area for polar cod, and their eggs accumulate along the underside of the ice.

When sea ice is breaking up, especially in spring and summer, floes turned around often expose thick mats and curtains of algae on the underside, and small fish – polar cod – are occasionally thrown up on the ice when the floes are tumbling around, evidencing that there is a whole ecosystem associated with the ice. This is a specialised ecosystem based on bacteria, microalgae, micro- and meiofauna in and under the ice, and macrofauna primarily found on the underside of the ice and in larger cavities. This ecosystem occurs both in drift ice and in fast ice, and one of the most important structural parameters for the community is the age of ice; multiyear ice having much more developed and richer communities than first-year (Quillfeldt et al. 2009). The term 'sympagic' is often applied to this ecosystem – sympagic fauna and flora for example.

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

Strong patchiness of the sea ice algae is commonly reported (Gosselin et al. 1997, Gradinger et al. 1999, Rysgaard et al. 2001, Quillfeldt et al. 2009), caused by the heterogeneity of the ice as well as varying snow cover affecting light conditions (e.g. Tedesco et al. 2019). Rysgaard et al. (2001) found, in their study in Young Sund within the assessment area, that the patchiness of algal activity was strongly linked to the corresponding patchiness in the light regimes below the ice.

A synthesis on Arctic and Antarctic studies of sympagic flora and fauna showed significant patterns in microalgal community structures with autotrophic flagellates that characterize ice surface communities, while interior communities consist of mixed microalgal populations, and pennate diatoms dominate bottom communities (van Leeuwe et al. 2018). Algae contribute to the biomass of the sea ice communities with 43%, bacteria with 31%, heterotrophic flagellates with 20% and meiofauna with 4% in the Greenland Sea (Gradinger et al. 1999). Diatoms are the main primary producers, and contribute with up to 60% of total algal biomass. *Melosira arctica*, together with the pennate diatom, *Nitzshia frigida*, tend to be the dominant diatom species off Northeast Greenland/Barents Sea (Gutt 1995, Gosselin et al. 1997, Quillfeldt et al. 2009), and when the ice melts it is supposed that the diatom sinks to the 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).

Apparently, there is a high spatial variability in species composition of Arctic algal communities (e.g. van Leeuwe et al. 2018). In Baffin Bay, Irwin (1990) found dominance of a centric diatom, *Cosinodiscus* sp., which accounted for 63% of the total number of cells in ice floes at the Labrador Shelf, while Michel et al. (2002) found that pennate diatoms completely dominated (85% in first-year ice) in the North Water Polynya. Somewhat conflicting results have been reported for the colonial, centric diatom species, *Melosira arctica* (Table 2). This diatom is found to be either very dominant or rare/absent (Gutt 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).

Sea ice is a very diverse and potentially very productive habitat, with primary production estimated to amount to 2–24% of total production in sea ice-covered marine areas (Arrigo 2016). Production estimates from Arctic waters range from 5-15 g C m^{-2} year^{-1} depending on seasonal ice cover (Mikkelsen et al. 2008). The ice algal production in the northern part of the Barents Sea is reported to be 5 g C m^{-2} year^{-1}, which corresponds to 16-22% of the total annual primary production (Quillfeldt et al. 2009). In the ice-covered Arctic Ocean the ice algae were found to contribute on average 57% of the entire primary production (15 g C m^{-2} year^{-1}) (Gosselin et al. 1997) while Rysgaard et al. (2001) found that the ice algae only accounted for <1% of the pelagic primary production (<1 g C m^{-2} year^{-1}) from coastal fast ice environments in Young Sund

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

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

during the measuring period. Horner & Schrader (1982) reported that the ice algae provided about two-thirds of the total, pelagic primary production in the nearshore regions of the Beaufort Sea during spring bloom. Booth (1984) found that the ice algae only contributed with <1% of the annual production of the phytoplankton in the Davis Strait, but considered the contribution as important as it preceded the phytoplankton spring bloom and constituted the only algal biomass under heavy pack ice, which is in correspondence with Michel et al. (2002). They also found that ice algae only represented a small fraction of the total algal biomass (<3%) in the North Water Polynya but as they considered limited grazing inside the ice, this biomass could play a significant role in ensuring availability of ice algae for under-ice pelagic and benthic grazers during spring.

Ice algal production is largely governed by environmental factors on a small scale and therefore cannot be linked to specific ice types (van Leeuwe et al. 2018). A study on algal biomass within ice ridges and at the interface between snow and ice (i.e. on top of the ice) concluded that these environments represent largely unstudied algal hotpots that may become more abundant in a changing climate (Fernández-Méndez et al. 2018).

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 shifting of the ice seasons toward more favourable light conditions may increase ice algal production above 74° N, while only small changes may be observed in the 66° N to 74° N band.

The annual production estimates of the ice algae communities in Arctic seas are presented in Table 3.

Van Leeuwe et al. (2018) found an overlap between landfast and pack ice communities, which supports the hypothesis that sympagic microalgae originate from the pelagic environment. The role of sea ice algae in seeding pelagic blooms, however, remains 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.

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

Table 3. Ice algal annual production (g C m^{-2} $year^{-1}$) in different areas of the Arctic.

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

*Calculated from an ice algal contribution averaging 57% of the entire primary production (15 g C m^{-2} $year^{-1}$).

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 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 Sund did not seem to be caused by high grazing pressure since the biomass of grazers was not exceptionally high in the location. In addition, Michel et al. (2002) concluded that very little ice algal production was channelled through the meio- and microfauna within the ice in the North Water Polynya due to suboptimal prey size for predators.

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

A study on fatty acids and other markers in abundant under-ice fauna species including copepods, ice-associated amphipods, pelagic amphipods and pteropods from the central Arctic Ocean, showed that the species thrived on the carbon synthesised by ice algae (Kohlbach et al. 2018).

Therefore, the production of the ice community may be of great importance to the marine ecosystem at times of the year where the pelagic and benthic productions are relatively low, especially just before the spring bloom of phytoplankton.

The sea ice is an important feeding area for polar cod, and in winter, they spawn here; the eggs rise in the water column to accumulate under the ice (see below).

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: Important areas are likely to be found in the multiyear ice and the MIZ and will follow the distribution and movements of the ice. However, it should be noted that the multiyear sea ice habitat is rapidly decreasing and in few decades may be restricted to very small patches along the north Canadian and north Greenland coasts (Wang & Overland 2009).

3.6 Fish

Caroline Bouchard (GINR) & Ole Jørgensen (GINR)

The diversity, abundance and distribution of fish in the assessment area has been little studied. However, studies of the fish populations during surveys in 2017 as part of the *Strategic Environmental Study Program for Northeast Greenland* confirmed previous studies that fish diversity on the East Greenland shelf is low, compared to low Arctic and sub-Arctic regions. As elsewhere in the circumpolar Arctic, polar cod is a key species in the marine ecosystem while the less numerous ice cod is also common. The coastal part of the region is inhabited by Arctic char, a species of high ecological, cultural and economic value in several Arctic regions. The 2017 studies also revealed aggregations of lanternfish in waters more than 400 m deep.

3.6.1 Diversity and distribution of demersal fish: pre-2017 studies

According to Muus et al. (1990) about 26 species can be found on the Northeast Greenland shelf. Most of them belong to the Cottidae, Zoarcidae and Liparidae, which predominantly are benthic living species (Dunbar 1985). They are of minor commercial value but play an important role in the Arctic ecosystem (Atkinson & Percy 1992), being an important food source for many Arctic seabirds and seals (Dorrien 1993 and references therein). Two arctic Gadidae, the Arctic cod and the polar cod are also ubiquitous in the area and play a crucial role in the ecosystem (Bouchard et al. 2016 and references therein).

During a cruise of RV *Polarstern* in summer 1990 (ARK 7/2), the distribution of fish at the continental margins of Northeast Greenland was studied (Figure 32). The region is characterised by the cold East Greenland Current coming from the Arctic Ocean and flowing southward along the east coast of Greenland. The investigations were focused on the Northeast Water Polynya. Using an Agassiz trawl, a large bottom trawl and an underwater camera, 21 stations off Northeast Greenland (75° to 82° N) were sampled (Dorrien et al. 1991). In total, 23 fish species were found (Figure 33). At most sampling sites the following five species were most abundant: polar cod (up to 5000 indv./km^2), *Artediellus atlanticus* (up to 4500 indv./km^2), *Icelus bicornis* (up to 4000 indv./km^2), *Triglops nybelini* (up to 2000 indv./km^2) and *Liparis fabricii* (up to 4000 indv./km^2).

Both the polar cod and its near relative the Arctic cod were present in the polynya (Figure 33). Arctic cod was the most abundant fish species in the trawl catches in the northernmost part of the study area, where it probably replaces polar cod (Dorrien et al. 1991).

In a more recent multidisciplinary study in 2003 (TUNU-MAFIG), diversity of marine fishes was studied in the fjords and coastal waters of Northeast Greenland between Danmarkshavn (77° N) and Eskimonæs (74° N). At each station, species composition and abundance was estimated (Figure 34). In total, 33 species belonging to 13 families were recorded (Christiansen 2003). The most species rich families were the Zoarcidae (8 species), Liparidae (6 species) and Cottidae (5 species), whereas the most frequent species were *Liparis fabricii*, polar cod and Arctic cod.

About 70% of the fish species analysed were ‘Arctic' or ‘mainly Arctic', according to common zoogeographical classification (Karamushko et al. 2003). The total number varied between 36 and 10,780 specimens for a standardised one-hour trawl haul (Figure 34). On most stations (excluding those in deeper water), polar cod and Arctic cod were the absolute dominant species (up to 95% by number and biomass).

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

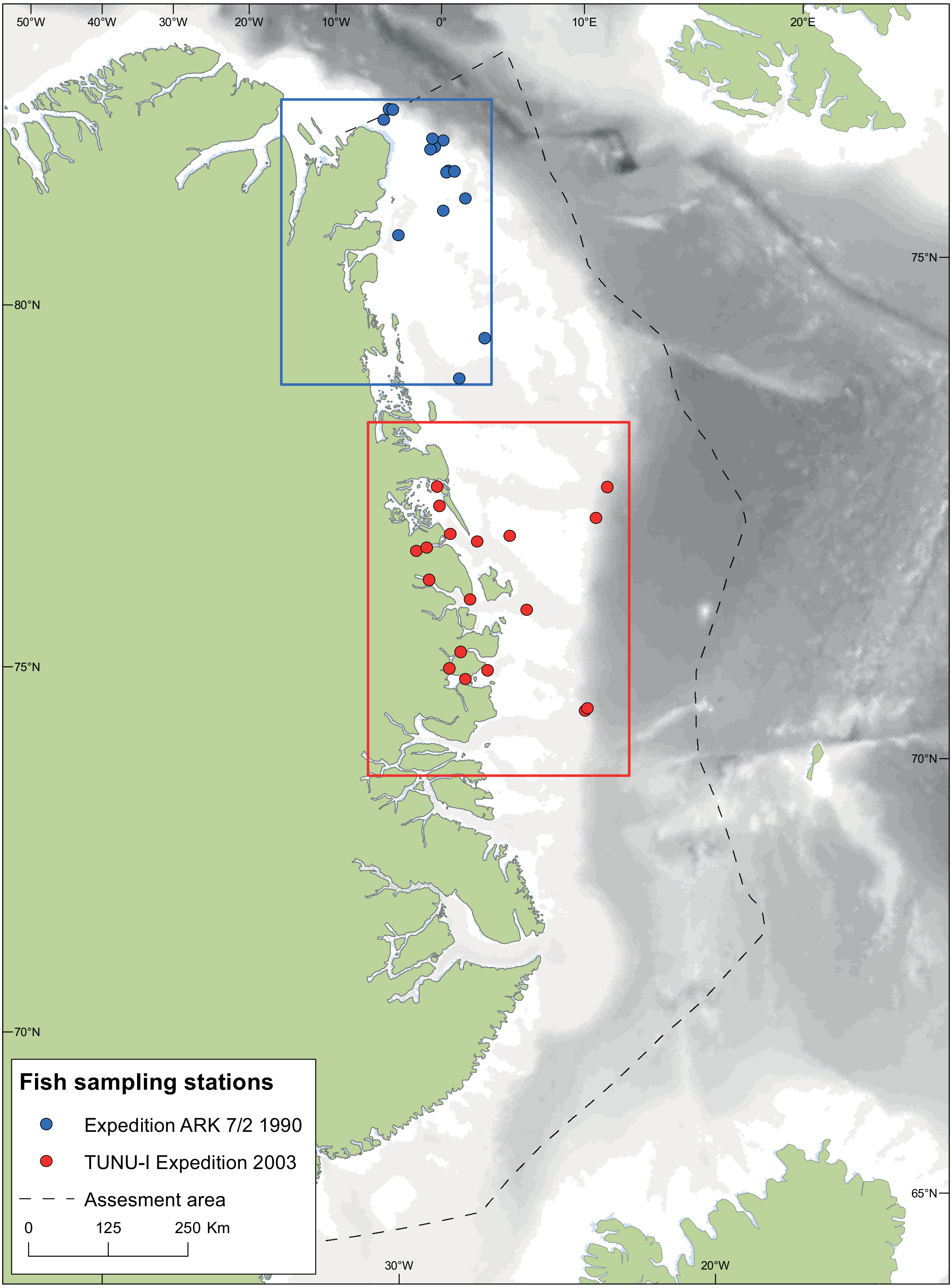


Figure 32. Sampling stations during the Polarstern cruise ARK 7/2 in 1990 and during the TUNU-1 cruise in 2003 (Dorrien et al. 1991, Christiansen 2003).

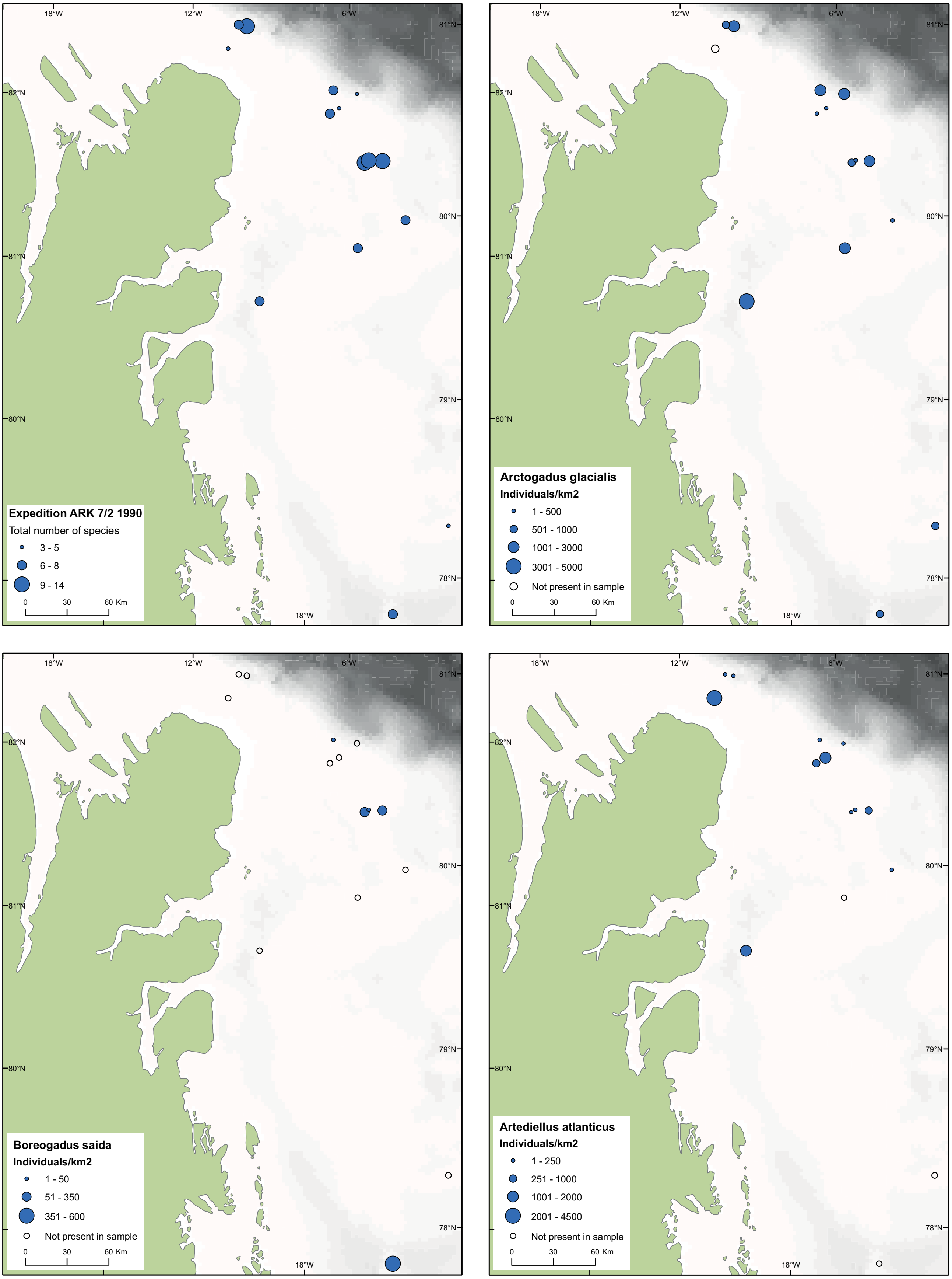
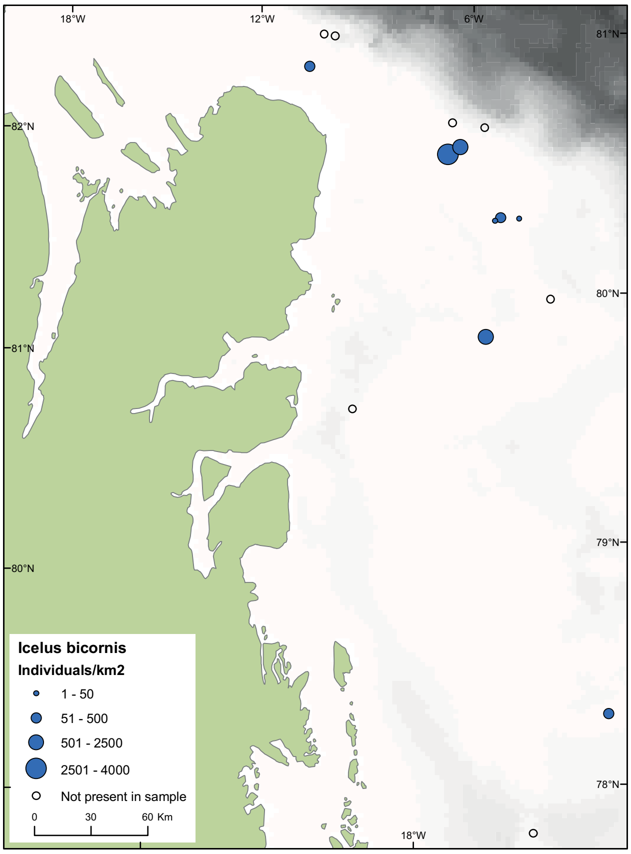
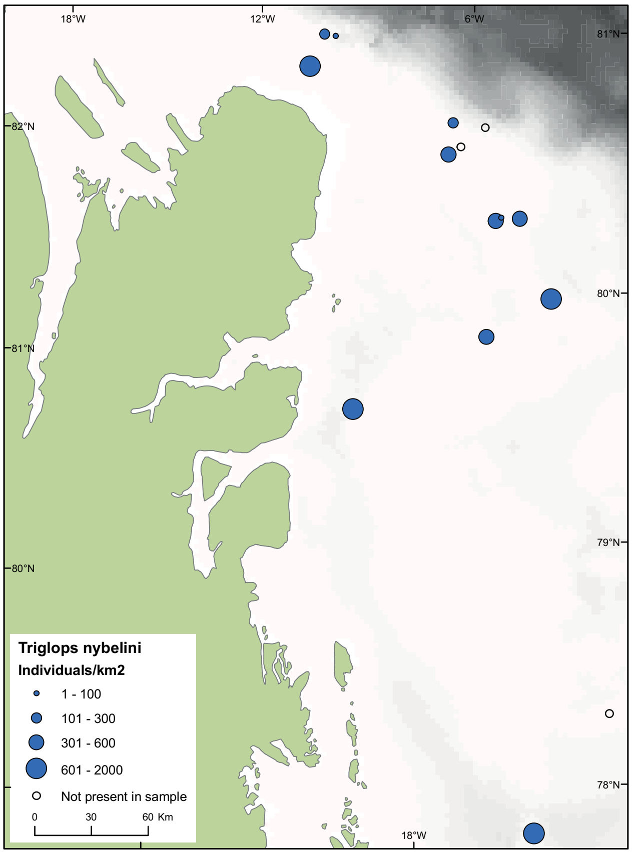


Figure 33. See legend on page 81.





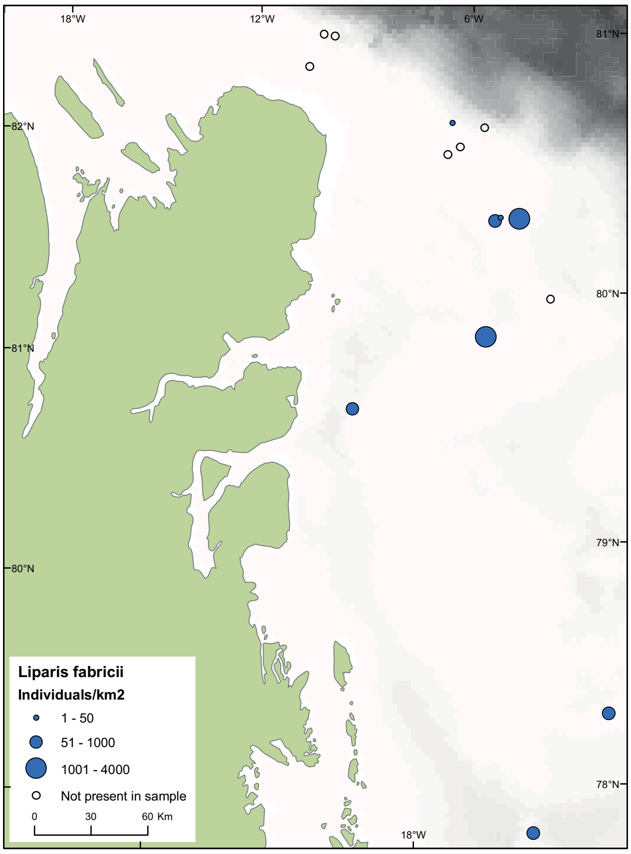


Figure 33. Occurrence of some abundant fish species in the northern part of the assessment area in 1990 (Dorrien 1993); dots represent sampling stations. *Boreogadus saida* = polar cod and *Arctogadus glacialis* = Arctic cod.

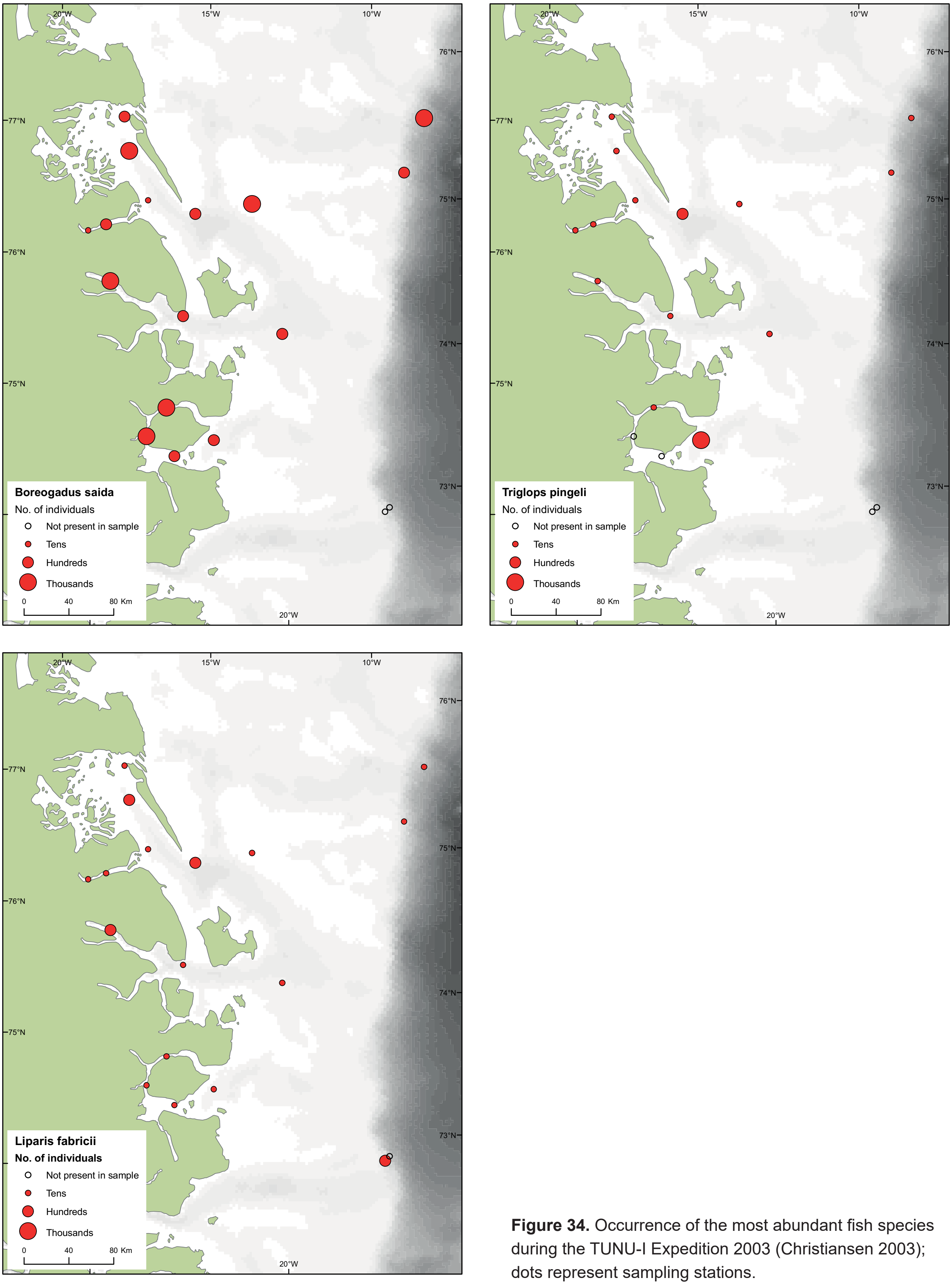


Figure 34. Occurrence of the most abundant fish species during the TUNU-I Expedition 2003 (Christiansen 2003); dots represent sampling stations.

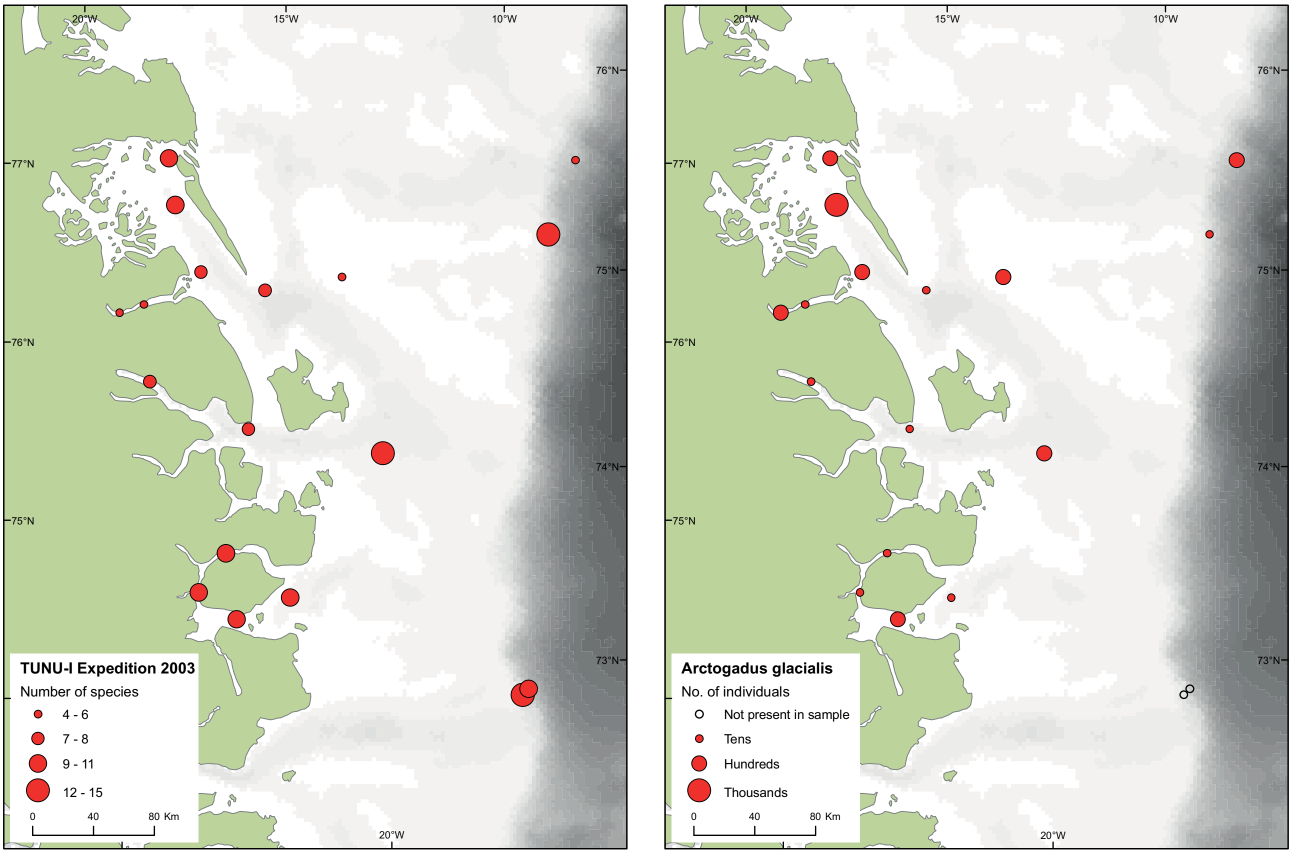


Figure 34. See legend on page 82.

3.6.2 The 2017 survey

The fish fauna was studied during the *Strategic Environmental Study Program for Northeast Greenland* carried out on the Northeast Greenland shelf in the northern part of the assessment area in August/September 2017. Bottom trawling was performed for 30 min. at 10 stations in depth ranging between 194 and 1010 m.

In total, 36 species of fish were recorded (Jørgensen et al. 2019). Polar cod was by far the most common species and constituted 67.8% of the fish biomass and was caught at all stations except two deep stations with water depths of 1010 m and 567.5 m. The length ranged from 5 to 23 cm with a mode at 14 cm and the age ranged from 1 to 4 years. Sexual maturation starts already at age one, and all examined specimens were maturing, indicating that spawning takes place every year. Polar cod is probably relatively stationary which implies that spawning takes place within the survey area. See also section below.

The small sculpin species *Triglops nybelini* and *Artediellus atlanticus* were also relatively abundant at depths down to 394 m.

Species of commercial interest were only caught in small numbers. In total, 104 redfish were recorded (5-27 cm, most of them < 11 cm). Furthermore, 10 Greenland halibut (10-52 cm), 18 American plaice (21-46 cm) and one Atlantic cod (6 cm) were caught.

The catches of shrimps were recorded in 9 of the 10 valid hauls. In total, 10 different species from four families were noted. Crangonidae was the most abundant family with four species and generally also the most abundant family in weight and numbers. Northern shrimp *Pandalus borealis* (the commercial species) was found in 8 out of 9 hauls, but in low numbers.

Another part of the environmental studies included sampling of fish and fish larvae (ichthyoplankton) in the water column. Ichthyoplantkon sampling comprised 36 net deployments at 25 stations. Eight midwater trawl hauls were deployed at different stations and in different layers chosen to ground-truth acoustic signals seen on real-time echograms (see acoustic section below) (Bouchard 2020).

In total, 862 fish larvae were collected and identified to species level, or to the highest taxonomical level possible. The ichthyoplankton was composed of 53% of the Gadidae, polar cod and Arctic cod (which at this stage are extremely similar and can only be identified using genetics or otolith microstructure analysis, Bouchard et al. 2013), 29% *Triglops nybelini* and 17% *Liparis fabricii*. Two specimens of *Gymnocanthus tricuspis* were also captured. The Cottidae and Liparidae were dominant on the shelf, while the Gadidae dominated the assemblages on the continental slope and offshore.

With very few species, the taxonomical composition of the larval and juvenile fish assemblages collected during the 2017 study was similar to that of another survey carried out in the Greenland Sea in 1993 (Michaud et al. 1996). However, the early life dynamics of polar cod may have changed since then. Considering the size range of the individuals collected in the present study in relation to the capture dates and growth rates typical of the species in the circumpolar Arctic (Bouchard & Fortier 2008, 2011), it appears that the hatching season was from mid-March to mid-July in 2018, compared to mid-May to the end of July in 1993 (Fortier et al. 2006).

A total of 12 taxa were collected in the midwater trawl: The lanternfish *Benthosema glaciale* (Myctophidae), *Liparis fabricii* (Liparidae), *Triglops nybelinii* (Cottidae), polar cod, Arctic cod, Atlantic cod, unidentified Gadidae – and the invertebrates *Gonatus fabricii* (squid), *Parathemisto libellula* (amphipod), *Periphila periphila* (jellyfish) and *Meganyctiphanes norvegica* (krill) and unidentified krill species (Euphausids).

The most abundant fish species collected was the lanternfish. The other fish species collected in the pelagic trawl corresponded to the species captured as larvae and juveniles: polar cod, *Triglops nybeli*nii and *Liparis fabricii*. Krill (Euphausids) was the species collected in the highest biomass in the midwater trawl and was also collected in large quantities among the ichthyoplankton.

Acoustic surveys

A Simrad EK60 hull-mounted split-beam echosounder operating at frequencies of 18, 38 and 120 kHz was recording continuously during the 2017 cruise. The real-time echograms were scrutinized each day between UTC 6:00 and 18:00 whenever the ship was transiting between stations. Two dedicated ten-hour surveys were also carried out in the southern and eastern parts of the sampling area.

The midwater trawl deployments provided opportunities for associating echo patterns with specific organisms in the water column. For example, at station 14 at a depth of max. 455 m the thick scattering layer between approx. 300-500 m was the typical acoustic signature of lanternfish aggregations. This scattering layer was present every time the ship was in water depths greater than approx. 400 m.

Another typical acoustic pattern that could be associated with a specific species consisted of multiple, thin, often strong scattering layers in approx. 50-150 m depth. These were associated with the squid *Gonatus fabricii*.

The acoustic data from the surface waters confirmed the results from the ichthyoplankton nets showing the highest densities of fish larvae (especially Gadidae) in the northeastern part of the study area. This area also appeared as a region of relatively high biomass for the entire water column. The area encompassed the shelfbreak, a habitat polar cod is known to occupy in other Arctic regions, such as the Beaufort Sea (Geoffroy et al. 2016, Parker-Stetter et al. 2011).

The acoustic data also showed the lanternfish aggregations are ubiquitous in deep areas and provided further support to the notion that upwelling at the shelfbreak is a feature that enriches surface waters with nutrients and support relatively high biomass of phyto-, zoo- and ichthyoplankton, and create local pelagic "hotspots".

3.6.3 Important species

Polar cod

Polar cod play a very important role in the Arctic marine food web and constitute an important prey for many marine mammals and seabird species (see species descriptions below), notably ringed seal, harp seal, thick-billed murre, northern fulmar, black-legged kittiwake and ivory gull. Polar cod was the most abundant fish species recorded in the 2017 study (see above).

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

Polar cod spawn fairly large eggs in ice-covered waters in winter, November-March (Hop & Gjøsæter 2013, Narhgang et al. 2015). The eggs float under the ice or in open waters during a long incubation period. The larvae hatch over a long period of time between late winter and late summer (Bouchard & Fortier 2008, 2011, Bouchard et al. 2016), and feed in the surface waters until they reach a length of approx. 35 mm. They then migrate down in the water column and join the adult population in deep overwintering grounds.

Polar cod is largely a zooplankton-feeder eating copepods and pelagic amphipods (Panasenko & Sobolova 1980, Ajiad & Gjøsæter 1990). As they grow larger, they also take small fish. In coastal waters, they feed on epibenthic mysids (Cohen et al. 1991) and in the ice, they take ice-associated amphipods (Hop et al. 2000).

Arctic char

Arctic char is the most northern ranging freshwater fish and it is found throughout the circumpolar region. It is widespread in Greenland including in the most northern areas (Muus et al. 1990). Arctic char occur in different life history types. Resident populations live their whole lives in lakes and rivers, while anadromous populations migrate to the sea during summer to feed and move back to rivers and lakes in the autumn to spawn and winter. Arctic char constitute an important resource for many Arctic communities, e.g. in Greenland (Rigét & Böcher 1998).

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

The eggs of the char are deposited during the autumn in gravel in deep river pools or in lakes. The fry emerge in April–May and live off their yolk sac for about a month before feeding on small plankton organisms along the margins of rivers or lakes (Muus et al. 1990). The young char called 'parr' remain in freshwater for several years before their first migration to the sea. At length 12–15 cm, corresponding to an age of 3 to 6 years depending on growth conditions, they begin their annual migration to the sea (Rigét & Böcher 1998). The young char undergo morphological and physiological changes that make them able to live in saltwater. The seaward migration generally coincides with the spring freshet (river flush resulting from spring snow and ice melt), which occurs in May-June, depending on the latitude. After their first seaward migration, the char return to rivers and lakes to winter and spawn. The anadromous char mature at a size of 35–40 cm (Muus et al. 1990), corresponding to an age of 5–7 years.

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

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

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

There are several rivers in the assessment area where Arctic char are known to spawn (Figure 35) but there are probably many more rivers with Arctic char, although no comprehensive overviews are available.

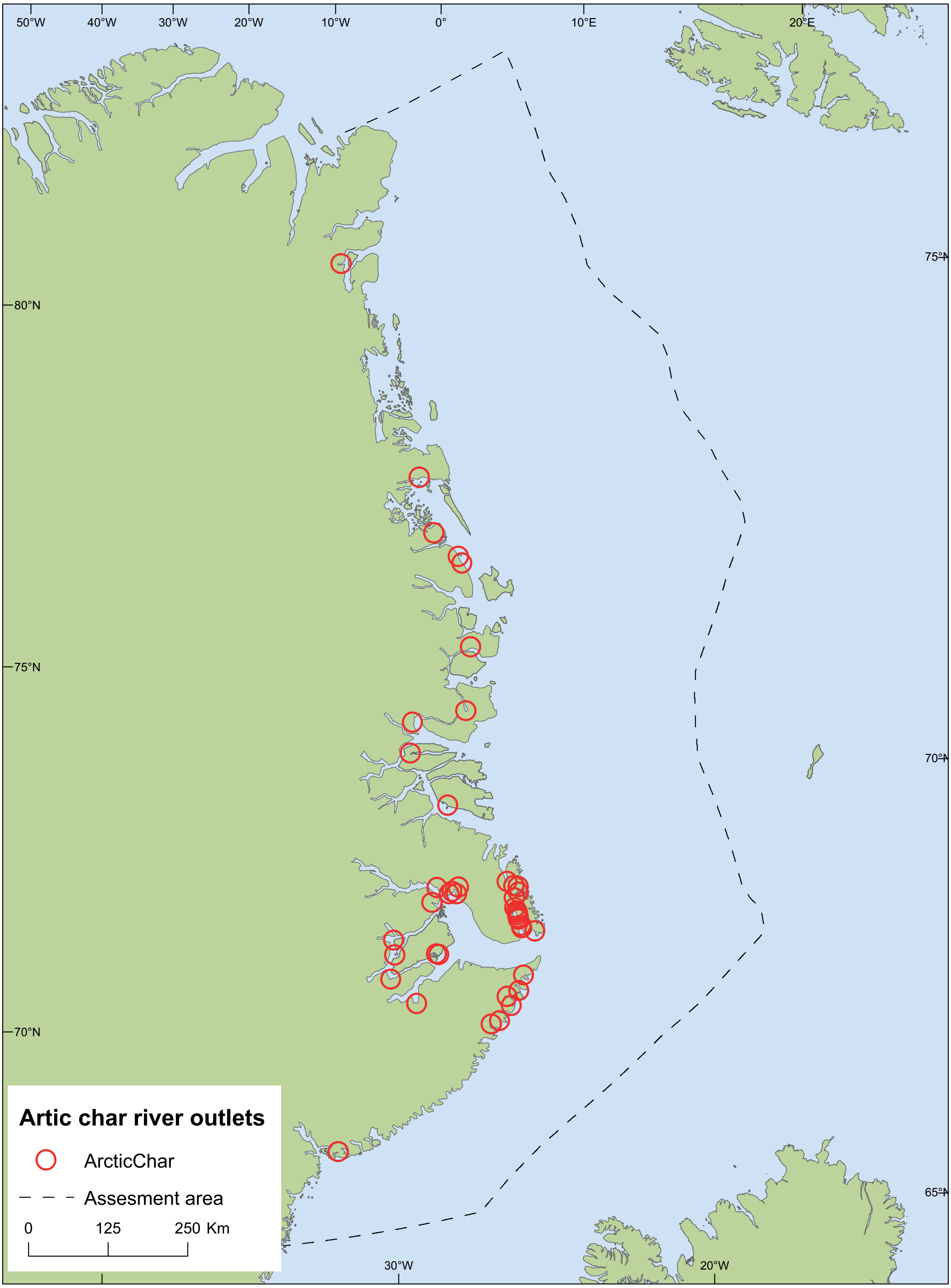


Figure 35. Outlets of rivers where anadromous Arctic char spawn and winter (red circles); there are probably many more rivers with Arctic char in the assessment area, but no comprehensive reviews have been published. Data sources: Grønlands Fiskeri- og Miljøundersøgelser (1986), Sandell & Sandell (1991), Petersen (1993), Mikkelsen (2008), Rysgaard et al. (1998), Aastrup et al. (2005), DCE unpubl.

Capelin

The capelin is a small pelagic schooling fish. It is a cold-water species that occurs widely in the northern hemisphere. The capelin in the Iceland-East Greenland-Jan Mayen area is considered to be a separate stock that spawn in waters off west and south Iceland and undertakes extensive feeding migrations north into the cold waters of the Denmark Strait and Iceland Sea during summer.

Around the mid-1990s, a rise in both temperature and salinity was observed in the Atlantic water south and west of Iceland. In the same period, capelin shifted both their larval drift and nursing areas far to the west to the colder waters off East Greenland (Carscadden et al. 2013). The arrival of adults on the wintering grounds on the outer shelf off North Iceland was delayed, and migration routes to the spawning grounds off south and west Iceland became moved farther offshore from North and East Iceland, and do not reach as far west along the south coast as was the rule in earlier years (Figure 36).

Total annual catch from this stock has decreased in recent years from 1,600,000 tonnes in 1996/1997 to 200,000 tonnes in 2007, followed by only 15,000 tonnes in 2009, 150,000 tonnes in 2010, 765,000 tonnes in 2011 and then decreasing to 0 t in 2018 and 2019 (https://www.fishsource.org/stock_page/752).

Capelin also spawn in intertidal and subtidal waters in Southeast Greenland, and these fish may belong to another stock or to several local stocks. The northernmost spawning sites were until recently at Tasiilaq (south of the assessment area), but in recent years spawning has been confirmed in the Scoresby Sund area (GINR unpublished).

The capelin is a key forage fish in low Arctic and northern boreal ecosystems. With climate warming it can be expected that the species extend the spawning sites further north in East Greenland.

Greenland halibut

The Greenland halibut is a sub-Arctic and Arctic species. Although a flatfish, spending most of its life on the bottom, it makes frequent migrations into the water column to feed, and it occurs typically in deep water along continental slopes. It is often found in the vertical, transitional layers between warmer and colder water masses at temperatures of 1-2° C (Alton et al. 1988, Godø &

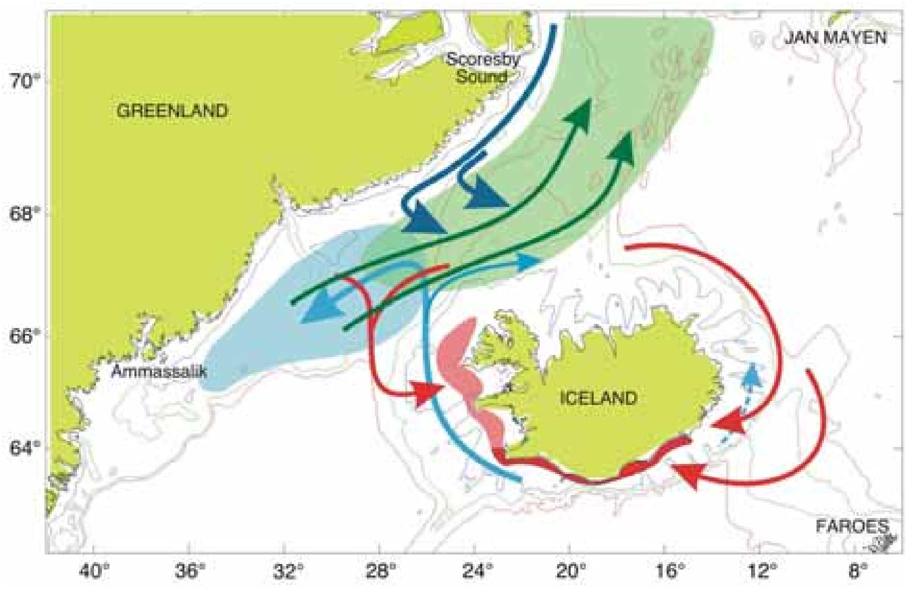


Figure 36. Likely changes of distribution and migration routes of capelin in the Iceland/Greenland/Jan Mayen area in the years 2005-2008. Green: Feeding area; Light blue: Area for juveniles; Red area: Main spawning grounds; Lighter red colour: Lesser important spawning areas; Light blue arrows: Larval drift; Dark green arrows: Feeding migrations; Dark blue arrows: Return migrations; Red arrows: Spawning migrations. Depth contours are 200, 500 and 1000 m (ICES 2008).

Haug 1989, Bowering & Brodie 1995). Greenland halibut spawns a large number of pelagic eggs over an extended period during winter (August-May). The eggs have a long maturation period, and they and the larvae drift with the currents to nursery areas.

The Greenland halibuts in the assessment area may belong to the Iceland/Greenland stock also found further south in the Denmark Strait. Small (less than 20 cm long) Greenland halibut are rarely found in the assessment area – a total of ten were caught during the 2017 survey (see above). The nearest known nursery ground is east of Svalbard, and there seems to be a spawning site at a bank at 62° N off Southeast Greenland (Gundersen et al. 2011). How juvenile fish from these sites distribute after hatching is not known. However, due to the prevailing current system it is plausible that there is a net transportation of juvenile pelagic Greenland halibut from the Norwegian nursery areas into the area being assessed in this report.

In 2006, a bottom trawl survey covered the offshore area from 67° to 72° N and the outer part of Scoresby Sund fjord at depths down to 1500 m (Jørgensen et al. 2007). Greenland halibut was caught in the entire area. Apart from the sampling that took place in the same areas where commercial fishing is ongoing (Figure 73), catches were generally low. The species was almost absent in areas with bottom temperatures below zero, which were in the southeastern part of the survey area. In 1988 in the same offshore area a joint Japan/Greenland survey also caught Greenland halibut in most of the area. The catches were generally small except a few large catches in the southern part of the area (Jørgensen & Akimoto 1990).

Other species

The 2006 bottom trawl surveys in the southern part of the assessment area have proved the presence of several species of potential economic interest e.g. capelin, roughhead grenadier, Atlantic cod and polar cod; only Greenland halibut were found in higher concentrations (Jørgensen et al. 2007). A proportion (2.4-12%) of Atlantic cod offspring transported into the open ocean from the Barents Sea drifts to the northeast Greenland shelf, and discoveries of young cod on the northeast Greenland shelf indicate that conditions may support survival for Northeast Arctic cod offspring (Strand et al. 2017).

The predicted climatic changes with higher temperatures, less sea ice and an increase in freshwater discharges into the fjords will probably lead to a change in the ecosystem favouring species of more commercial interest such as Atlantic mackerel and Atlantic herring. In 2010 a research quota was given for exploratory fishing of these species off Southeast Greenland waters and a mackerel fishery has developed here since 2014 (Jansen et al. 2016).

3.6.4 Important areas and potential anthropogenic impacts - fish

In case of an oil spill, the river mouths and their adjacent coastal areas, where migrating Arctic char assemble before they move upstream, are the most sensitive habitats. The published knowledge on these sites in the assessment area is fragmented, and there is no doubt that many more sites than shown on the map (Figure 35) are important to Arctic char.

Subsurface spill from the seabed may have the potential to impact ichtyoplankton, but more knowledge on aggregations and their spatial distribution is needed.

Polar and Arctic cod eggs assemble below the sea ice where they may be exposed to accumulations of oil. Narhgang et al. (2016) showed that polar cod eggs had a high sensitivity to realistic post spill oil concentrations in the water. Hence, a spill accumulation under the sea ice in late winter/early spring could potentially cause severe impacts on the population, with cascading effects up in the ecosystem as these cod species are key species. However, there is no information on where and how concentrated spawning polar and Arctic cod occur in the assessment area.

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

3.7 Seabirds

David Boertmann (AU)

Seabirds are an important component of the ecosystem of the assessment area, and they show wide variation in abundance within the area and through the year. In the breeding season (summer), they assemble in colonies along the coasts and particularly at the large polynyas high numbers are found. Most pronounced in the mouth of Scoresby Sund, where millions of little auks breed in numerous colonies and where two colonies of thick-billed murres are located. At the Northeast Water there are large colonies of northern fulmar and ivory gulls have their primary breeding area in Greenland here, while kittiwakes and common eiders breed in high numbers at the Sirius Water. These birds utilise the adjacent waters up to 100 km from their nests. A study in 2017 and 2018 focused on the habitat use of Sabine's gull and ivory gull, and showed that the Sabine's gulls were feeding in waters close to the breeding site (30-40 km), while ivory gulls were feeding up to 500 km from their nest sites. The little auks perform a moult migration from the breeding colonies to the shelf and shelfbreak off Northeast Greenland, where they occur in dense concentrations. In autumn, and probably also spring, densities of seabirds on the shelf are generally low but little auks in particular may occur in high density spots, where the birds moult after the breeding season. Such high-density spots were especially frequent at the shelfbreak in August/September 2017. Almost all birds leave the assessment area for the winter.

Seabirds can locally be very numerous in the assessment area and they constitute an important link between the productive marine ecosystem and the relatively low productive terrestrial ecosystem, as they transport nutrients from the sea to the land around the breeding colonies. About 17 species breed within the assessment area; some are very numerous and occur in very high concentrations while others are rare and/or occur in low numbers and very locally. The occurrence of the seabirds is governed by the production in the sea and the presence of sea ice, which explains why they can be scarce in large regions during summer, and almost absent in winter but, on the other hand, very numerous in areas with high production and predictable open waters in spring and summer.

Knowledge on birds associated with the marine environment varies between regions in the assessment area. Some coastal areas are well known from the reports of natural history expeditions since the late 19th century (Bay 1894, Manniche 1910, Degerbøl & Møhl-Hansen 1935, Pedersen 1926, 1930, 1934, 1942, Meltofte et al. 1981a, Hjort 1976, Hjort et al. 1983, Elander & Blomqvist 1986) and from work carried out by local residents (Meltofte 1975, 1976, Forchhammer 1990, Forchhammer & Maagaard 1990), while other areas have not have not been visited by ornithologists (Boertmann et al. 2020). The offshore areas are less known than the coastal areas. Norwegian surveys have studied the waters between Svalbard and Greenland (Mehlum 1989) in summer, and in the early 1990s extensive studies were carried out in the Northeast Water Polynya, including bird studies (Falk & Møller 1995, 1997, Falk et al. 1997a, Joiris et al. 1997). However, reports from the migration periods and the winter are very few (e.g. Hjort 1976, Brown 1986, Petersen 1995, Byrkjedal & Madsen 2008). This lack of knowledge was addressed in August/September 2017 when several bird studies were carried out in the assessment area as a part of the *Strategic Environmental Study Program for Northeast Greenland* carried out in 2016-2019 (see below).

When the previous version of this SEIA (Boertmann & Mosbech 2012) was prepared, DCE and GINR conducted aerial surveys of seabird along the coasts and in offshore areas in spring and summer of 2008 and again in the summer of 2009, supplemented by seabird observations from ship-based seismic data acquisition surveys and some fish research surveys. For this updated SEIA, data from surveys up to 2017 were also included (see overview of survey transects in Figure 42A).

Finally, Norwegian seabird researchers published maps with the distribution of tracked seabirds from several colonies in the northwest Atlantic area (mainland Norway, Svalbard, Iceland, Scotland and Russia) on their Seatrack-webside (Link). Many of the tracked birds stayed in or moved through the assessment area, and this information is included in the following accounts.

Most of the seabirds in the area are colonial breeders, i.e. many pairs breed in very restricted areas. The largest breeding concentrations of seabirds are found on the coasts of the Scoresby Sund Polynya (see map of main polynyas in Figure 12), where an estimated 3.5 million little auks breed in a large number of colonies on the Liverpool Land coast and the Volquart Boon Kyst (Figure 37) (Kampp et al. 1987). This area also holds the only breeding sites for thick-billed murre in East Greenland (Figure 37). The second most important polynya for seabirds is the Northeast Water (NEW) in the northern part of the assessment area that holds significant seabird breeding colonies, mainly northern fulmars and common eiders, but also the rare species ivory gull which has a stronghold here with numerous colonies on the coasts. A third important polynya is the waters east of Wollaston Forland, the Sirius Water Polynya (Pedersen et al. 2010), where large numbers of particularly eiders occur.

Besides the true seabirds, a number of species utilise the marine environment during critical phases of their annual life cycle. These are species utilising freshwater habitats during breeding time: divers and ducks. They depend on coastal habitats with early ice break-up, for example coastal polynyas, river outlets and narrow straits with strong tidal currents. Such sites are presumed to hold concentrations of both migrant seabirds and inland waterbirds – red-throated diver, king eider, long-tailed duck, and perhaps red phalarope – waiting for lakes and freshwater habitats to become accessible after the winter.

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

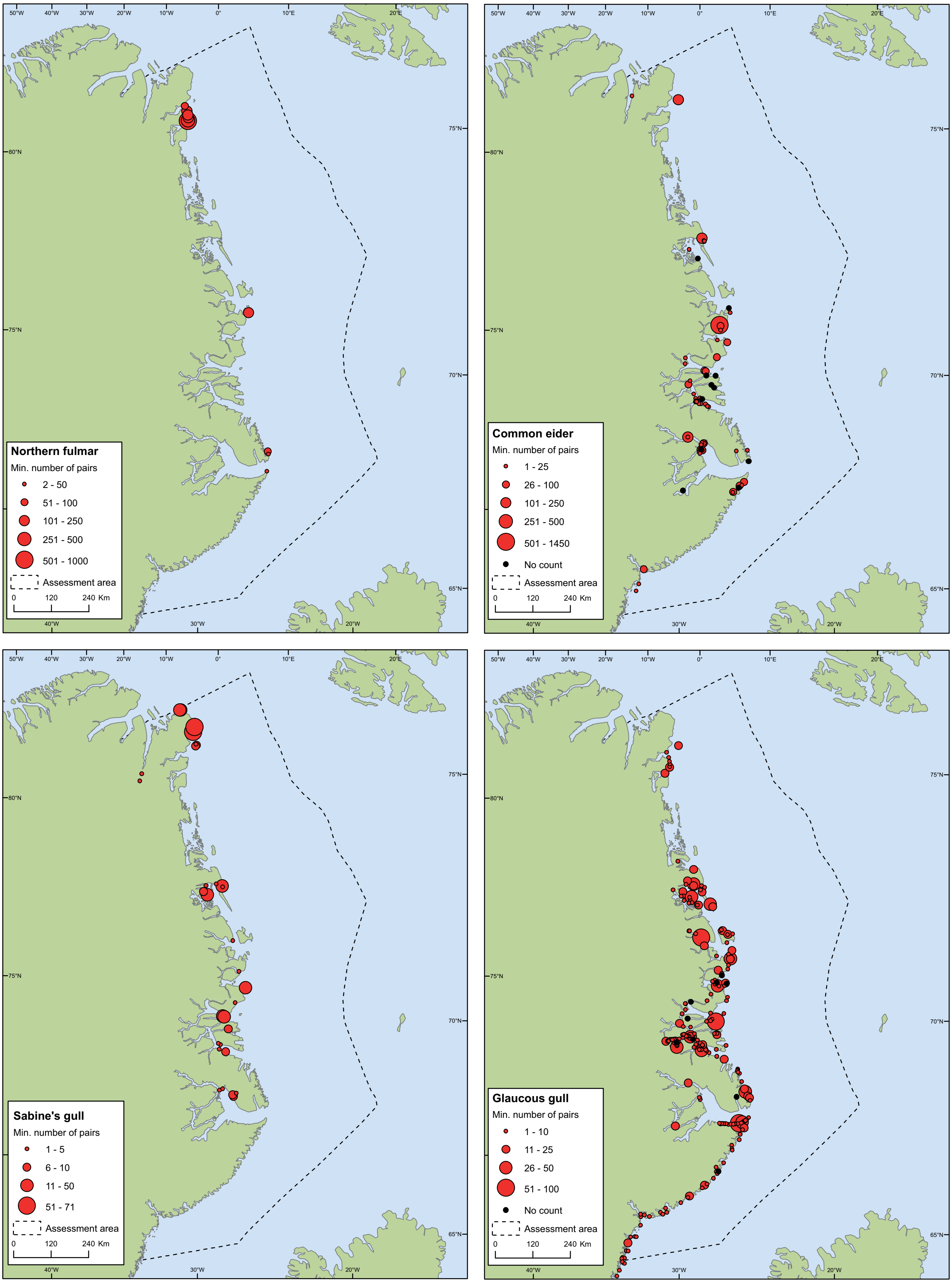
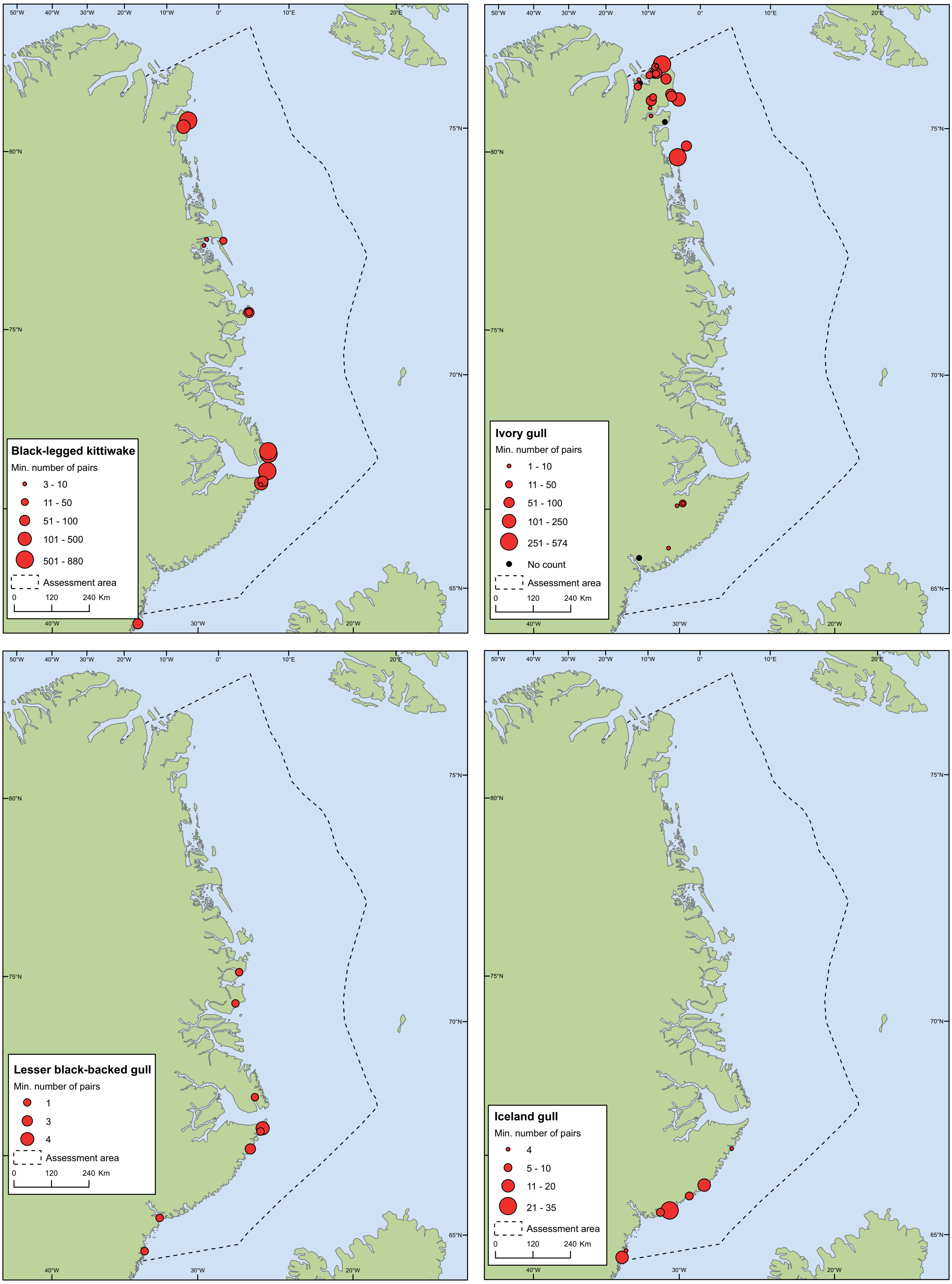


Figure 37. Distribution and size of breeding colonies for seabirds in the assessment area. The size of the little auk colonies in and near the entrance to Scoresby Sund is not known, but the population was estimated at 3.5 million pairs in 1985.



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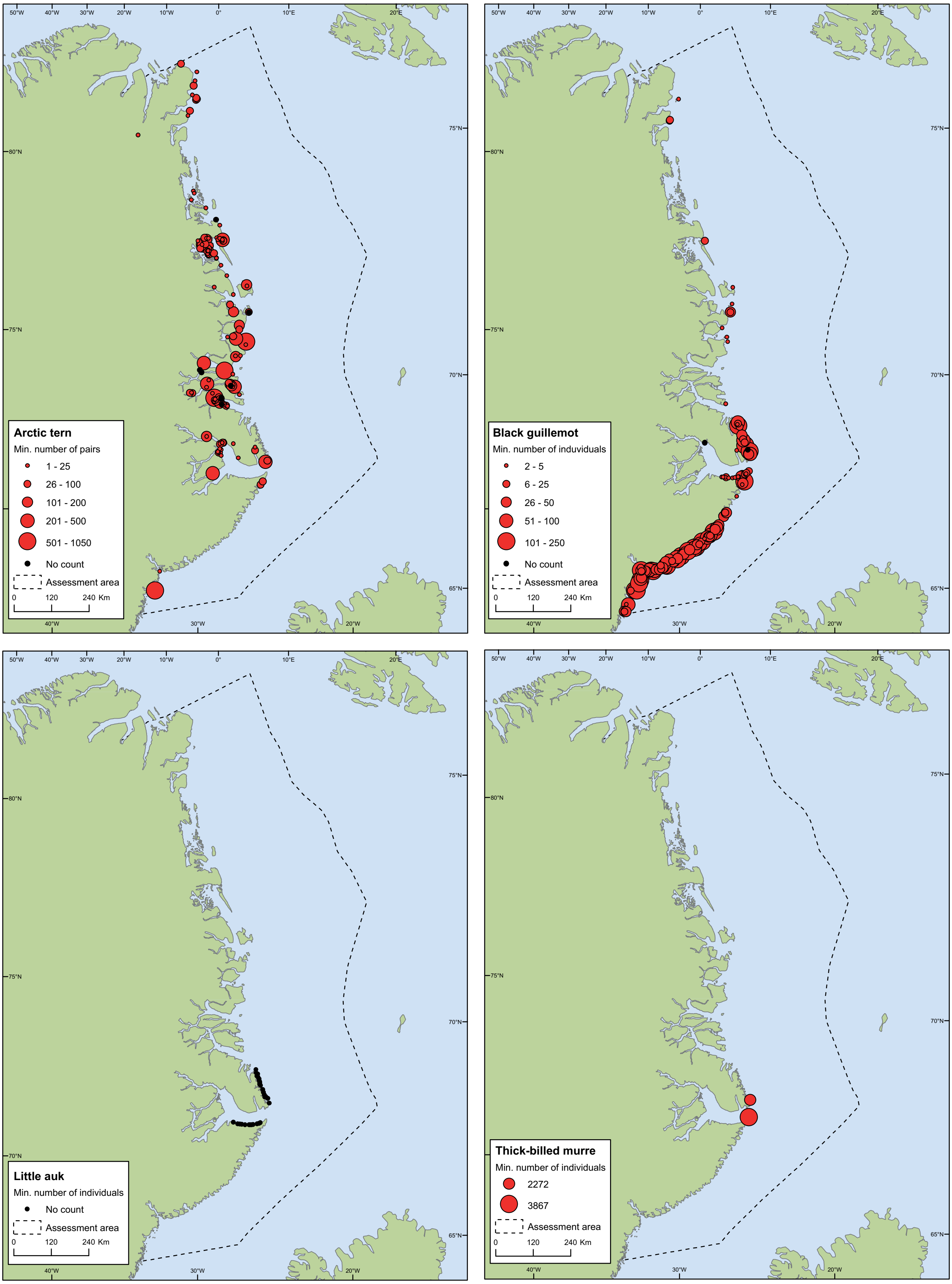
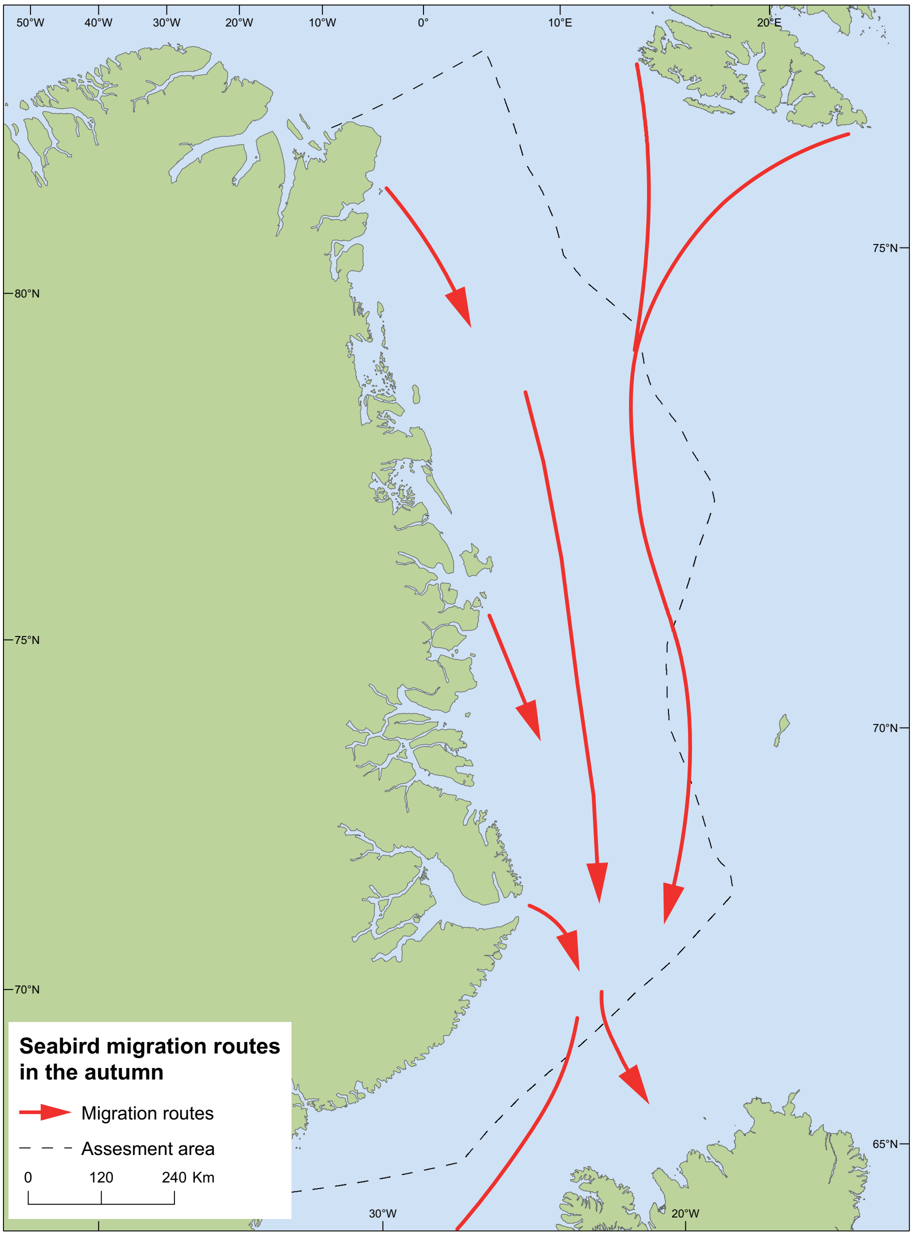


Figure 37. See legend on page 104.

Figure 38. Expected autumn migration routes for seabirds in the assessment area. At least 2 million little auks, 2 million thick-billed murres, an unknown number of black guillemots and probably thousands of ivory gulls migrate through or along the eastern margin of the assessment area each year. The main source is the big colonies at Svalbard, but also birds from Arctic Russia may follow these flyways through the assessment area. In addition to these extralimital breeding birds, the populations breeding within the assessment area move out for the winter – to Iceland (common eider), the waters off Southwest Greenland and Labrador/Newfoundland, and further away (see Boxes 3.3 - 3.11).



In autumn, large numbers of seabirds from Svalbard and Russian Arctic move to winter quarters off southwest Greenland and Newfoundland. These were expected to pass through the assessment area, but the 2017 studies showed that at least the thick-billed murres stay east of the shelfbreak and only move across a marginal part of the area (Figure 38). The threatened ivory gull also use this migration pathway, but over the shelf and within the drift ice (Hjort 1976b, Bensch & Hjort 1990, Byrkjedal & Madsen 2008). Ivory gulls from all the northeast Atlantic populations (Greenland, Svalbard, Russia) move through the area (Gilg et al. 2010). High numbers of black guillemots may also use this flyway (Bensch & Hjort 1990, Byrkjedal & Madsen 2008). The results of the surveys in 2017 indicated that at least the thick-billed murres actually avoided the shelf and confirmed that little auks occurred there in high numbers.

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

An overview of the seabird species occurring in the assessment area is given in Table 4.

Besides the published accounts, unpublished data from the many seismic surveys which have taken place in the waters off Northeast Greenland are included. The Marine Mammal and Bird Observers (MMSO) shall submit their data to a database with offshore observations of seabirds and marine mammals kept at Aarhus University, and so far data from 1995, 2006, 2007, 2009-2017 are included (Figure 42).

The *Strategic Environmental Study Program for Northeast Greenland* carried out in 2016-2019 included following seabird studies:

- *Offshore seabird concentrations in the Greenland Sea*. This included both aerial and ship-based systematic surveys of offshore seabirds in August and September 2017 (see Box 3.3).
- *Population size and habitat use of breeding seabirds in Northeast Greenland*. This included tracking studies of Sabine's gulls and ivory gulls, and breeding ecology studies of little auks (see Boxes 3.5-3.7). It also included a survey of ivory gull colonies in July/August 2019 and an aerial photo survey of the little auk colony in order to map the distribution.

3.7.1 Important bird species occurring in the assessment area

This section gives an account of important birds in the assessment area. See also Table 4, which lists a number of important species.

Northern fulmar

Breeding distribution: Small breeding colonies are located in and near the mouth of Scoresby Sund. Compared with colonies in other part of the north Atlantic, these are small and hold up to a few hundred pairs (Meltofte 1976). A few colonies have been claimed further north along the coast, at Hvalros Ø (Stemmerik 1990) and Home Foreland (Bay & Boertmann 1989) but have not been confirmed at later visits (Boertmann et al. 2020). However, much larger concentrations of breeding fulmars occur at the Northeast Water shores where more than 1475 pairs were estimated in six colonies on the coasts of

Table 4. Overview of selected species of birds from the assessment area. b = breeding, b? = perhaps breeding, s = summering, w = wintering, m = moulting, mi = migrant visitor, c = coastal, o = offshore. Importance of study area to population indicates the significance of the population occurring within the assessment area in a national and international context as defined by Anker-Nilssen (1987).

Species	Occurrence		Habitat	Red-list status in Greenland	Importance of assessment area to population
Northern fulmar	b/s/w	year-round	c & o	Least Concern (LC)	Low
Brent goose	b	summer	c	Near Threatened (NT)	High
Common eider	b/m	summer	c	Least Concern (LC)	High
King eider	b/m	summer	c (in spring)	Least Concern (LC)	Medium
Long-tailed duck	b/m	summer	c (in spring)	Least Concern (LC)	Medium
Grey phalarope	b/mi	summer	c (in spring)	Least Concern (LC)	Low
Pomarine skua	s	summer	o	Least Concern (LC)	Low
Arctic skua	b	summer	c	Least Concern (LC)	Low
Black-legged kittiwake	b/s/mi	summer	c & o	Vulnerable (VU)	Low
Glaucous gull	b/s/mi	summer	c	Least Concern (LC)	Low
Sabine's gull	b	summer	c	Near Threatened (NT)	Medium
Ross's gull	b/s	summer	c & o	Vulnerable (VU)	Low
Ivory gull	b/s/w	year round	c & o	Vulnerable (VU)	High
Arctic tern	b	summer	c	Near Threatened (NT)	Medium
Thick-billed murre	b/s/mi	summer	c & o	Vulnerable (VU)	High
Black guillemot	b/s/w	year round	c & o	Least Concern (LC)	Low
Atlantic puffin	b	summer	c & o	Vulnerable (VU)	Low
Little auk	b/mi	summer	c & o	Least Concern (LC)	High

Holm Land and Amdrup Land (Falk et al. 1997a, Falk & Møller 1995, 1997). Breeding birds are present on the cliffs from April and the fledglings leave the nesting ledges in early October (Falk & Møller 1997).

Offshore distribution: Fulmars occur everywhere but in relatively low concentrations in the open-water areas in summer from April at least until October (Meltofte 1975, Bensch & Hjort 1990, Byrkjedal & Madsen 2008). During the ship-based surveys in 1994, 1995, 2006, 2007 and 2009-2017 they were generally widespread but in low densities. Almost the same pattern was apparent during the aerial surveys in 2008, where the highest concentrations were found along the southern ice edge of the Northeast Water Polynya. The results of Norwegian surveys indicate that densities of fulmars are low in the western Greenland Sea compared to the eastern part off Svalbard and the Barents sea, and that the highest concentrations in the western part was located in the Northeast Water (Mehlum 1989, 1997). In early spring (February-April) and, possibly, also in winter, fulmars occur in the open waters east of the drift ice belt (Brown 1986).

The 2017 surveys confirmed this distribution pattern. Fulmars were present in low densities almost everywhere in open waters. They were absent from areas with dense ice, and smaller concentrations were observed here and there. The Norwegian Seatrack data indicate that fulmars from Svalbard, Iceland and NW Europe only to a limited degree are present in the assessment area in the autumn so most of the observed birds may have a local origin.

Conservation status: The fulmar population in the assessment area has a favourable conservation status and there are no apparent threats within the area. The species is not considered as threatened, neither nationally nor internationally (categorised as of 'Least Concern' (LC) on the Greenland and the global Red Lists).

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

Sensitivity and critical areas: The breeding colonies are sensitive to oil spills because many fulmars often rest on the water surface below the breeding cliffs. Recurrent offshore concentration areas are not known but may occur, e.g. along the marginal ice zone in spring. No large offshore concentrations were located during the surveys in 2008 and 2017.

Geese

Geese usually utilise inland habitats, but may stage, moult and feed in coastal habitats of which salt marshes are the most important. There are several species of geese in the assessment area: Snow goose, brent goose, barnacle goose, pink-footed goose and Canada goose. The most important and numerous are pink-footed geese and barnacle geese. Both occur as breeders and in large, non-breeding flocks which spend the summer moulting (Boertmann et al. 2015b). Besides the risk of being exposed to oil spills in the marine habitats, geese are especially sensitive to disturbance during moulting (Mosbech & Glahder 1991). In the northernmost part of the assessment area, brent geese utilise coastal habitats both for moulting and for rearing chicks (Boertmann et al. 2015b). These brent geese belong to a small population (unfavourable conservation status) breeding only in Northeast Greenland, Svalbard and Franz Josef Land. It is categorized as 'Near Threatened' (NT) on the Greenland Red List.

Common eider

Breeding distribution: Breeding common eiders occur along most of the coasts close to the Greenland Sea. Many breed dispersed, but there are also several breeding colonies, some holding thousands of pairs (Figure 37). Most colonies are found on small islands and skerries, while solitary breeders also occur on mainland coasts. The total breeding population is roughly estimated at around 16,000 pairs (Boertmann et al. 2020).

The largest colony known in the area is found at the military outpost Daneborg (up to 3000 nests), where they seek shelter from fox predation among the tethered sled dogs (Meltofte 1978).

Non-breeding occurrence: Common eiders arrive in April and May to the open-water areas of the assessment area (even in the north), and from here they disperse to the coasts as soon as these become ice-free, for example, in early June at Zackenberg and Danmarkshavn (Meltofte 1975, 1976, Hansen et al. 2007). At first, the common eiders assemble in pre-breeding congregations before they move to the breeding sites. At least 2500 common eiders were counted in

Box 3.3

Aerial surveys for seabirds in the Greenland Sea

David Boertmann (AU)

In August and September 2017 an aerial survey for seabirds in the Greenland Sea was conducted as part of the Strategic Environmental Study Program for the Northeastern Greenland area. The aim was to search for concentrations of particularly migrating seabirds, which could be vulnerable to oil spills.

The survey platform was a DHC-6 Twin Otter, and the airstrips at Danmarkshavn and Daneborg was used as bases. The survey period was 24 August to 2 September 2017 and approx. 6000 km were flown along predefined transects spaced with 25 km (Figure 3).

In general few birds were observed. Most numerous and widespread were northern fulmar and black-legged kittiwake (Figure 2). The only species to be found in distinct aggregations was the little auk (Figure 3), which were found in two concentration areas, where they apparently assemble to moult. Arctic terns were seen in several flocks on direct migration. Notably was the complete absence of thick-billed murres. These were expected to occur in the surveyed area, as they migrate in large numbers from their breeding sites in Svalbard to wintering sites off Newfoundland and Southwest Greenland. Apparently, this migration takes place east of the surveyed area.

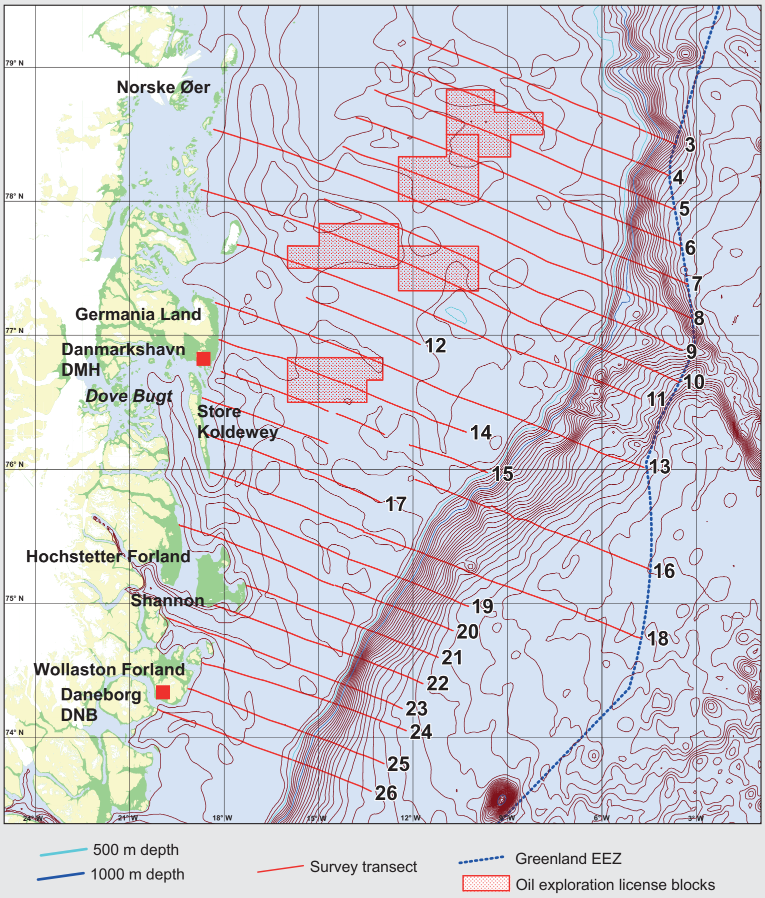


Figure 1. The transects flow during the survey in August and September 2017. The map shows the previous hydrocarbon licences in the centre of the surveyed area.

such pre-breeding flocks off Kilen in Kronprins Christian Land in 1993 (Falk et al. 1997a). During the survey in spring 2008 about 4200 were recorded in this area and more than 10,000 were counted in the Sirius Water Polynya off Wollaston Forland (Figure 39).

Common eiders assemble in moulting flocks during the summer (July). The flocks consist of males and non-breeding females. Meltofte (1976) describes the occurrence of moulting common eiders in the Scoresby Sund area, where the flocks occur from early July. However, knowledge on the distribution and abundance of these moulting birds is very sparse for other parts of the assessment area. The surveys in July/August 2008 and 2009 indicate that moulting common eiders occur in small flocks distributed along the coasts with the highest recorded concentrations in the fjords of the Blosseville Kyst (south of 70°) (Figure 40). During a survey in mid-July GINR (Merkel et al. 2010) also recorded common eiders along the Blosseville Kyst, indicating that they occur in high numbers throughout the entire coast (Figure 41). Satellite tracking of common eiders has confirmed the winter quarters in Iceland and documented the migration routes (see Box 3.4).

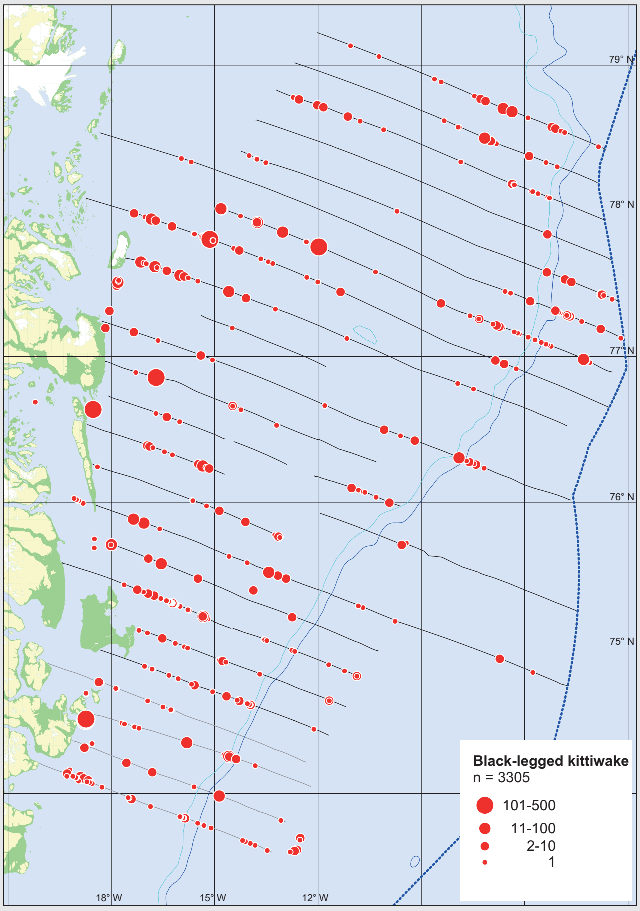


Figure 2. The distribution of observed black-legged kittiwakes. An example of a widespread species.

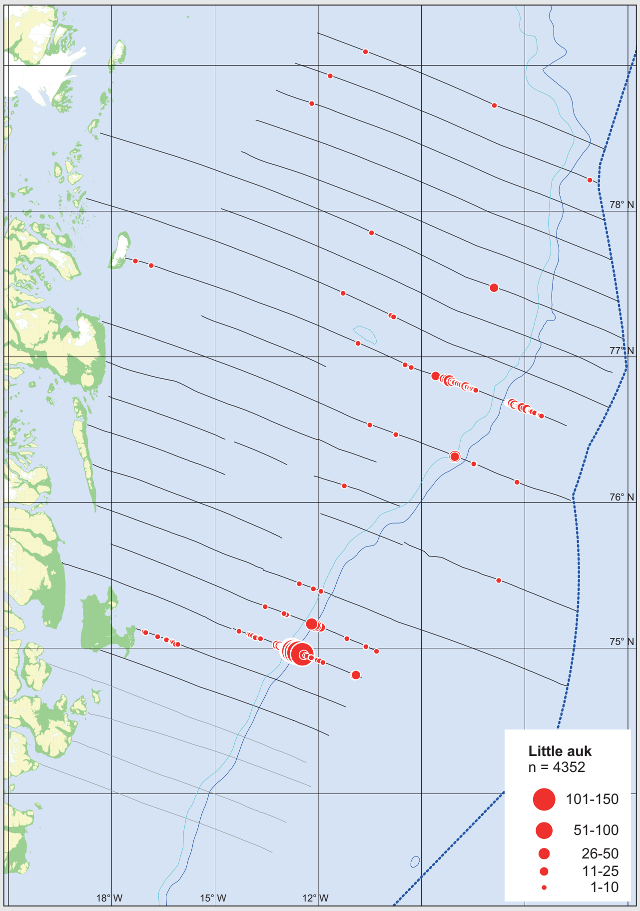


Figure 3. Distribution of observed little auks. An example of a species occurring in a few localised concentrations. Little auks are difficult to survey from the air, because of their small size. The simultaneous ship-based survey observed many mores little auks dispersed over large parts of the surveyed area.

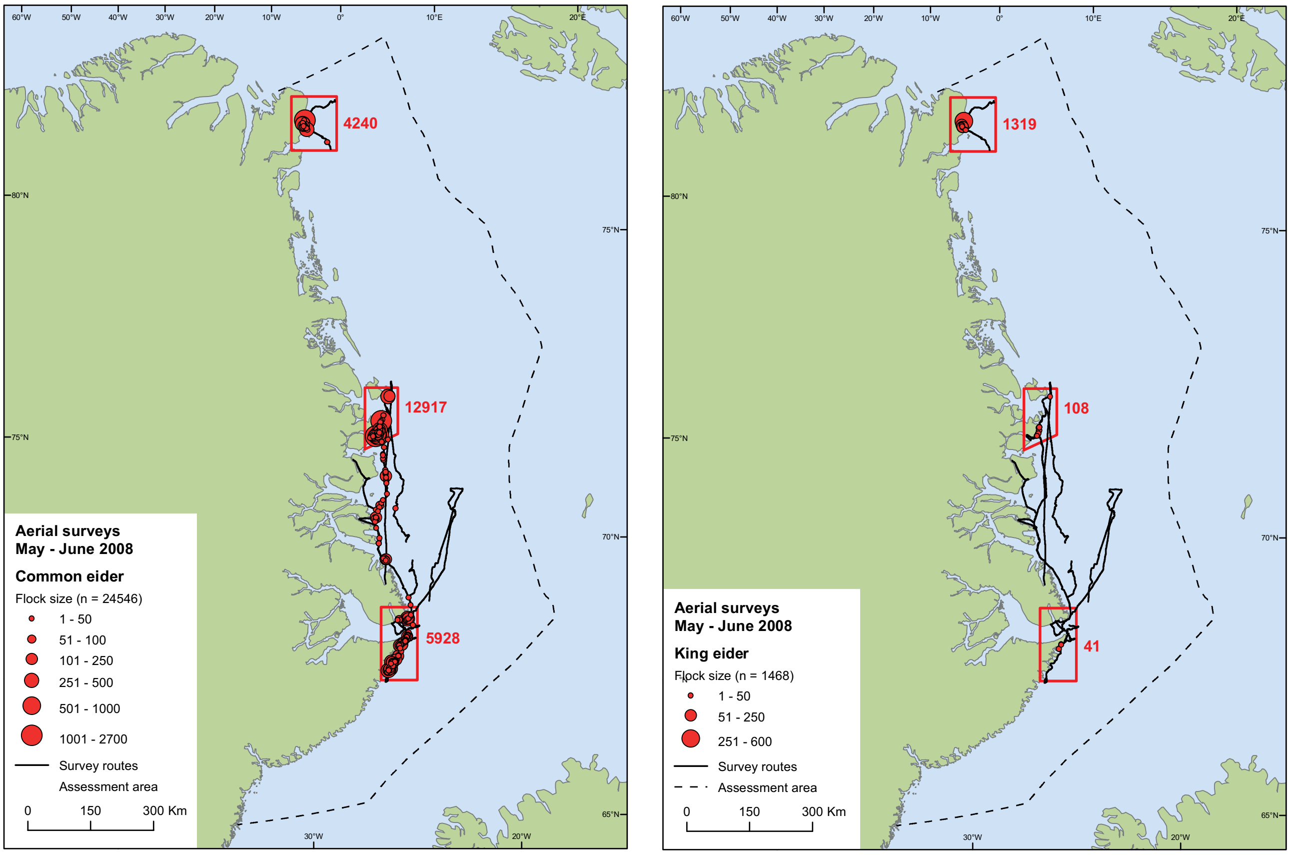


Figure 39. Maps showing the distribution and numbers of common and king eider observed during the aerial survey in May and June 2008; n = the total number of individuals counted during the surveys. The numbers of birds are given inside the framed areas. Black lines show the survey routes (Boertmann et al. 2009).

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

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

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

Black-legged kittiwake

Breeding distribution: Breeding colonies are found at a few sites along the coast of the assessment area. Most (n = 5) are found on the coasts of the Scoresby Sund Polynya with Kap Brewster as the largest numbering about 1300 nests in 2010 (Boertmann et al. 2020). Further north there are three small colonies on Hvalros Ø. In Dove Bugt a few colonies have been noted, although only one seems to be stable over the years. At the Northeast Water Polynya there are two colonies: one with 873 nests in 1993 and another with 200 birds in 2009 (Boertmann et al. 2020).

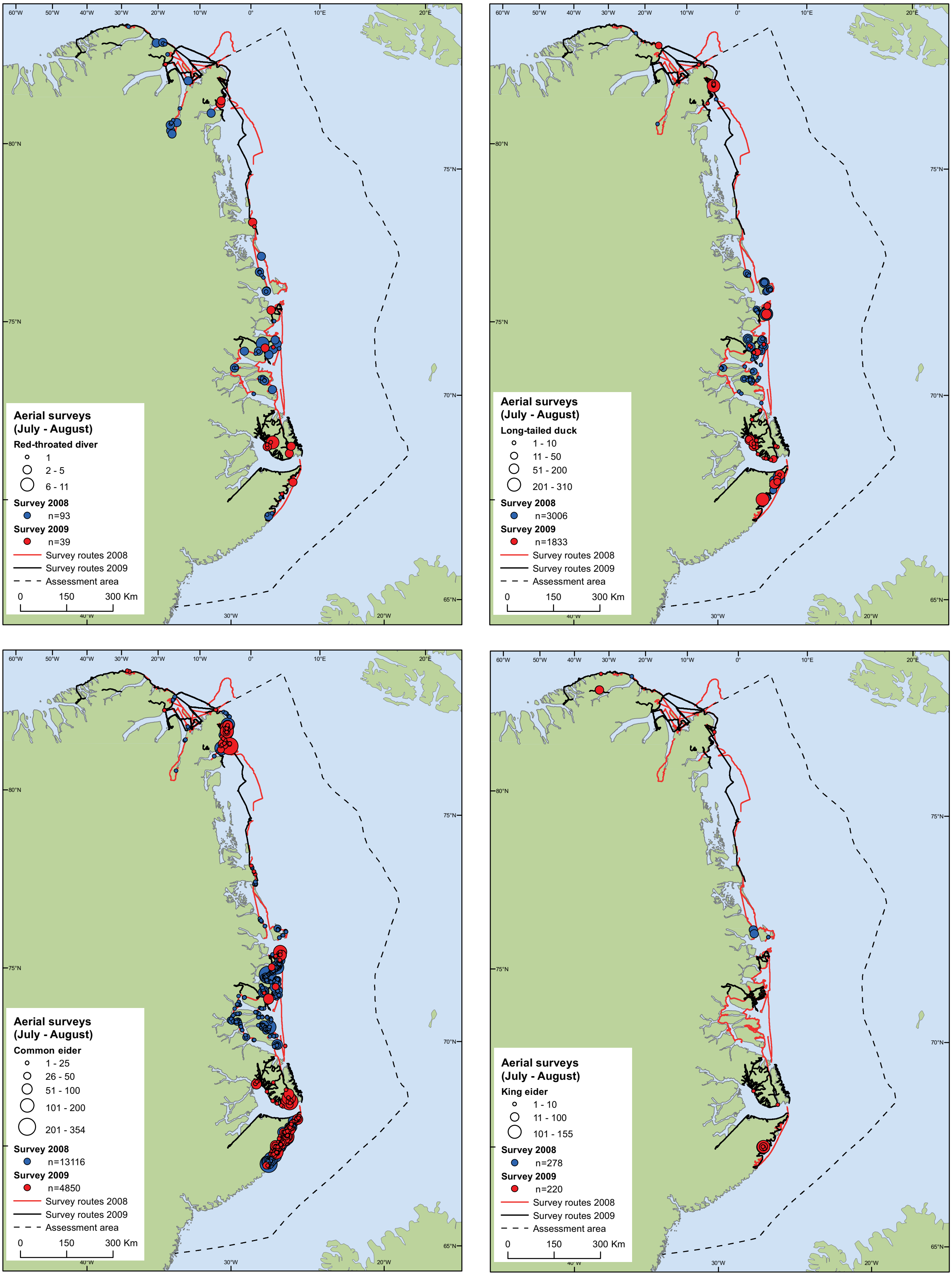


Figure 40. Maps showing the distribution and numbers of red-throated diver, common eider, king eider and long-tailed duck observed during the aerial surveys in July and August in 2008 and 2009; n = the total number of individuals counted during the surveys (Boertmann et al. 2009).

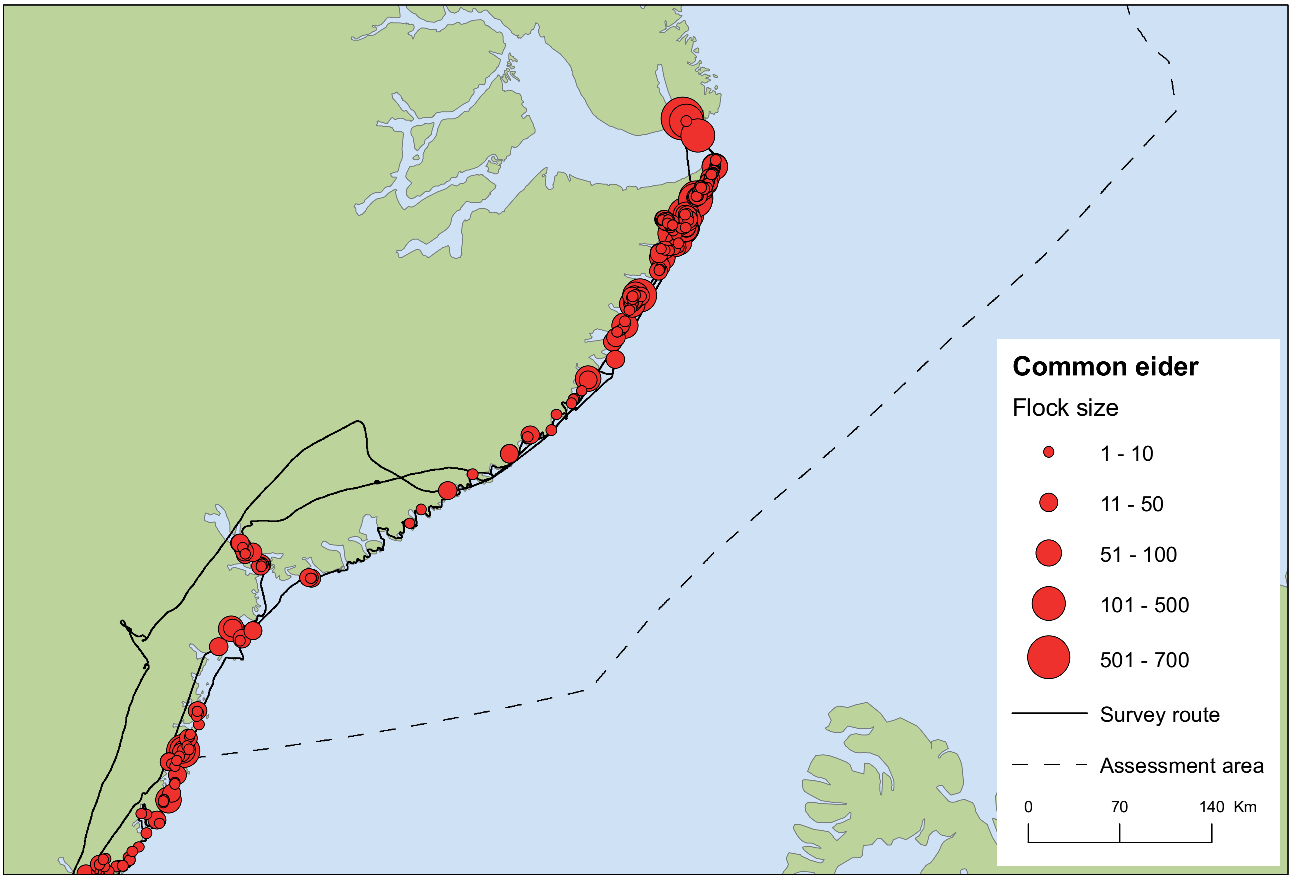


Figure 41. Distribution and abundance if common eider observed during the aerial survey along the Blosseville Kyst 20 July 2008. Black line is the flying route (Merkel et al. 2010).

Offshore distribution: Offshore, non-breeders occur in flocks here and there and occasionally in large concentrations May-September; for example, in the Scoresby Sund Polynya (Meltofte 1976). The Norwegian surveys 1980–1984 found only few kittiwakes in the western part of the Greenland Sea and mainly in the Northeast Water (Mehlum 1989), and during the surveys in July/August 2008 only few were recorded in offshore areas. Low densities were also recorded by the ship-based surveys with some higher densities off the mouth of Scoresby Sund.

The 2017 surveys showed that kittiwakes were widespread, but occurred in low numbers within the surveyed area. Here and there larger flocks (≤ 500) were observed.

The Norwegian Seatrack-data shows that kittiwakes from Svalbard, Iceland and mainland Norway are present in the assessment area in the autumn months.

Kittiwakes are usually absent from the assessment area in winter, but may occur in small numbers during unusual weather conditions (Brown 1986, Forchhammer 1990).

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

Box 3.4

Satellite tracking of common eider

Anders Mosbech (AU) & Kasper L. Johansen (AU)

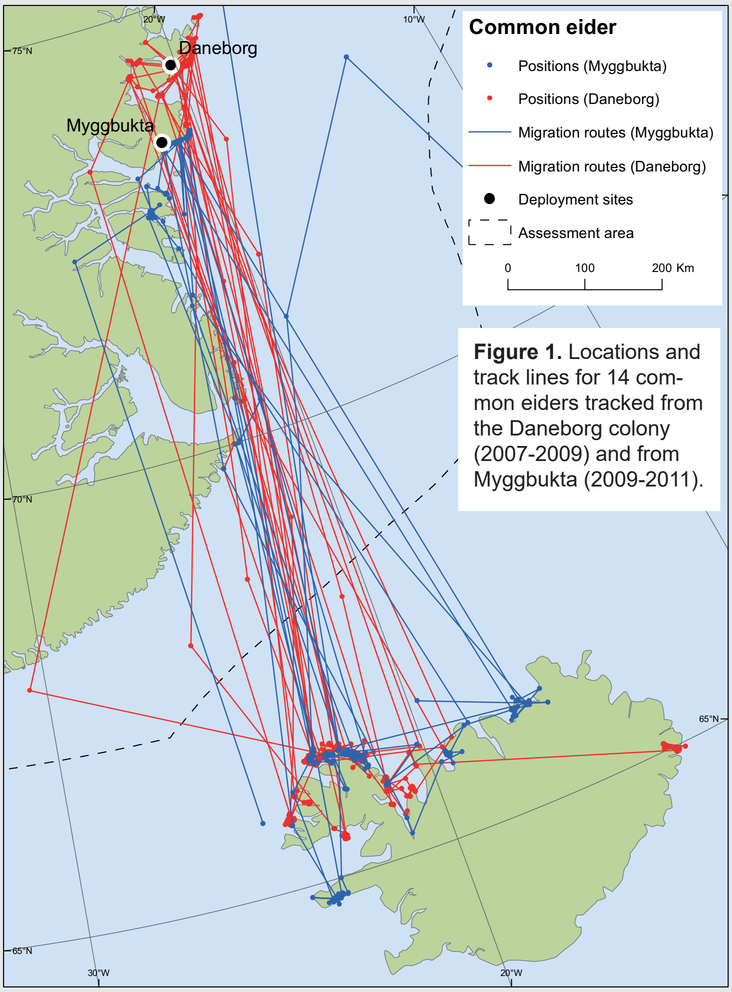


Figure 1. Locations and track lines for 14 common eiders tracked from the Daneborg colony (2007-2009) and from Myggbukta (2009-2011).

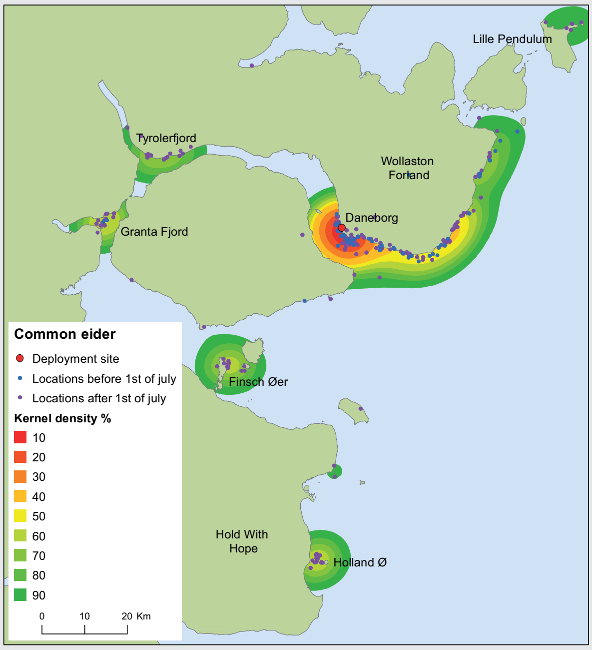


Figure 2. Kernel home range for the common eiders tracked from the Daneborg colony. Locations before 1 July including pre-breeding locations are shown by blue dots, and locations after 1 July including post-breeding locations are shown by purple dots. Locations from the whole tracking period within the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

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

Between 2007 and 2011, 14 common eiders from the assessment area were tracked by means of implanted satellite transmitters. In June 2007, six females and four males were instrumented at the eider colony in Daneborg, and in 2009 further 3 females and 1 male were captured in vicinity of the eider colony in Myggbukta. The eider colony in Daneborg is by far the largest in East Greenland totalling about 3000 pairs, whereas the colony in Myggbukta is significantly smaller (minimum 120 pairs). Several of the eiders were tracked through more than 2 seasons.

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

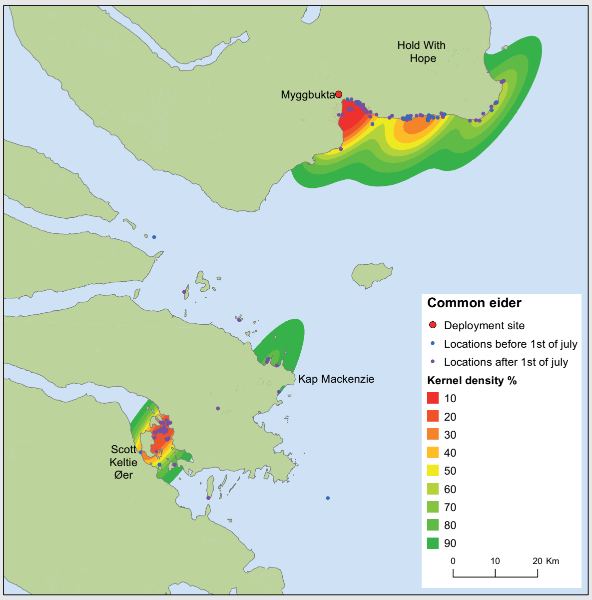


Figure 3. Kernel home range for the common eiders tracked from the Myggbukta colony. Locations before 1 July including pre-breeding locations are shown by blue dots, and locations after 1 July including post-breeding locations are shown by purple dots. Locations from the whole tracking period within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

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

Conservation status: Nationally, the kittiwake is considered threatened and categorised as 'Vulnerable' (VU) due to its decline in West Greenland. However, the small East Greenland population seems to be increasing (Labansen et al. 2010b). Internationally it is considered threatened and is categorised as 'Vulnerable' (VU), because of a general decline in most of the North Atlantic range.

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

Sabine's gull

Breeding distribution: This gull breeds in small colonies mainly on low islands in company with Arctic terns. At least 14 colonies were known before 2008 from the assessment area (Figure 37) (Boertmann 1994, Hansen et al. 2007, Boertmann et al. 2020). The surveys in July/August 2008 and 2009 confirmed the presence of most of these and located a few more (Boertmann et al. 2009a, Boertmann & Nielsen 2010b). The best-known colony within the assessment area is Sandøen in Young Sund. The highest number of birds recorded here were 300 in 1999 (Levermann & Tøttrup 2007, Egevang & Stenhouse 2007). Approximately 50 pairs nested at Henrik Krøyer Holme in the Northeast Water in 1993 (Falk et al. 1997) and in 2017 about 50 pairs attempted nesting, although fox predation led to near-total egg loss (Frederiksen et al. 2019).

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

Offshore distribution and concentrations: Very little information is available on offshore distribution, but the very few observations from the ship-based surveys and a tracking study at Sandøen in 2007/08 indicate that the birds stay a few weeks after breeding in the area and then rapidly move through the assessment area (Box 3.5, Egevang et al. 2010). None were observed during the surveys in 2017.

Conservation status: Sabine's gull is included on the Greenland Red List as 'Near Threatened' (NT) due to the small national population size. It is, however, of favourable conservation status and its numbers seem to be increasing. Internationally it is considered as of 'Least Concern' (LC).

Biology: Sabine's gulls are surface feeders living from small fish and invertebrates, which they take from the sea surface or during shallow dives, and they feed mainly close to the breeding colony. They may also feed on invertebrates in wetland areas (Day et al. 2001). GPS tracking at Henrik Krøyer Holme in 2017 showed that Sabine's gulls during the egg-laying period mainly foraged along the ice edge, within approximately 50 km of the colony (Frederiksen et al. 2019). Outside the breeding season, they are true pelagic seabirds.

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

Glaucous gull

Breeding occurrence: This is the most widespread and common breeding seabird within the coastal part of the assessment area (Figure 37). Small breeding colonies (usually less than 50 pairs) and solitary pairs usually occur at steep cliffs facing the sea, or on low islands. Breeding concentrations are often found in areas with high numbers of other breeding seabirds; for example in the little auk colonies in the Scoresby Sund area.

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

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

In 2017 only few glaucous gulls were observed during the offshore surveys in the assessment area, and most of them close to the shores.

Conservation status: The glaucous gull population in the assessment area is of a favourable conservation status and the species is not considered as threatened, neither nationally nor internationally.

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

Sensitivity and critical areas: Glaucous gulls are less sensitive to oil spills than many other seabirds staying for longer periods on the water surface. The population is dispersed (many small colonies; Figure 37), hence, even a large oil spill in the assessment area will most likely only affect relatively few individuals.

Ross's gull

Breeding occurrence: Ross's gull is a very rare species, breeding occasionally in Greenland only at two sites. One of these sites is located within the assessment area: Henrik Krøyer Holme in the Northeast Water Polynya (Egevang & Boertmann 2008). Here a few pairs have been recorded among the ivory gulls and Arctic terns during recent (but not all) visits to the islands (Figure 37).

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

Offshore occurrence: Non-breeders occur in relatively high numbers in the Northeast Water during summer (Falk et al. 1997a, Meltofte et al. 1981b), and small flocks were also seen during the previous ship-based surveys (Figure 42). None were observed during the 2017 offshore surveys.

Conservation status: The Ross's gull is considered as threatened in Greenland and categorised as 'Vulnerable' (VU) on the national Red List. Internationally it is listed as of 'Least Concern' (LC).

Box 3.5

Arctic tern and Sabine's gull migration study

Carsten Egevang (GINR)

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

In order to map the migration and utilization of marine areas outside the breeding season, Arctic terns and Sabine's gulls were equipped with geolocators – small devices recording light intensity which subsequent can be transformed into geographical positions. Geolocators were deployed on 50 Arctic terns and 30 Sabine's gulls at Sandøen, Young Sund (74° 43° N, 20° 27° W) in July 2007. In July the following year, ten and eleven loggers were retrieved respectively from the two species. The study revealed novel knowledge on some of the longest annual migrations performed within the animal kingdom (Egevang et al. 2010, Stenhouse et al. 2012). In the following the tracking results inside and near the assessment area are described.

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

Arctic tern: The post-breeding departure of the terns from the Young Sund area takes place immediately after fledging of the young. The study revealed that the Arctic terns left the Sandøen colony primo to mid-August and migrated south through the Denmark Strait region – likely without the use of significant stop-over sites along the way (Figure 1). The birds didn't pause the migration until around 50° N (far south of Greenland waters) where they spend an average of 25 days at sea, before continuing the migration into and across tropical regions. The winter was spent in the Wendell Sea off Antarctica, and the north-bound migration was initiated mid-April. The Arctic terns of Sandøen entered southern Greenland waters late May. But at this time day-night light difference were too low to produce accurate geographical positions (Figure 2). However, primo June the Young Sund is still covered by sea ice and it is likely that the terns utilize the open water marine areas east of Young Sund, until egg laying is initiated in ultimo June/primo July (Egevang & Stenhouse 2007, Egevang et al. 2008).

Sabine's gull: The post-breeding migration of the Sabine's gulls differed from the Arctic terns by a more eastward migration from the Young Sund area. The Sabine's gulls left Sandøen medio August and moved into the marine areas east and southeast off the coast. Here, in the southern part of the assessment area the birds spend between 10 and 14 days before continuing their southbound migration (Figure 1). The winter quarters were identified to the marine areas off southern Africa (Benguela Upwelling System), with distinct stop-over sites in autumn (in the Bay of Biscay) and in spring off the west African coast (Morocco, Mauritania, Senegal) (Stenhouse et al. 2012). By the time the Sabine's gulls of Sandøen returned to East Greenland late May/earlyJune day-night light difference were too low to produce accurate geographical positions and movements within the assessment area cannot be elucidated (Figure 2).

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

Ivory gull

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

Breeding concentrations: Breeding colonies are located on steep cliffs, often on remote nunataks, on low gravel islands, low beaches, coastal plains or even on debris covered ice floes or icebergs (Boertmann & Nielsen 2010b, Boertmann et al. 2010, Nachtsheim et al. 2016). The most important breeding site known in the assessment area was, until recently, Henrik Krøyer Holme in the Northeast Water, where up to 300 (2003) pairs have been breeding (Figure 37). However, since 2009 no ivory gulls have been breeding at this location. Several new colonies were found during the aerial surveys 2008 and 2009 in July and August in and north of the assessment area (Figure 40, Boertmann et al. 2009). GPS tracking near Station Nord north of the assessment area in 2018 revealed three new colonies with more than 150 pairs (Frederiksen et al. 2019). And during a survey for ivory gull colonies in 2019 (a part of the *Strategic*

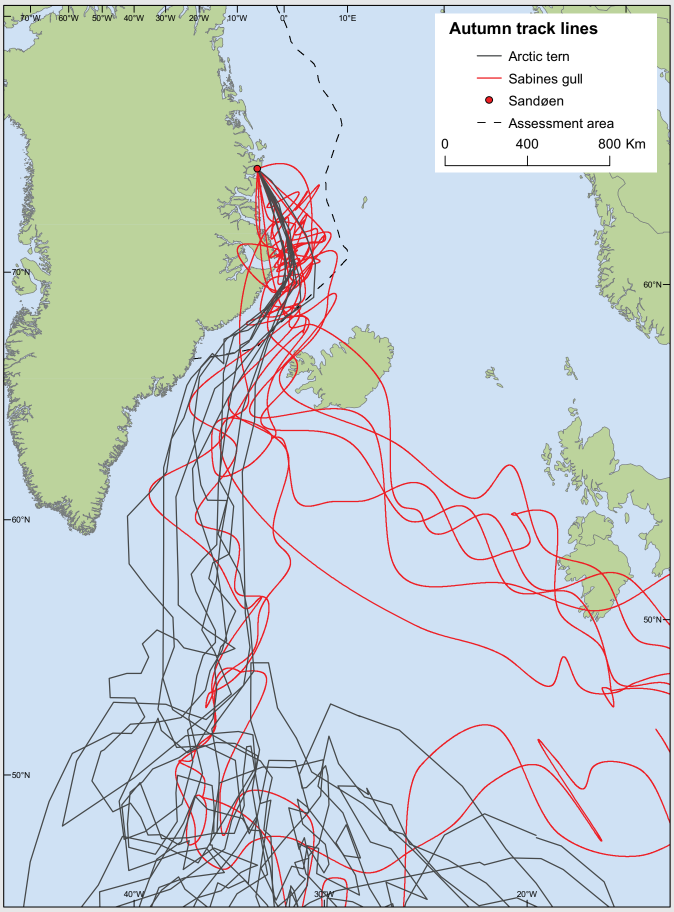


Figure 1. Autumn track lines of Arctic terns and Sabine's gulls equipped with geolocators on Sandøen in Young Sund, East Greenland. The Arctic terns move quickly out of the assessment area towards staging areas in the central Atlantic, while the Sabine's gulls seems to move more around and spend some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

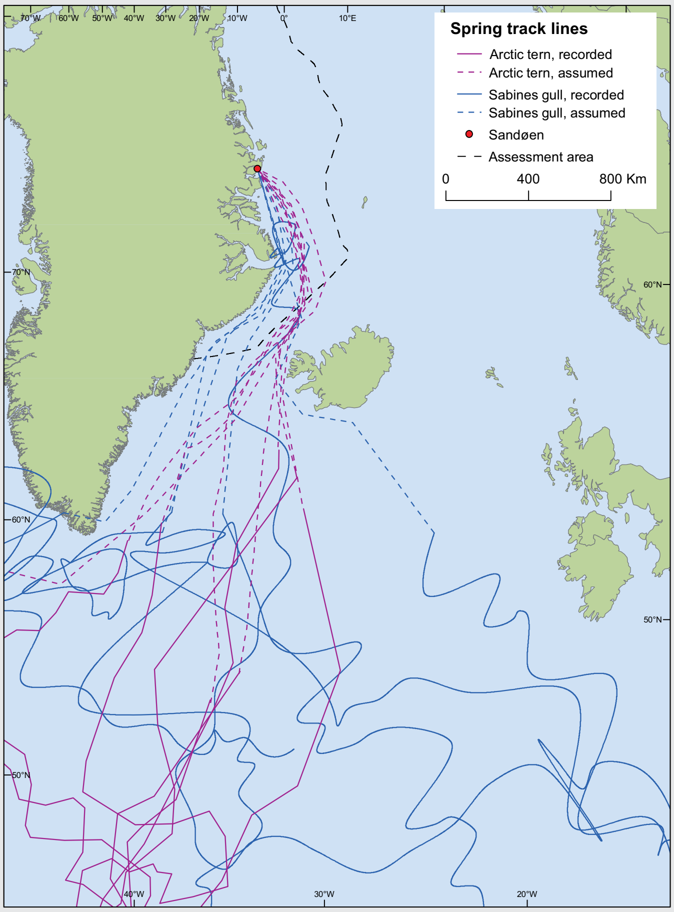


Figure 2. Spring track lines of Arctic terns and Sabine's gulls equipped with geolocators on Sandøen in Young Sund, East Greenland. Due to the midnight sun conditions most of the track lines within the assessment area are assumed.

Environmental Study Program for Northeast Greenland) a new colony with 820 birds was located on Norske Øer. The entire Greenland breeding population is assessed at 1000-2000 pairs, with the majority concentrated at the Northeast Water Polynya (Gilg et al. 2009, Boertmann & Nielsen 2010b). There is also a small southern population breeding in the inland between Scoresby Sund and Tasiilaq. The survey in 2019 recorded approx. 2000 individuals in 25 colonies, of which 22 colonies were located in the land areas adjacent to the Northeast Water Polynya and three in the southern part of the assessment area.

It is well known that ivory gulls have a low site fidelity and move between colony sites from year to year (de Korte & Volkov 1993), that they can establish colonies at temporary substrates as gravel covered ice floes or icebergs (Boertmann et al. 2010a, Nachtsheim et al., 2016) or at new sites. For example, two new sites were located in 2018, 18 and 24 km from the historical colony at St. Nord (M. Frederiksen pers. comm. 2018). Well known colony sites can also be without breeding birds for years, such as the largest colony in Greenland (Henrik Krøyer Holme), which was empty in 2009, 2017, 2018 and 2019, or they can be occupied, but totally unproductive in some seasons due to unsuitable weather conditions, such as rain storms (Yannic et al. 2014).

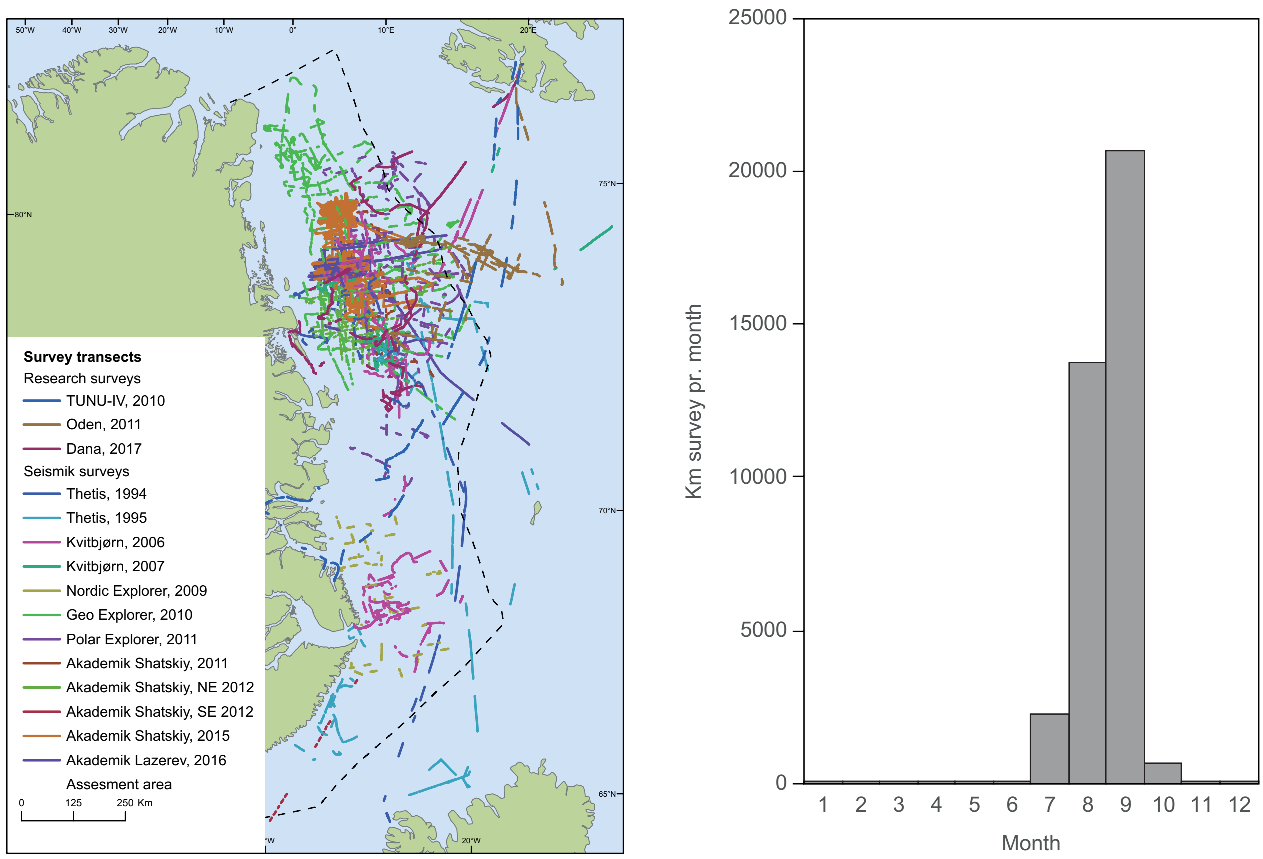
Biology: The research on ivory gulls have intensified in recent years, and much new information have been presented (Strøm et al. 2019). The migration of ivory gulls from the Northeast Water area has been tracked (Gilg et al. 2010, see below). GPS tracking of ivory gulls near Station Nord in 2018 targeted birds that foraged in the offshore pack ice up to several hundred km from the colony, in open-water areas within 100 km of the colony, and at calving glaciers with subglacial discharges of melt water. For further details, see Box 3.6.

Ivory gulls are surface feeders, living from small fish and crustaceans taken in leads and pools in the ice. They also feed on remains from polar bear kills and are attracted to human activities that create open waters in the ice as well as to garbage and discards, for example at military outposts.

Distribution outside the breeding season: Post-breeding migration takes place from late August and some birds move east in the Polar Ocean before all move south in the drift ice belt off the East Greenland shore. Substantial numbers have been recorded, e.g. in early September 1975 when hundreds were observed migrating south (Hjort 1976b) and likewise hundreds were observed in mid-October in the marginal ice zone at about 74° N (Byrkjedal & Madsen 2008). Bench & Hjort (1990) also reported ivory gulls from the drift ice in October. During the ship-based surveys in 1994-2017, ivory gull was among the most frequently observed species (Figure 42). Tracking studies show that birds from all the Northeast Atlantic breeding areas (Greenland, Svalbard, Arctic Russia) occur in the assessment area (Gilg. et al. 2010).

The winter grounds are found in the ice margin in the Labrador Sea, but some also winter off Southeast Greenland (Orr & Parsons 1982, Gilg et al. 2010, Strøm et al. 2019), and they are also present in the Greenland Sea in February–April (Brown 1986). A few individuals migrate along the Siberian coast and winter in the Bering Sea (Gilg et al. 2010). In mid- and late-May 2002 many

Figure 42. See legend on page 108.



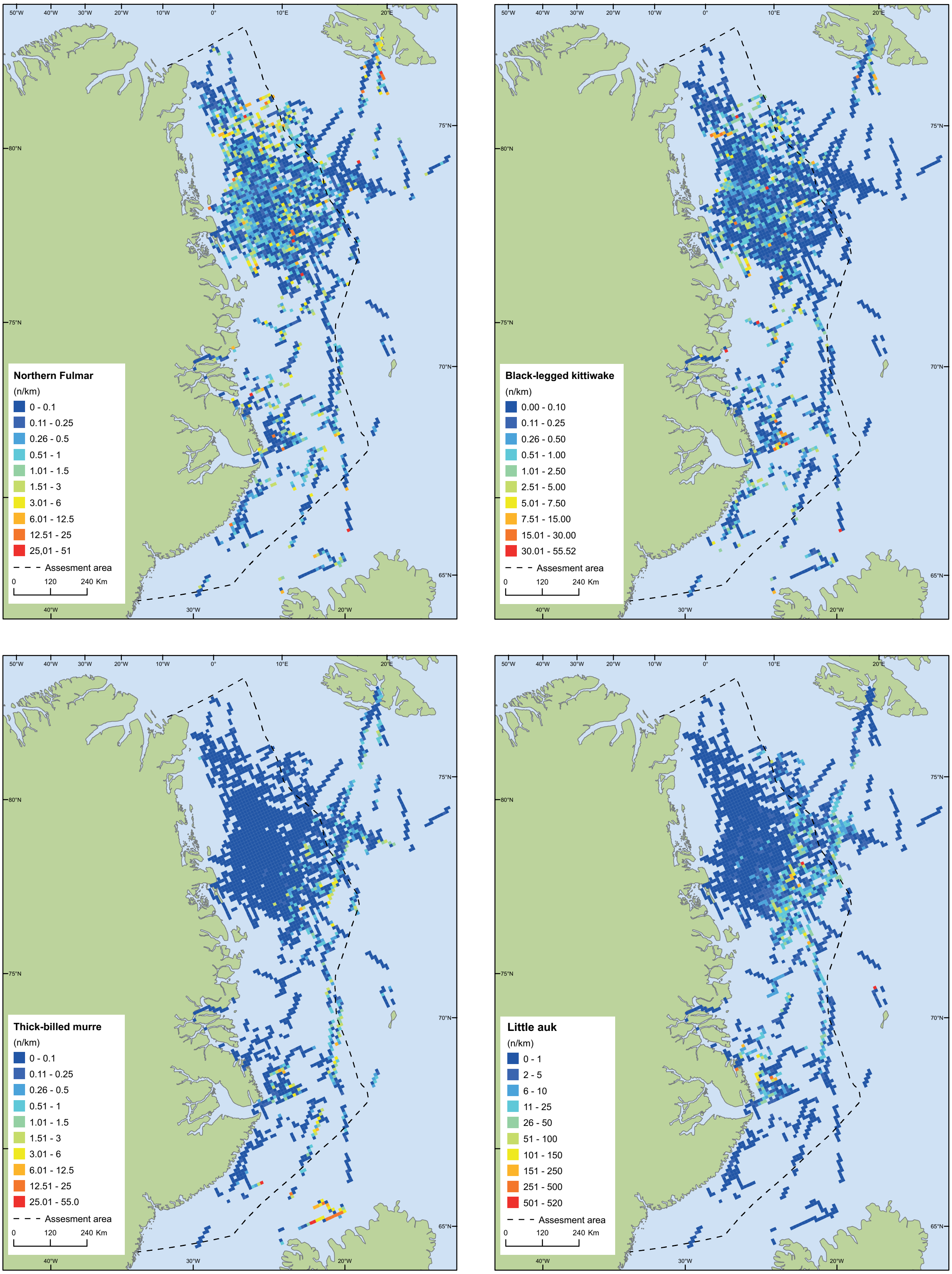


Figure 42. Seabird observations during seismic, research and fishery surveys in 1994, 1995, 2005, 2006 2009-2017: A) shows the spatial coverage of the observation transects and B) the temporal coverage of the surveys. The other maps show number of birds recorded per km in 10×10 km grid cells.

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

During the offshore surveys in 2017 only 16 individuals were observed from the aircraft (mainly in the northern part of the survey area, where the ice concentration was highest), while 95 were observed from the ship.

Conservation status: The global ivory gull population has an unfavourable conservation status (Gilchrist et al. 2008): It is small (estimated at 6325-11,500 pairs) and a significant decrease in the Canadian breeding population, and some decline in Svalbard since 2009 has been reported (Strøm et al. 2019). Ivory gulls display high contaminant loads, especially mercury, organochlorines and perfluorinated alkyl substances (PFAS) (Gilchrist et al. 2008, Lucia et al. 2015, Strøm et al. 2019). A general population decline is expected due to climate change (Gilg et al. 2016). Therefore, the ivory gull was recently red-listed as 'Near Threatened' (NT) (BirdLife International 2006). In Greenland, the ivory gull is considered as threatened and categorised as 'Vulnerable' (VU) on the national Red List.

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

Arctic tern

Breeding distribution: Many breeding colonies are located along the shores of the assessment area (Figure 37). Most are small, but a few hold more than 500 pairs. Moreover, there are many Arctic terns breeding at inland sites at lakes. The breeding colonies are concentrated at polynyas and areas with early ice break-up, such as the outer parts of sounds and fjords: e.g. Vega Sund, Young Sund, Dove Bugt and Henrik Krøyer Holme.

Offshore distribution: Arctic terns arrive to the coastal waters in early to mid-June, and leave soon after the chicks have fledged in late August to early September. During the 2008 survey, flocks arrived in the outer parts of the offshore drift ice on 2. June (Boertmann et al. 2009a).

In the breeding season terns mainly stay close to the breeding sites and very few were observed during the Norwegian offshore surveys in 1980–1984 (Mehlum 1989). Both during spring and autumn migration, Arctic terns move through the offshore areas, but this is rapid (Box 3.5, Egevang et al. 2010). During the 2017 survey in August and September, many Arctic terns were seen heading southwards throughout the assessment area.

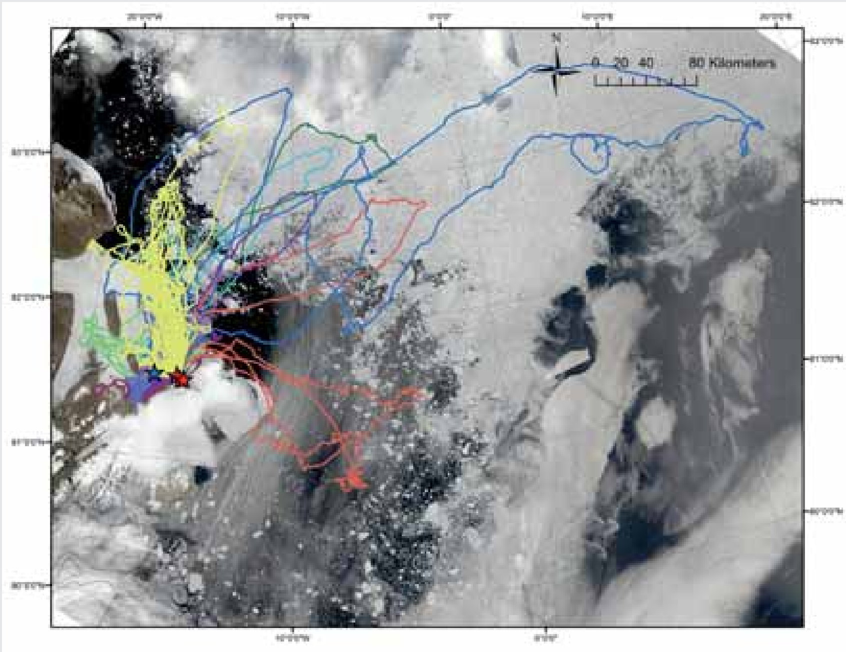
Biology: Arctic terns are surface feeders, catching fish and crustaceans by plunge diving from the air. In the breeding season Arctic terns are confined to coastal waters, but during migration they also occur far offshore.

Box 3.6

GPS tracking of ivory gulls 2018

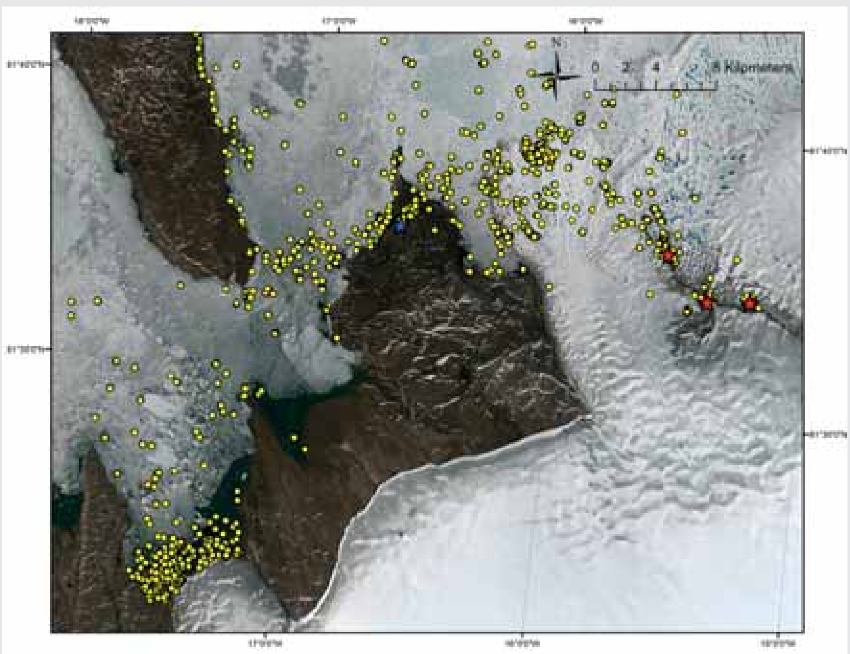
Morten Frederiksen (AU), Alejandro Corregidor Castro (AU), Henrik Haaning Nielsen (Avifauna Consult) and Jonas Koefoed Rømer (AU)

Adult ivory gulls were tracked with GPS devices during the breeding season (July-August 2018) in the Station Nord area. Birds were trapped at the station kitchen, and in a newly discovered colony 18 km east of the station (Figure 1), and equipped with 10 g solar-powered GPS devices mounted on a leg-loop harness. GPS devices downloaded data automatically to a base station. Eighteen birds were tagged, and useful data were obtained from ten of them. Two additional colonies were located based on the tracking data. All birds tagged at the station showed attachment to the colony area, although their breeding status was unknown. For more details on methods and results, see Frederiksen et al. (2019).



In total, 292 foraging trips were recorded (Figure 1), with an overall mean length of 214 km and mean duration of 18.5 h. The longest trip lasted 182 h and covered 1850 km, with a maximum distance from the colony of 502 km. The birds spent on average 65% of the time away from the colony, and were stationary (presumably at foraging sites) for on average 37% of the time they spent away from the colony.

Overall, the tracked ivory gulls used areas to the north of the colonies, mainly in and along the shores of the Wandel Sea (Figure 1). Foraging trips fell broadly into three categories: 1) Long meandering trips in the pack ice, presumably searching for unpredictable high-gain food sources such as seal carcasses, 2) Shorter and more direct trips to the open-water areas north of the colony, presumably searching for fish, crustaceans etc. at the surface, or 3) Trips directed to the marine terminus of the glacier Marsk Stig Bræ south-southwest of Station Nord (Figure 2). Here, the birds presumably fed on marine invertebrates stunned or killed by exposure to fresh meltwater.



No ivory gulls bred at the intended study site Henrik Krøyer Holme in the Northeast Water Polynya in 2017 or 2018, and it was therefore not possible to track birds using the assessment area. Although the tracked birds largely used the Wandel Sea to the north, it is likely that ivory gulls breeding along the shores of the Greenland Sea use similar habitats. Ivory gulls are generalist foragers and use all resources available within at least 2-300 km around the colony during the breeding season, whether in the pack ice, along ice edges, in open-water areas or along shorelines.

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

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

Thick-billed murre

Breeding distribution: There are only two breeding colonies within the assessment area (Figure 37), both situated at the Scoresby Sund Polynya (Meltofte 1976, Falk et al. 1997b). The colonies have been surveyed a number of times in recent decades, and the largest colony on Kap Brewster have shown a significant decrease: in 1995 it numbered 14,800 birds, in 2005 9500 birds, in 2010 4800 birds, and in 2018 3800 birds. The other colony on the island Raffles Ø, is smaller and held about 2599 in 1995, 2200 birds in 2004, 1500 in 2010 and 2300 in 2018 (GINR, unpublished, Merkel et al. 2014). A few murres have been observed on the bird cliff on Rathbone Ø, and they may be breeding in low numbers here (Boertmann et al. 2020).

The migration of breeding birds from the Kap Brewster colony has been studied by satellite tracking, see Box 3.7.

Offshore distribution: Murres are numerous in and near the Scoresby Sund Polynya in summer, but further north in the assessment area only few occur, and in the Northeast Water they occurred sparsely in 1991-1994 (Mehlum 1989, Falk et al. 1997a). In September, numbers increase in the offshore areas (Figure 42) and high densities of thick-billed murres have been recorded in polar waters between Iceland and Greenland with up to 30 bird/km^2 (Petersen 1995). This influx of birds consists mainly of breeders from Svalbard (approx. 520,000 pairs in 2014, Anker-Nilssen et al. (2015)) on autumn migration towards the winter quarters off Southwest Greenland and Newfoundland.

The survey in August and September 2017 revealed that almost no thick-billed murres were present on the shelf, and most were observed at the shelfbreak. This indicates that the migration takes place along or to the east of the shelfbreak, which is also the pattern shown by the Norwegian Seatrack data.

Winter observations are very few, but at least in late winter 1982 few were observed in the eastern parts of the assessment area (Brown 1986). Also, the Norwegian Seatrack data show that birds from breeding populations in Iceland, Svalbard, Jan Mayen and Bjørnøya occur in the southern part of the assessment area in winter.

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

Box 3.7

Satellite tracking of thick-billed murres from Kap Brewster

Anders Mosbech (AU) & Kasper L. Johansen (AU)

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

In late July 2009 three male and two female thick-billed murres from the colony at Kap Brewster were caught on the ledge with noose pole and equipped with implanted satellite transmitters. With an estimated maximum of 4800 birds, the colony at Kap Brewster is the larger of only two murre colonies in the assessment area, both related to the Scoresby Sund Polynya.

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

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

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

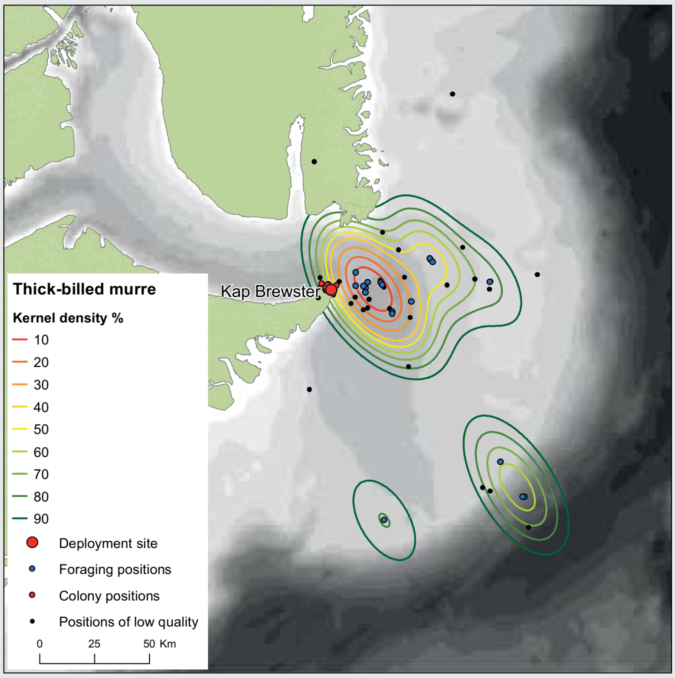


Figure 1. Foraging areas of a female thick-billed murre (ptt ID 36372) tracked with satellite transmitter while commuting between the colony at Kap Brewster and foraging areas. The foraging areas are estimated as Kernel home range contours, only including high accuracy positions away from the colony.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

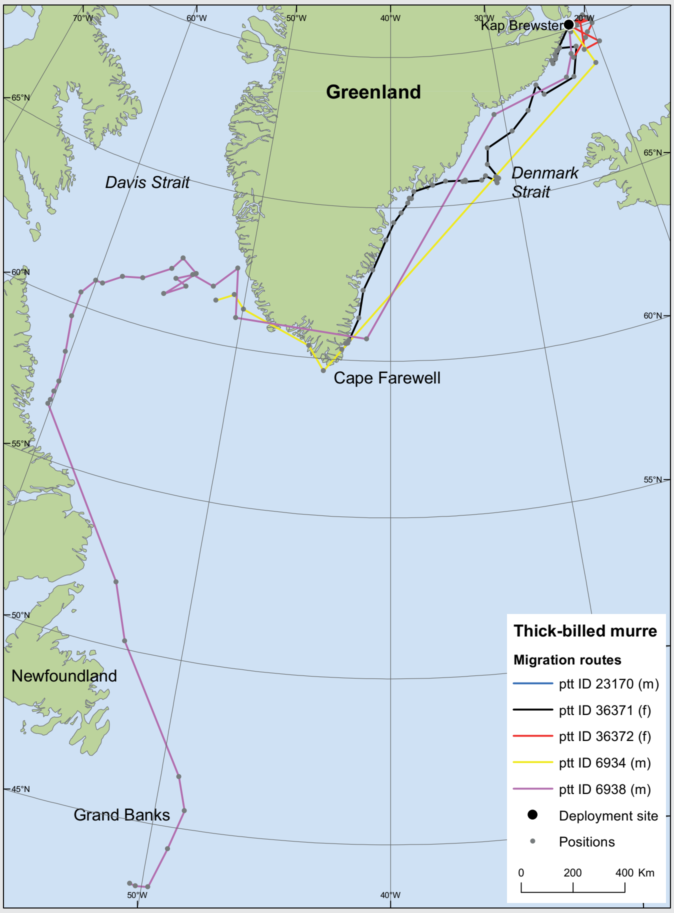


Figure 2. Locations and migrations routes for 5 thick-billed murres tracked from the Kap Brewster colony in 2009.

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

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

Black guillemot

Breeding distribution: The black guillemot is a common breeder on coasts of the southern part of the assessment area as far north as Liverpool Land (Boertmann et al. 2020). Further north, colonies are scarce and associated with areas with early ice break-up or polynyas, e.g. at Hvalros Ø and at Holm Land (Falk et al. 1997a, Boertmann et al.2020), and they are somewhat unstable in their occurrence, probably governed by the annual variation in ice distribution (Figure 37).

Offshore distribution: Very few black guillemots were reported by the Norwegian summer surveys in 1980-1984 in the northern part of the assessment area (Mehlum 1989). During the ship-based surveys (Figure 42) black guillemots were rather numerous in the drift ice, and also Byrkjedal & Madsen (2008) reports black guillemots in autumn. The number of birds recorded during these autumn surveys exceeds by far the numbers breeding in Northeast Greenland, suggesting that birds move in from Svalbard. Very few were seen during the 2017 surveys in August and September, perhaps because the black guillemots had not yet arrived.

In winter, Brown (1986) observed a few black guillemots and mainly in the marginal ice zone.

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

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

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

Little auk

Breeding distribution: This species is by far the most numerous seabird breeding in the assessment area. However, the breeding distribution is limited to the coasts near the Scoresby Sund Polynya (Figure 37), where the population has been estimated at approx. 3.5 million pairs (Kampp et al. 1987). Breeding outside this region has been suggested at Hvalros Ø (74° 30′ N) and at Kap Dalton (69° 30′ N) but has not been confirmed during several visits in recent years (Stemmerik 1990, Boertmann et al. 2020).

Offshore distribution: In summer, breeding birds undertake foraging flights up to approx. 100 km from the colonies (Box 3.8), and within this range little auks can occur in very dense concentrations. Further offshore and north of the breeding range, little auks are much scarcer in summer as shown by the Norwegian surveys in 1980-1984 (Mehlum 1989). Little auks probably move to Southwest Greenland and Newfoundland waters for the winter, but Brown's survey (1984) indicates that little auks are present also in winter (March), and then mainly in the marginal ice zone.

The surveys in August and September 2017 showed that little auks were distributed throughout the survey area in low densities, and that here were some high density areas at the shelfbreak (Box 3.3). These high density areas could be the moulting areas recently revealed by tracking of birds from Kap Höegh near Scoresby Sund (Mosbech et al. 2012) (see Box 3.8). The Norwegian Seatrack data also indicate that birds from Svalbard and Bjørnøya occur in the assessment area in autumn.

Previous ship-based surveys in October revealed only few little auks (Bensch & Hjort 1990, Byrkjedal & Madsen 2008), suggesting that the autumn migration through the assessment area peaks earlier.

In winter, little auks from Svalbard, Bjørnøya and Franz Josef Land have been tracked to the southern part of the assessment area.

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

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

Sensitivity and critical habitats: Little auks are very vulnerable to oil spills, and the most sensitive occurrences are the breeding colonies along the coasts of the assessment area. Large offshore aggregations will also be very sensitive. The moulting aggregations found by tracking (Mosbech et al. 2012) and observed during the 2017 are such examples, but their predictiveness is unknown.

Other species

Four species of skuas occur frequently in the assessment area in the summer period. Breeding birds are confined to terrestrial and coastal habitats, but non-breeders and failed breeders move to offshore areas and are usually common and widespread. They are all migrants and leave the assessment area for the winter. Only few skuas were recorded during the surveys in August and September 2017: In total, two Arctic skuas, ten long-tailed skuas, 22 pomarine skuas and two great skuas were observed on the airborne survey.

Box 3.8

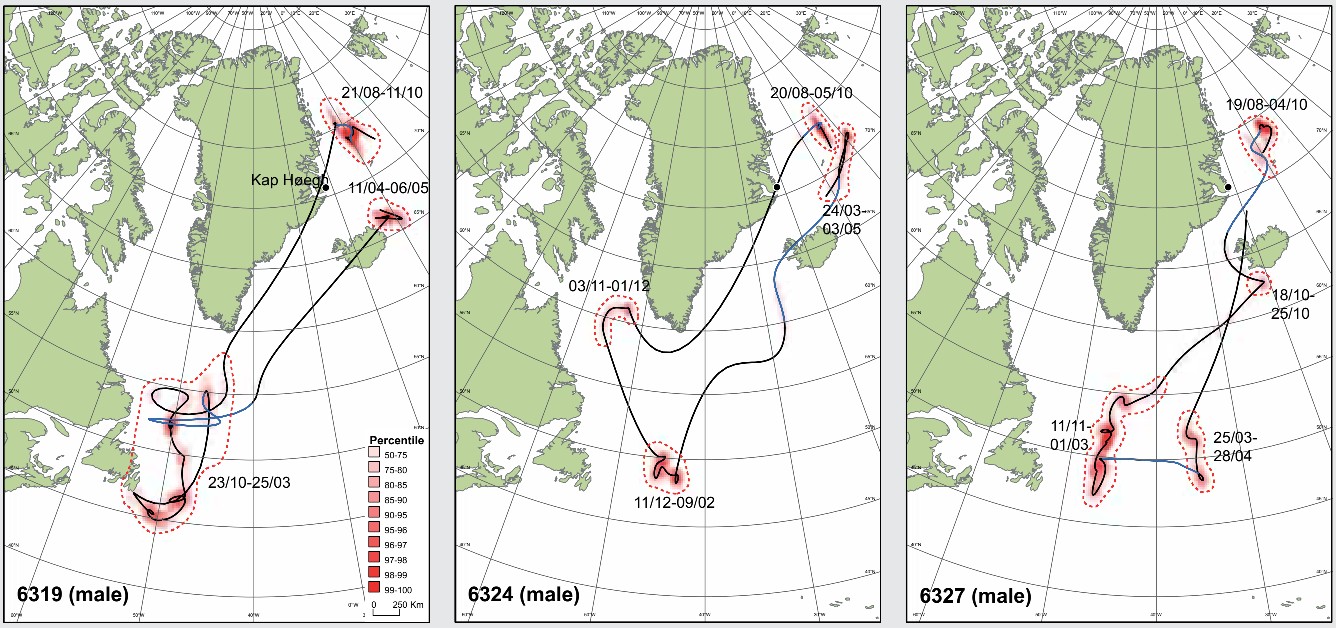
Little auk ecology and key habitats in the assessment area

Anders Mosbech (AU), Jerome Fort (LIENS), Manon Clairbaux (University of Montpellier), David Grémillet (CEFE) & Kasper L. Johansen (AU)

The little auk is the most numerous seabird in the North Atlantic and a key component of its ecosystem with significant impact on terrestrial and marine trophic networks (González-Bergonzoni et al. 2017, Mosbech et al. 2018). Greenland is estimated to hold 80 % of the world breeding population, making it a species of national responsibility. In the assessment area, a minimum of 3.5 mill little auk pairs are estimated to breed at the coasts in vicinity of the Scoresby Sund polynya (Kampp et al. 1987). Little has been known about the ecology and key marine habitats of this little auk population. However, since 2005, French researchers (CEFE and LIENSs) and DCE/GINR have conducted studies at Ukaleqarteq (Kap Höegh), Liverpool Land, to investigate the ecology of this high Arctic species. The main objectives have been to understand its responses to a changing environment (climate, food resources and contaminants) and locate important at-sea areas during the seasonal cycle.

Migration and staging areas

In the breeding seasons of 2007 and 2008, little auks were caught at nests and fitted with small geolocators on tarsus bands (Mosbech et al. 2012). Five geolocators were retrieved the following breeding season and the recorded light regime data were downloaded and converted into geographical positions. The accuracy of the positions is quite coarse, typically within approximately 200 km for individual locations. However, a model-based smoothing was applied, and coordinates predicted daily for each bird were connected in chronological sequence to reconstruct paths of movement during the non-breeding season (Figure 1). The daily predictions of longitude and latitude were also used for identifying staging areas.



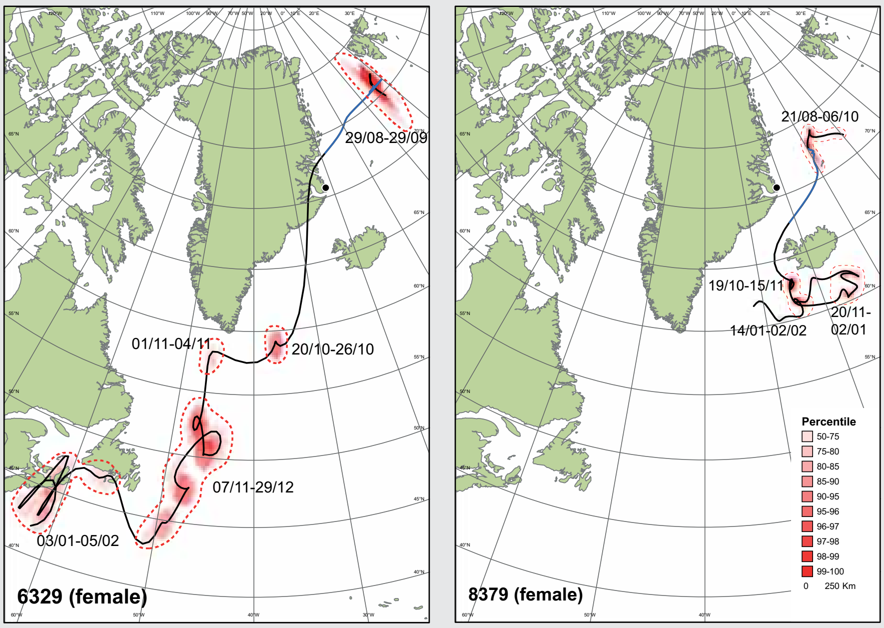


Figure 1. Paths of movement of 5 little auks (3 males and 2 females) equipped with a geolocator at the breeding colony Ukaleqarteq (Kap Höegh) near Scoresby Sund in 2007 and 2008. All birds were recaptured a year after deployment. The maps show the most likely track for each bird based on modelling of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

For the five recaptured birds, the median post breeding departure time from the colony was 8 August (range 25 July-13 august), while arrival the following year could be determined for three birds, which arrived from the beginning of May to mid-June. This is in accordance with data from a time lapse camera installed in the Ukaleqarteq colony, which revealed that the last birds departed 29 August in 2018 and the first birds arrived 29 April in 2019 (Mosbech, unpublished). A remarkable result is that after breeding all birds moved towards northeast and staged in the Greenland Sea between Jan Mayen and Svalbard during the end of August and the beginning of October (Mosbech et al. 2012). This peculiar migration pattern of little auks from East Greenland has been confirmed by further tracking in the years 2009-19 (Fort, unpublished), and little auks from Svalbard and Russia (Franz Josef Land) apparently also use the same staging area (data from SeaTrack.no; see Møller et al. 2019, Descamps et al. subm.). This northern staging and (presumably) moulting area was further confirmed in 2017 during both a ship-based oceanographic survey (Møller et al. 2019) and an aerial survey (Boertmann et al. 2018, see Box 3.3). During winter, the little auks from Ukaleqarteq mostly stay far offshore Newfoundland (Mosbech et al. 2012, Fort et al. 2013, Amélineau et al. 2018), but there is large individual variation: e.g. one bird staged most of November offshore Southwest Greenland and one bird remained south of Iceland until February (Mosbech et al. 2012). Amélineau et al. (2018) analysed the winter distribution of 94 little auks from Ukaleqarteq and found that they targeted areas with high prey densities and moderately elevated energy requirements. Climate change will probably impact the little auks' wintering strategies through reducing their energy requirements (Amélineau et al. 2018), sea ice melt (Clairbaux et al 2019) or latitudinal shift of their prey (Reygondeau & Beaugrand 2011). Research indicates that the winter season may already be an important bottleneck for the little auk populations; the winter foraging effort is two-fold higher than the breeding season when the birds have to forage for both themselves and their chicks (Fort et al. 2009, Harding et al. 2009). In addition, little auks are exposed to elevated mercury concentrations at their wintering grounds. This negatively impacts their body condition as well as their subsequent reproduction through carry over effects (i.e. decreased egg size, chick mass and chick growth rate (Fort et al. 2013, Amélineau et al. 2019, Fort et al. unpublished)).

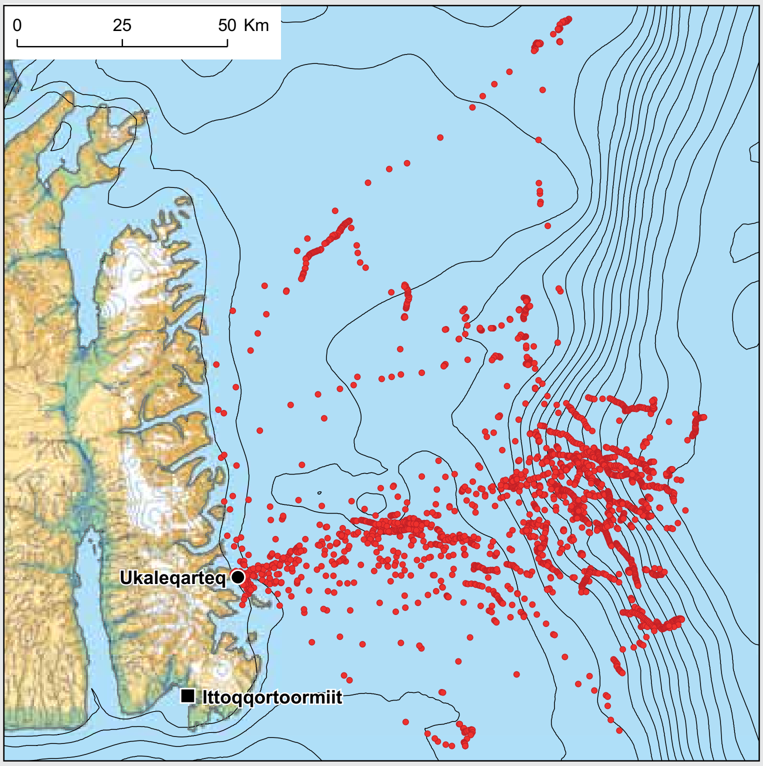


Figure 2. Locations from 21 little auks tracked with GPS dataloggers from the Ukaleqarteq colony during the breeding season 2019. The locations show that the main foraging area is located at the shelf edge about 85 km east of the colony, secondarily in an area close to the colony. Here, prey items like copepods are found within the 50 m diving range of little auks.

Foraging ecology during the breeding season

The chick meals at Ukaleqarteq (Kap Höegh) are dominated by *Calanus* copepods (95 %) (Harding et al. 2009, Amélineau et al. 2019), and it has been estimated that chick-rearing little auks need to catch about 59,800 copepods per day. This is equivalent to about six copepods per second spent underwater by the chick-rearing adults, which use suction-feeding to efficiently catch so many prey items (Harding et al. 2009, Enstipp et al. 2018). These astonishing results underline the importance of areas with dense patches of large, energy-rich copepods available to the little auks. The quality of little auk foraging areas is to some extent determined by ocean temperature, which conditions the distribution and abundance of the large lipid-rich *Calanus* copepod species associated with cold water (Falk-Petersen et al. 2007, Loeng & Drinkwater 2007, Møller et al. 2018).

Welcker et al. (2009) did a comparative study of foraging ecology during chick rearing involving Ukaleqarteq (Kap Höegh) and three colonies in Svalbard (Hornsund, Isfjorden and Kongsfjorden). They found that at Ukaleqarteq, sea surface temperature was lower (0.34° C compared to between 1.96° C and 5.64° C at the Svalbard colonies), little auks spent less time foraging (80 % compared to 87-93 % at the Svalbard colonies) and their "long" foraging trips where shorter (69 ± 11 km compared to between 129 ± 16 km and 219 ± 17 km at Svalbard). These results highlight the relatively favourable foraging conditions present at Ukaleqarteq for this high Arctic seabird. Little auks at Ukaleqarteq forage mainly at the shelf break approx. 85 km east of the colony and in a nearshore foraging area close to the colony (Figure 2, see also Amélineau et al. 2016). Contrary to previous hypotheses, they seem not to be dependent on the presence of sea ice in their foraging area (Gremillet et al. 2012, Amélineau et al. 2016). In fact, foraging success, as indicated in adult body condition and chick growth rate, seems to improve in years with less sea ice (Amélineau et al. 2019).

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

The most numerous of these species are the king eider and the long-tailed duck. During the spring 2008 survey about 1300 king eiders were observed in the Northeast Water Polynya, 100 at the Wollaston Forland Polynya and 40 at the Scoresby Sund Polynya (Figure 39). Long-tailed ducks were most abundant in the Scoresby Sund Polynya with about 100 birds followed by the Northeast Water with 40 birds. Red-throated divers were recorded in small numbers and very dispersed.

Long-tailed ducks, king eiders and red-throated divers were captured on breeding grounds in the central part of the assessment area in 2008 and 2009 and equipped with satellite transmitters. The subsequent tracking of these birds is described in Boxes 3.9-3.11.

Another period when such birds may use the marine environment is during the summer when they moult. The most numerous species are again long-tailed ducks and king eiders. During the 2008 and 2009 aerial surveys in July and August, moulting long-tailed ducks were located at many sites (Boertmann et al. 2009). Flocks were usually small with less than 100 birds, but at a few sites, e.g. the coast of Wollaston Forland, more than 1000 birds were recorded in 2008 and 460 in 2009 off a river outlet (Figure 40). Moulting king eiders were found in Knighton Fjord on the Blosseville Kyst (with 150 birds in 2008 and 245 in 2009) and to a lesser degree in the waters east of Shannon (Figure 40).

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

3.7.2 Important areas for seabirds

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

Polynyas (Figure 12) are particularly important as staging and feeding areas in the spring when the sea elsewhere is covered with ice. Large numbers of seabirds assemble in such areas, mainly the mouth of Scoresby Sund, the Sirius Water Polynya and the Northeast Water (Meltofte 1976, Falk et al. 1997a, Boertmann et al. 2009a). These sites are of regional importance, holding birds from a large region for a short period of time.

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

Moulting ducks often assemble in undisturbed areas, and concentrations are known from the Scoresby Sund area (see above, common eider), but other moulting areas may be found within the assessment area. Such sites are particularly sensitive to disturbance, from e.g. low-level helicopter flights. During the 2008 and 2009-surveys, moulting common eiders were found dispersed along many coasts, but not in large concentrations. Most were found in the fjords of the Blosseville Kyst, where the only concentration of moulting king eiders also occurred. Moulting long-tailed ducks were recorded at many sites, mainly in shallow bays and at river outlets; the largest concentration was approx. 1000 birds at the coast of Wollaston Forland (Figure 40).

Moulting little auks were recently shown to move to the Greenland Sea after the breeding season (Mosbech et al. 2012), and the concentrations located in August and September 2017 could very well be such moulting birds. These high-density areas were located at the shelfbreak. Whether these concentration sites are recurrent is not known but in general the shelfbreak seems to be an area with heightened biological significance.

As mentioned above, the marginal ice zone in the Greenland Sea may be a very important habitat for migrating seabirds in spring. The major part of these birds have their breeding grounds in Svalbard and their wintering grounds in Southwest Greenland and Newfoundland waters. In the Barents Sea the marginal ice zone is designated as a particularly important area due to, e.g., concentrations of feeding seabirds in spring. But as the Greenland shelf is an outflow shelf with low productivity (see Chapter 2.2 on oceanography) it may not have the same potential as in the Barents Sea.

3.8 Marine mammals

The marine mammals constitute the top levels in the marine food web, with seals, whales and on top of them all the polar bear (see Table 5 for an overview of their occurrence and status in the assessment area). The marine mammals in the assessment area show very diverse life strategies: Ringed seals and polar bears usually stay within the assessment area, although the bears in particularly make extensive use of both the coasts and the ice-covered offshore areas (documented by tracked individuals in 2017-2019); narwhals perform regular migrations between distinct summer habitats in the fjords and winter habitats on the shelfbreak; bowhead whales perform long trips to Svalbard and further east (documented by tracked individuals in 2017-2019); harp seals and hooded seals have specific whelping grounds on the drift ice and disperse widely in the North Atlantic after the whelping season (harp seal movements documented in 2017-2018); walrus males and females assemble on specific and segregated haul-outs on the coast. In spring, large whales (fin, blue, humpback, sperm) arrive from the south and utilise particularly the mixed waters above the shelfbreak. Aerial suveys in 2017 and 2018 showed that the Northeast Water is an important habitat for the now increasing population of bowhead whale both in winter and summer, that narwhals have important summer habitats in Dove Bugt and off Jøkel Bugt, and that the walrus population may be smaller than assessed previously: only five of 27 known terrestrial walrus haul-out sites seemed to be active. Other sources have recently found a spring aggregation area for bowhead whale over the shelfbreak between 76° and 78° N (de Boer et al. 2019). Polar bears were tracked in 2018-2019, and they used the entire shelf off Northeast Greenland extensively. In 2017 and 2018 narwhal response to seismic noise was studied in the assessment area.

Table 5. Overview of marine mammals occurring in the assessment area. Red List status from Boertmann & Bay (2019). Importance of study area to population indicates the significance of the population occurring within the assessment area in a national and international context as defined by Anker-Nilssen (1987).

Species	Period of occurrence	Main habitat	Distribution and occurrence in assessment area	Protection/ exploitation	Greenland Red List status	Importance of assessment area to population
Polar bear	Whole year	Ice-covered waters	Widespread	Hunting regulated	Vulnerable (VU)	High
Walrus	Whole year	Shallow coastal waters	Low numbers, Northern part	Hunting regulated	Near Threatened (NT)	High
Hooded seal	Whole year	Open waters, whelp and moult on drift ice	Numerous, widespread	Hunting unregulated	Vulnerable (VU)	High
Harp seal	Whole year	Open waters, whelp on drift and pack ice	Numerous, widespread	Hunting unregulated	Least Concern (LC)	High
Bearded seal	Whole year	Ice covered waters	Low numbers, widespread	Hunting unregulated	Least Concern (LC)	High
Ringed seal	Whole year	Ice covered waters	Common and widespread	Hunting unregulated	Least Concern (LC)	High
Bowhead whale	Whole year	Shelf, shelf breaks MIZ	Low numbers, widespread,	Protected (since 1932)	Vulnerable (VU)	High
Minke whale	Jun-Oct	Fjords and shelf breaks	Atlantic waters	Hunting regulated	Least Concern (LC)	Pot. medium
Sei whale	Jun-Oct	East of shelf break	Atlantic waters	Protected	Endangered (EN)	Low
Blue whale	Jul-Oct	East of shelf break	Atlantic waters	Protected (1966)	Vulnerable (VU)	Pot. high
Fin whale	Jun-Oct	Fjords, shelf breaks	Rather common, whole area	Hunting regulated	Least Concern (LC)	Pot. medium
Humpback whale	Jun-Oct	Fjords, shelf breaks	Numerous, whole area	Hunting regulated	Least Concern (LC)	Pot. medium
Pilot whale	Jun-Oct	Outside the ice-covered areas	Fluctuation, Southern part	Hunting unregulated	Least Concern (LC)	Low
White-beaked dolphin	Jun-Oct	Outside ice-covered areas	Rather common, southern part	Hunting unregulated	Least Concern (LC)	Low
Killer whale	Jun-Sep	Mainly ice-free waters, whole area	Not common, mainly southern part	Hunting unregulated	Data deficient (DD)	Unknown
Narwhal	Whole year	Fjords, ice edges	Certain fjords and shelf break	Hunting regulated	Endangered (EN)	High
Sperm whale	May-Nov	Deep waters	Low numbers, southern part	Protected (1985)	Vulnerable (VU)	Low
Northern bottle-nose whale	May-Nov	Deep waters only	Probably rare, mainly southern part	Hunting unregulated	Data deficient (DD)	Low

In the following, two species – polar bear and walrus – are treated in more detail than the other marine mammals. For both, intensive studies have been carried out for many years, and results of these studies are summarised here.

3.8.1 Polar bear

Kristin Laidre (GINR), Erik W. Born (GINR) & Ben Cohen (UW)

The historical distribution of polar bears in East Greenland was summarised by Pedersen (1945), Born (1983), Dietz et al. (1985), Born & Rosing-Asvid (1989), Born (1995) and Sandell et al. (2001) based on catch statistics and observations made by sealers, various expeditions and subsistence hunters living in the area. Furthermore, studies involving satellite telemetry during spring 1979 (Larsen et al. 1983) and 1993-1998 (Born et al. 1997, Wiig et al. 2003), supplemented with a habitat analysis by Laidre et al. (2015) spanning telemetry

Box 3.9

Satellite tracking of long-tailed ducks from Myggbukta

Anders Mosbech (AU) & Kasper L. Johansen (AU)

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

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

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

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

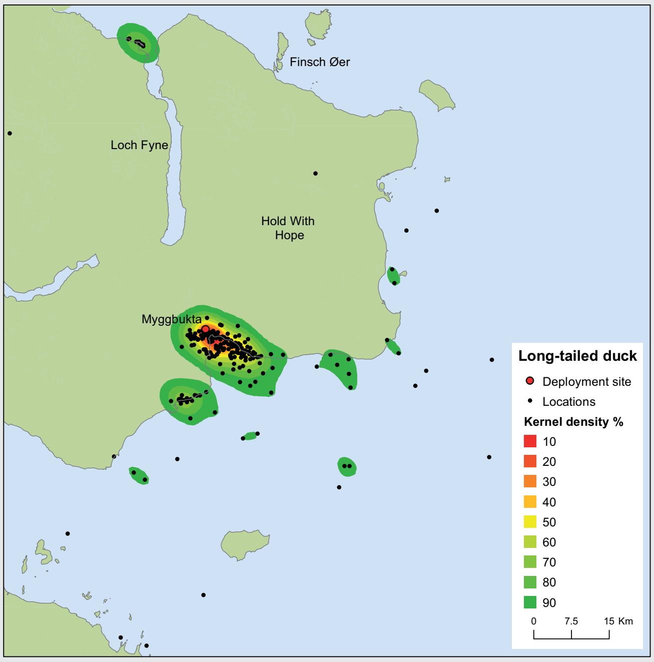
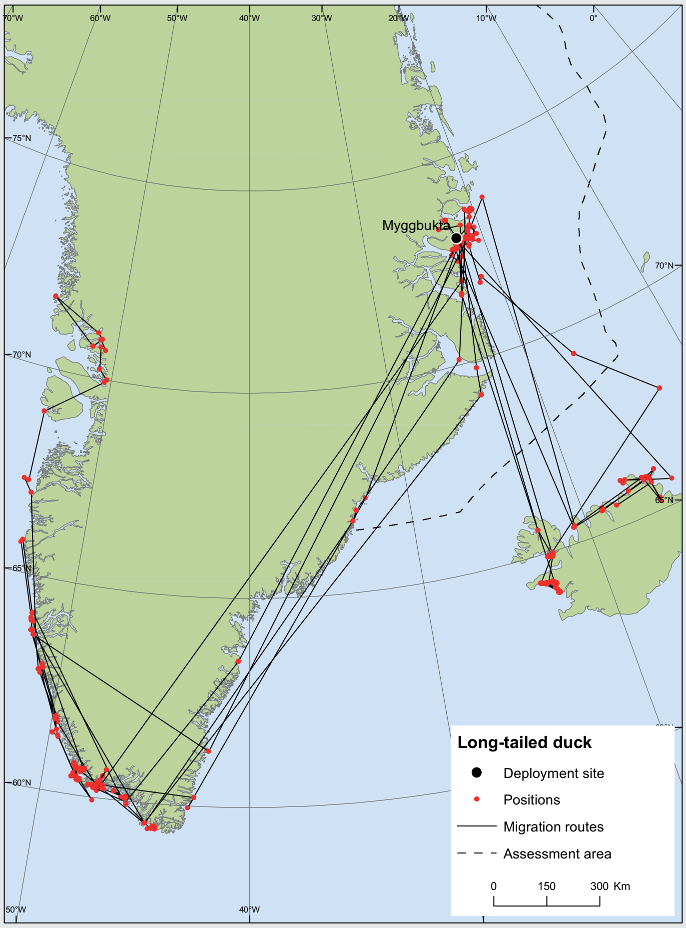


Figure 1. Kernel home range for the 11 long-tailed ducks from the Myggbukta breeding area deployed with satellite transmitters in 2007 and 2009. Locations from the whole tracking period within the area shown on the map are included in the kernel analysis (summers 2007, 2009 and 2010). The Kernel home range contours represent an estimation of the areas in which a certain percentage of the locations will be found. Thus 90% of the locations are found within the 90% probability contour.



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

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

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

Box 3.10

Satellite tracking of king eiders from Myggbukta

Anders Mosbech (AU) & Kasper Johansen (AU)

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

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

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

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

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

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

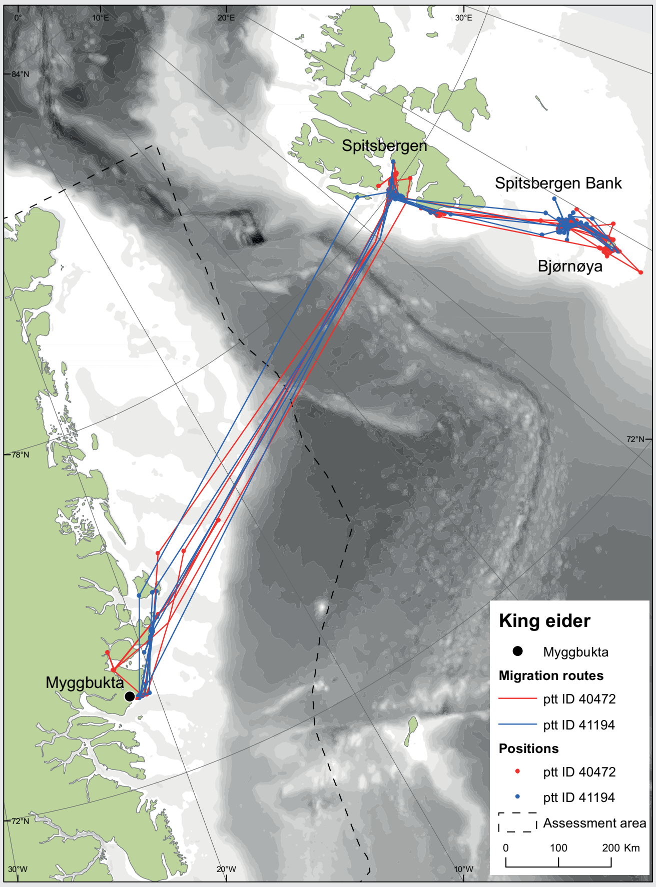
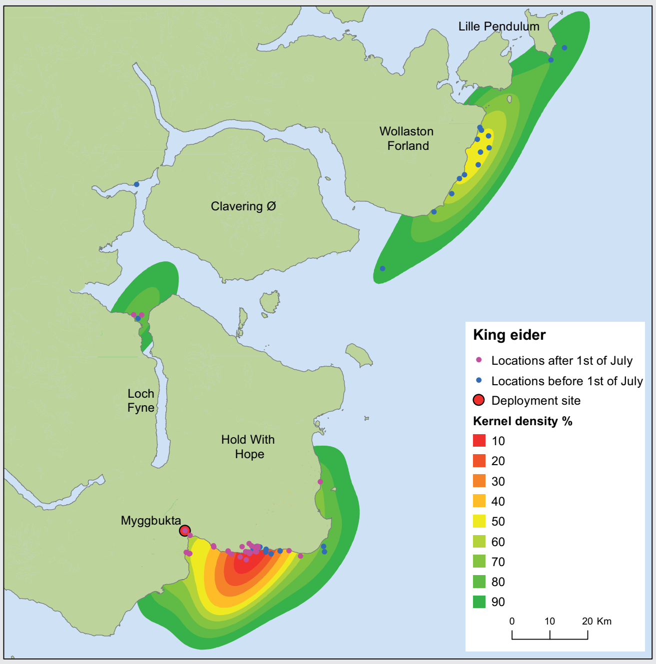


Figure 2. Kernel home range for the two king eiders tracked from Myggbukta. Locations before 1 July including pre-breeding locations are shown by blue dots, and locations after 1 July including post-breeding locations are shown by purple dots. Locations from the whole tracking period within the area shown on the map are included in the kernel analysis (summers 2009-2011).The Kernel home range contours represent an estimation of the areas in which a certain percentage of the locations will be found. Thus 90 % of the locations are found within the 90 % probability contour.



Box 3.11

Satellite tracking of a red-throated diver from Myggbukta

Anders Mosbech (AU) & Kasper L Johansen (AU)

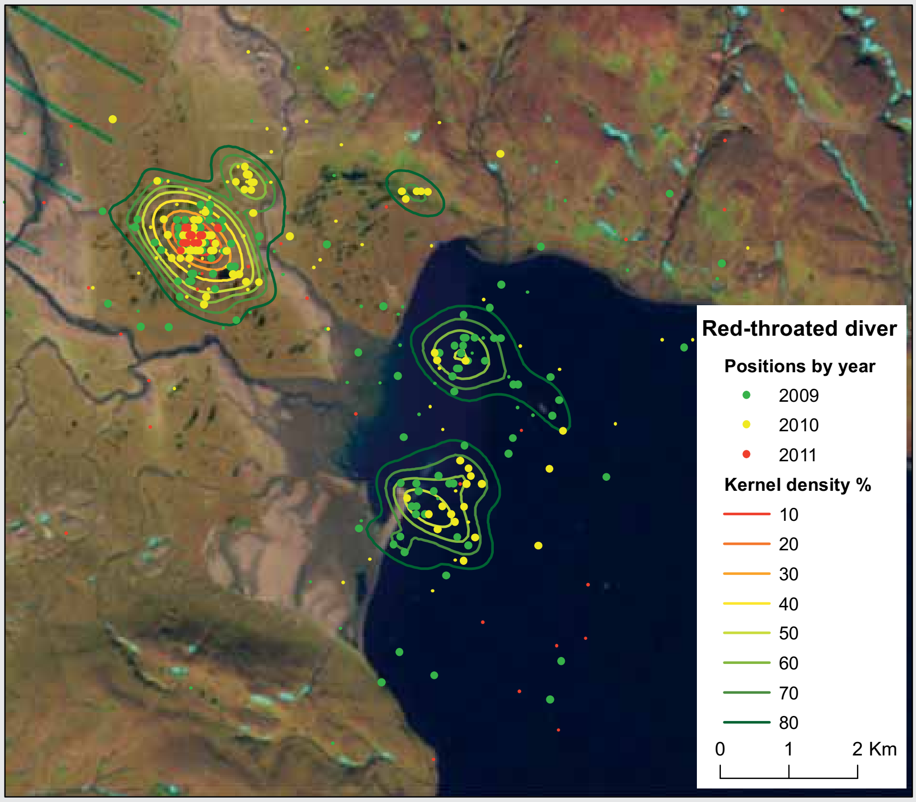


Figure 1. Kernel home range for the red-throated diver tracked from the breeding area in Myggbukta. The dots represent Argos positions differentiated by year (color) and accuracy (small = low, large = high). High accuracy positions from the whole tracking period within the area shown on the map are included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

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

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

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

The diver remained in Myggbukta until the onset of the autumn migration in the beginning of September (day of departure 6 September 2009 and 14 September 2010). It staged on the southwest coast of Iceland for 12-30 days (9-21 September 2009, 20 September-19 October 2010) before it embarked on the last leg of the trip to the wintering area along the coast of southeast England (Figure 2). Here it arrived 23 September in 2009 and 19 October in 2010 and remained until spring.

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

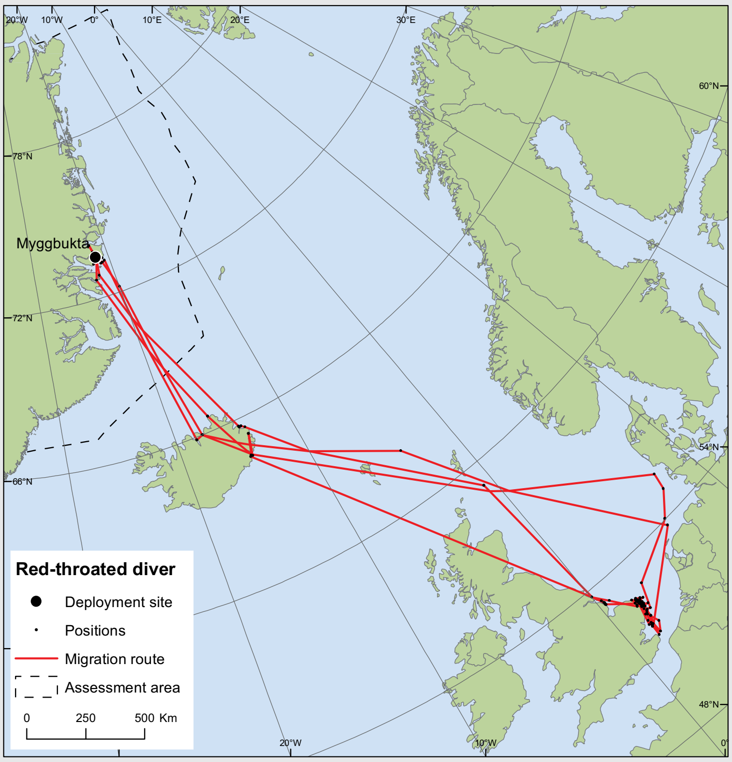


Figure 2. Locations and migration routes for a red-throated diver from Myggbukta tracked between 2009 and 2011.

data over 1993-2010, provided detailed information on movement of individual polar bears and habitat selection. More recent information is provided below with new data obtained in 2018 and 2019 from satellite transmitters deployed on adult female polar bears in April 2018 in Northeast Greenland.

Distribution and movements

In spring 2018, 10 satellite collars were deployed on polar female bears in Northeast Greenland during operations based in Danmarkshavn during 6-23 April, 2018 when approximately 65 helicopter flight hours were used searching for bears (Figure 43). Collar deployment was focused in the offshore region (n=7) within, or as close as possible to, the previous licence round area (Polar 43). A few collars (n=3) were deployed inshore with the goal of assessing whether polar bears using the coastal fast ice inshore also use the previous licence area. With additional external funding from the Danish Environmental Protection Agency's Dancea programme the efforts were expanded on the inshore coast areas and ten additional collars were deployed in this area in 2018, increasing the total numbers of tagged bears to 20.

Analyses of movements of these bears were restricted to covering the period between April 2018 and September 2019 (roughly 17 months), because collars will continue to transmit for up to 3 years. Therefore, the analyses presented here should be considered partial and incomplete, and will be updated in the future.

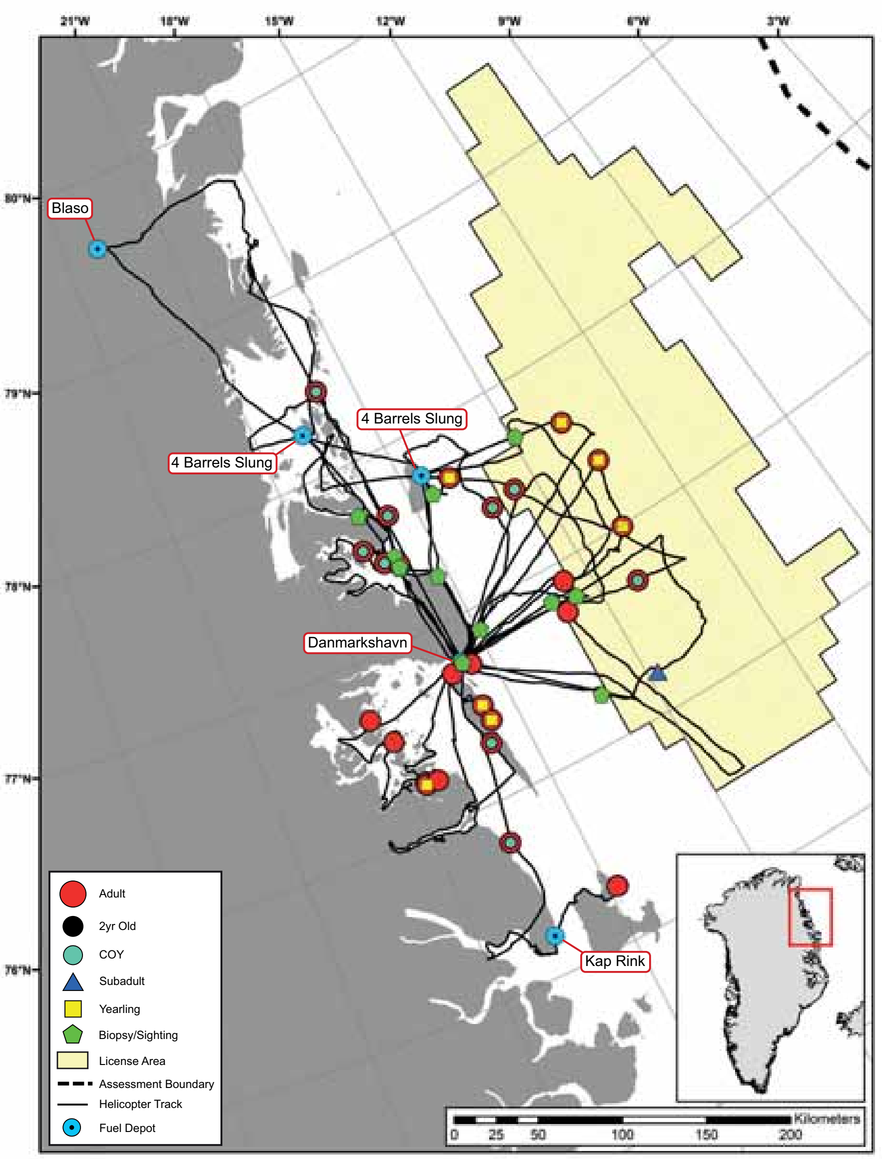


Figure 43. Flight paths during April 2018 searching for polar bears; tagging sites and the original licence area are shown. Field work was based out of the meteorological station Danmarkshavn and supported by fuel depots placed in summer 2017.

Table 6. List of adult female bears that were captured and collared in April 2018 based on field operations out of Danmarkshavn. Note that 10 bears were collared as part of the *Strategic Environmental Study Program for Northeast Greenland* ('Oil study') and 10 bears were collared as part of an externally funded program (Dancea).

Bear ID	Capture date	Category	Last transmission date	Collar drop	Total distance (km)	Transmission days	Days in licence area	% of transmissions in licence area	Funded by
2018115631	4/8/2018	Onshore	9/25/2019	No	3375.6	117	0	0.0	Dancea
2018115632	4/8/2018	Onshore	8/17/2018	No	42.0	34	0	0.0	Dancea
2018115633	4/8/2018	Onshore	7/15/2019	No	885.1	104	0	0.0	Dancea
2018115635	4/9/2018	Offshore	9/17/2019	No	6113.1	91	9	9.9	Oil study
2018115639	4/9/2018	Onshore	8/12/2018	Yes	N/A	N/A	N/A	N/A	Dancea
2018115636	4/10/2018	Onshore	9/29/2019	No	1737.3	98	0	0.0	Oil study
2018115638	4/10/2018	Onshore	9/29/2019	No	1449.4	105	1	0.9	Dancea
2018115642	4/10/2018	Onshore	9/28/2019	No	3408.6	127	0	0.0	Dancea
2018115641	4/10/2018	Onshore	9/28/2019	No	4214.6	121	2	1.7	Dancea
2018128259	4/11/2018	Offshore	9/28/2019	No	6346.4	100	15	15.0	Oil study
2018128258	4/11/2018	Offshore	7/30/2019	No	2050.1	111	8	7.2	Oil study
2018128263	4/14/2018	Onshore	9/20/2019	No	7464.1	99	10	10.1	Dancea
2018128260	4/14/2018	Onshore	9/28/2019	No	7352.0	91	5	5.5	Oil study
2018128262	4/14/2018	Onshore	9/1/2018	Yes	N/A	N/A	N/A	N/A	Dancea
2018128265	4/15/2018	Onshore	8/23/2019	No	5745.7	90	14	15.6	Dancea
2018128267	4/17/2018	Offshore	9/28/2019	No	6398.0	117	32	27.4	Oil study
2018131875	4/17/2018	Offshore	5/12/2018	Yes	N/A	N/A	N/A	N/A	Oil study
2018131876	4/18/2018	Onshore	7/7/2018	Yes	N/A	N/A	N/A	N/A	Oil study
2018131877	4/20/2018	Offshore	9/28/2019	No	3477.8	111	13	11.7	Oil study
2018131878	4/21/2018	Offshore	1/3/2019	No	3329.3	65	4	6.2	Oil study

Of the 7 offshore collars, one failed. Of the 13 inshore collars, three were dropped by the bear, or transmissions ended after a period of 3 months (Table 6). This left a total sample size of 16 collars for analysis, 6 "offshore" bears and 10 "inshore" bears to examine over the 17 month period of transmissions (Figure 44).

During the analysis period, bears moved extensively over the northeast and central eastern coastline and offshore into the assessment and the previous licence area (Figure 44). Bears used both fast ice and pack ice. A key finding was that both inshore and offshore collared bears use the licence area (Figure 45). The offshore bears spent between 6-27% of their time within the licence area boundaries during April 2018-September 2019. Half of the ten inshore bears with functional satellite transmitters spent between 1-15% of their time within the previous licence area boundaries during the same period while the remaining five did not visit the previous licence area. Of the 5 females that were captured with cub-of-the-year (COYs), 3 of them moved offshore into the previous licence area and used the regions extensively (Figure 46).

We assessed kernel ranges (95% probability) of inshore and offshore bears during the entire analysis period to examine space use and regions that were important for bears (Figure 47). The 10 inshore bears covered 151,344 km^2 with a kernel range focused in the inshore area but also the western half of the previous licence area. The 6 offshore bears covered 631,476 km^2 and their range was extensive covering the entire previous licence area and much of the assessment area. All bears together (n=16) covered 343,440 km^2.

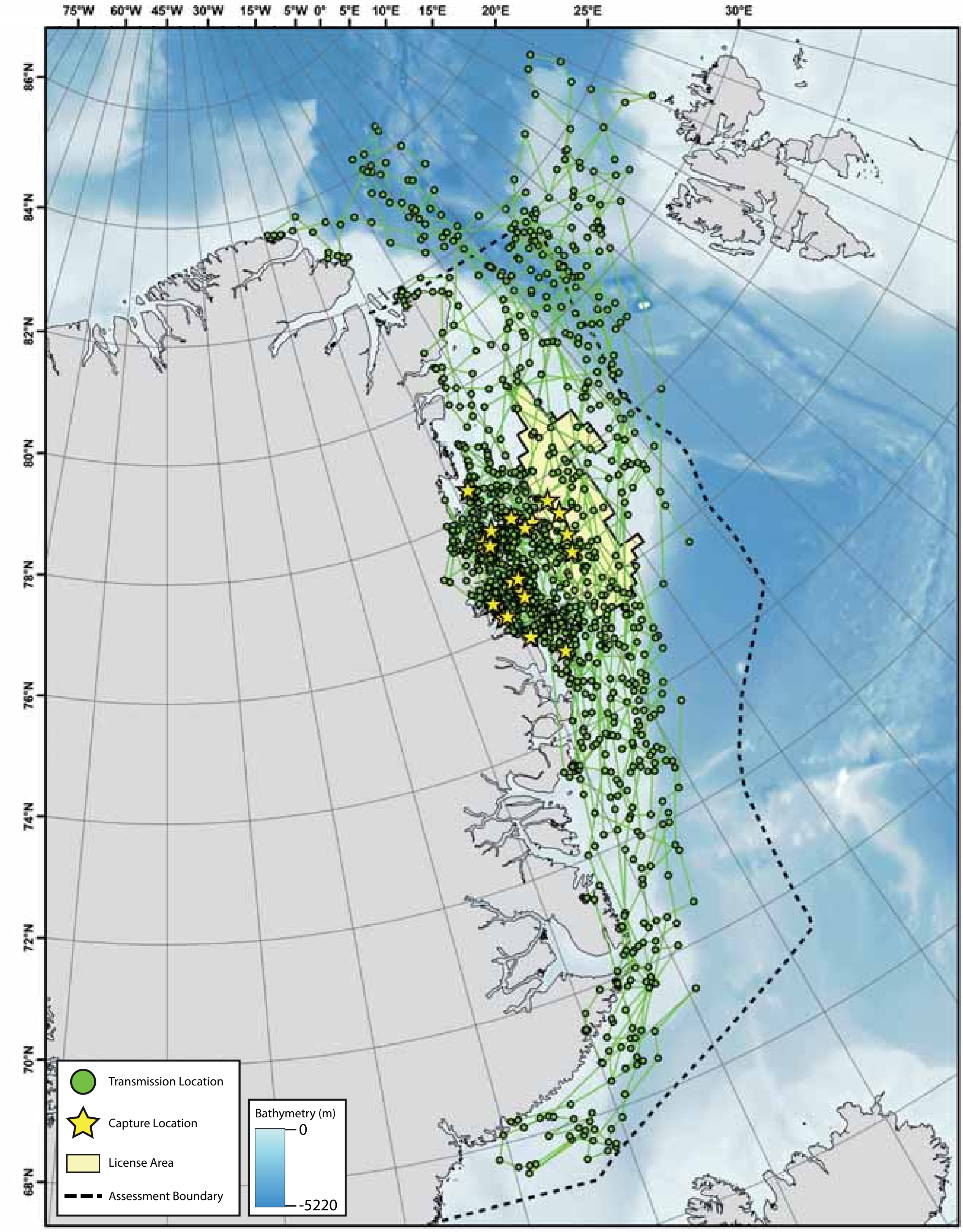


Figure 44. Capture locations and movements of 16 adult female polar bears collared in Northeast Greenland in April 2018. Movements are shown between April 2018 and September 2019. The original licence area is shown in yellow and the boundary of the entire assessment area is shown with a dashed line.

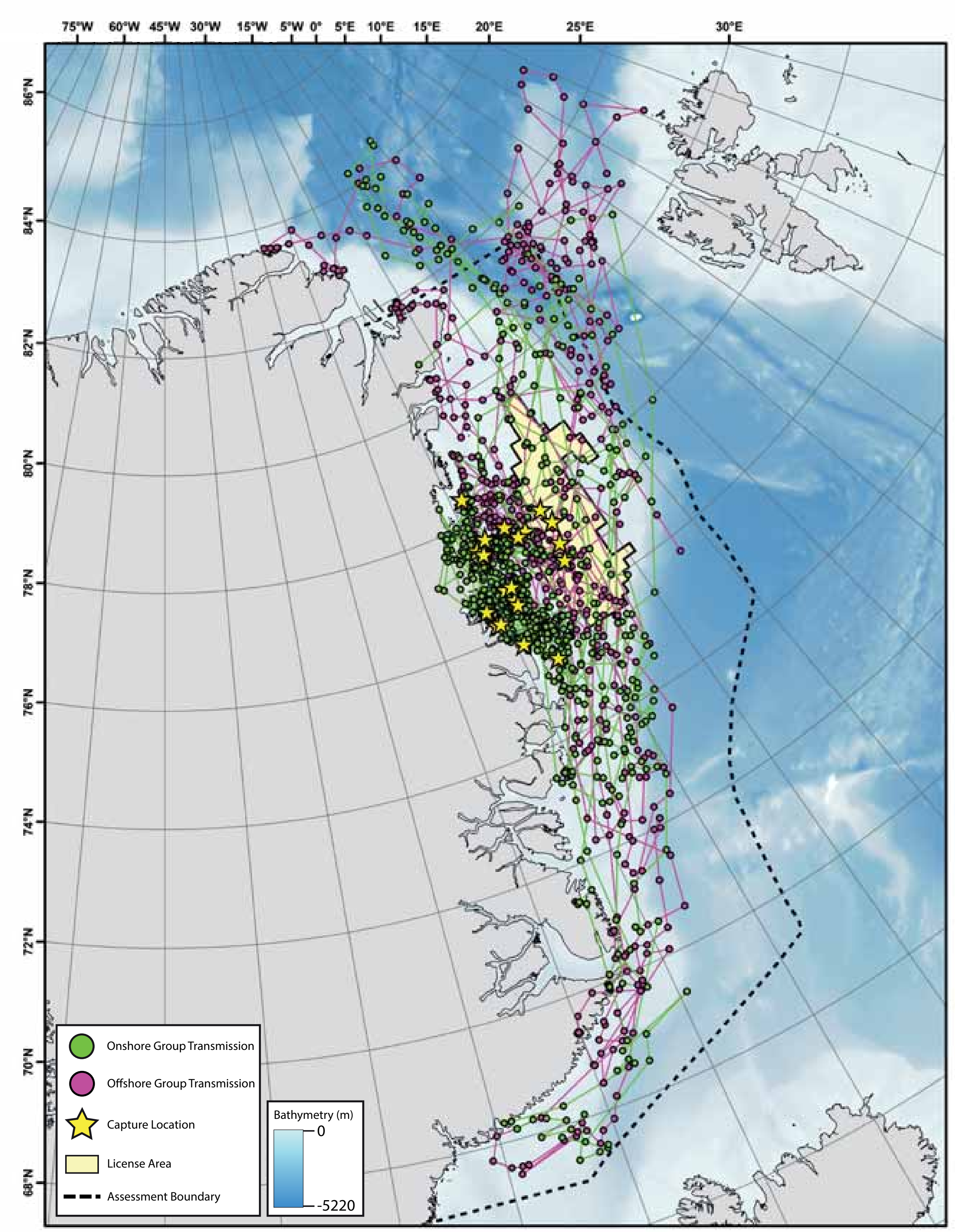


Figure 45. Movements of 16 adult female polar bears tagged in April 2018 split into “inshore” (green, n=10) and “offshore” (purple, n=6) animals based on tagging location.

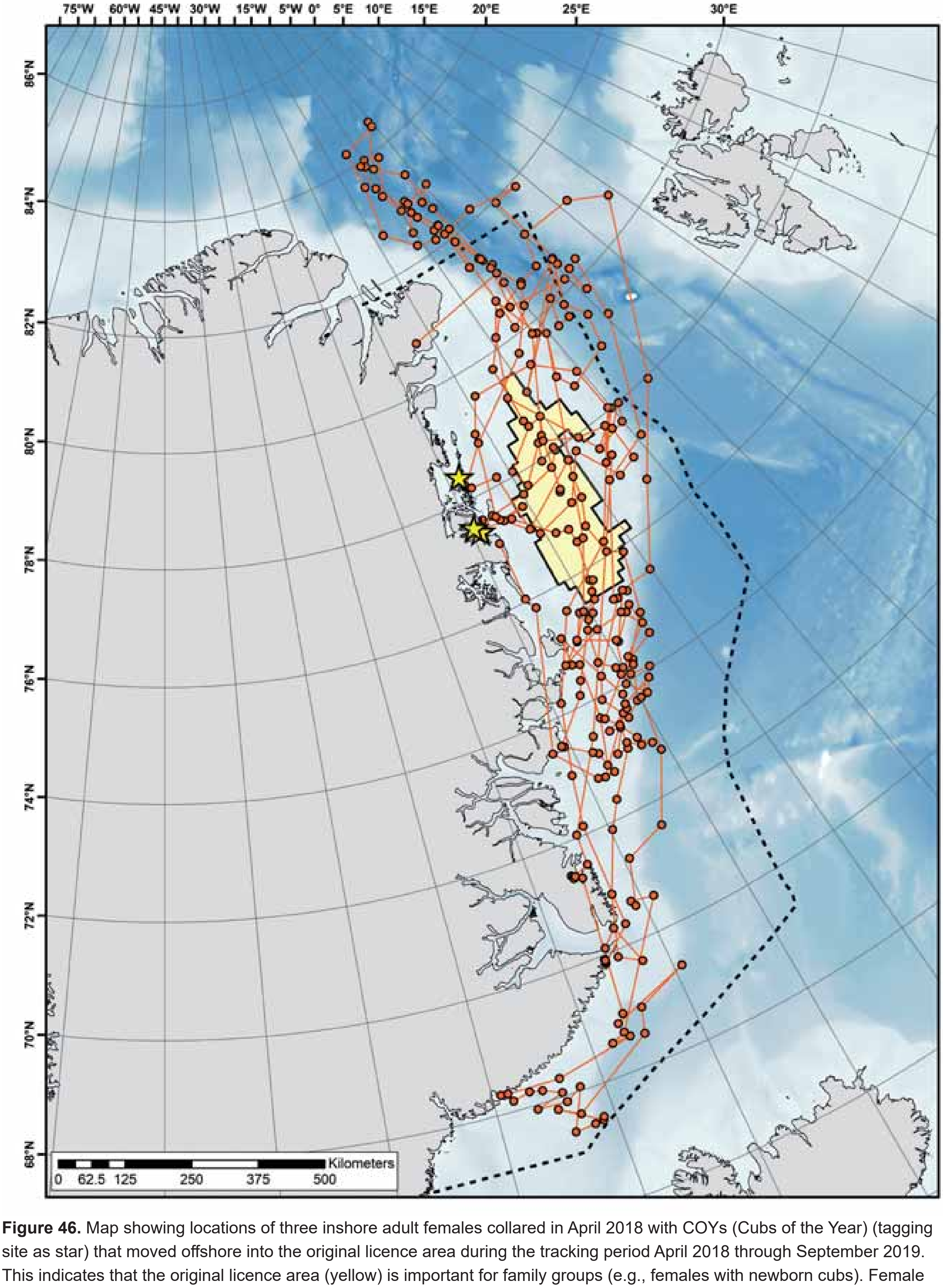


Figure 46. Map showing locations of three inshore adult females collared in April 2018 with COYs (Cubs of the Year) (tagging site as star) that moved offshore into the original licence area during the tracking period April 2018 through September 2019. This indicates that the original licence area (yellow) is important for family groups (e.g., females with newborn cubs). Female with COYs were also captured within the original licence area and on the border (dashed line).

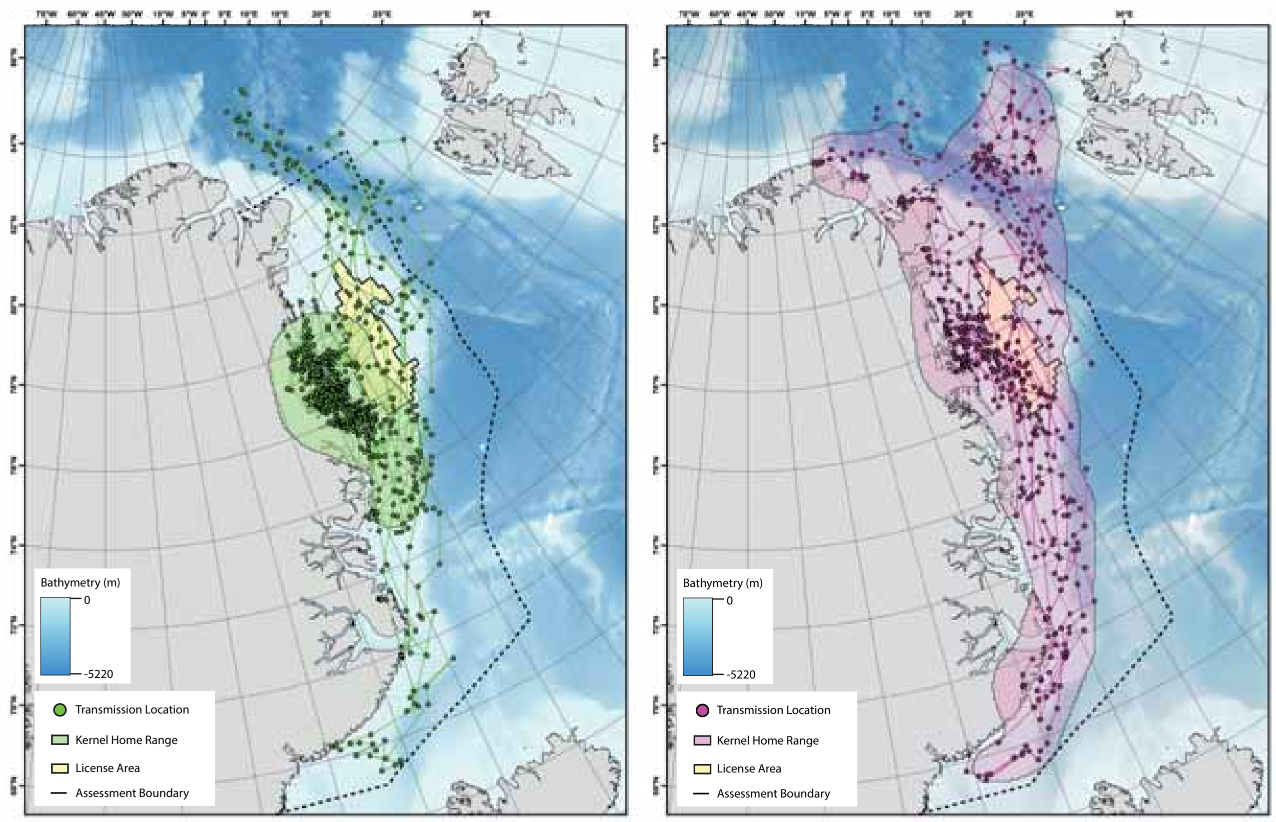


Figure 47. 95% kernel density area use plots for April 2018-September 2019 for inshore and offshore collared adult female polar bears, tagged in April 2018. The left plot shows 10 bears collared inshore while the plot on the right shows 6 bears collared offshore in (or on the border of) the original licence area (yellow).

We also assessed kernel ranges by season, looking at how 1) all bears, 2) offshore collared bears, and 3) inshore collared bears used the previous licence area. We examined three seasons: 'spring'' (April–June, also the mating season), ''summer'' (July–September, the reduced ice season), and ''winter'' (October–March) following Laidre et al. (2015). We crated kernels for each of the three categories of bears, and each of the three seasons.

Results showed that the previous licence area was used by bears in all seasons no matter whether they were collared "inshore" or "offshore" (Figure 48). The range of polar bears essentially covered the entire licence area for both all bears combined and offshore bears in spring, summer and fall. All bears combined had 95% kernel ranges that were 310,680 km^2 in spring, 295,524 km^2 in summer and 113,843 km^2 in winter. Offshore bears had range sizes that were 424,044 km^2 in spring, 445,572 km^2 in summer and 678,852 km^2 in winter. Inshore bears also used the previous licence area in all seasons, but less so in summer and winter. Inshore bears had 95% kernel ranges that were 185,940 km^2 in spring, 135,216 km^2 in summer, and 247,464 km^2 in winter.

Demographic identity of the East Greenland polar bear population

The polar bears in East Greenland are currently thought to constitute a single population with only limited exchange with other populations (Born 1995, Wiig 1995) and they are considered one management unit (PBSG 2010). Polar bears that are brought by the East Greenland pack ice to Southwest Greenland south of Paamiut (where they are also harvested) are thought to belong to the East Greenland population (Born 1995, PBSG 2010). The movements and habitat use by polar bears in Southeast Greenland south of Tasiilaq (approx. 65° N) are in the process of being studied outside of the scope of this work.

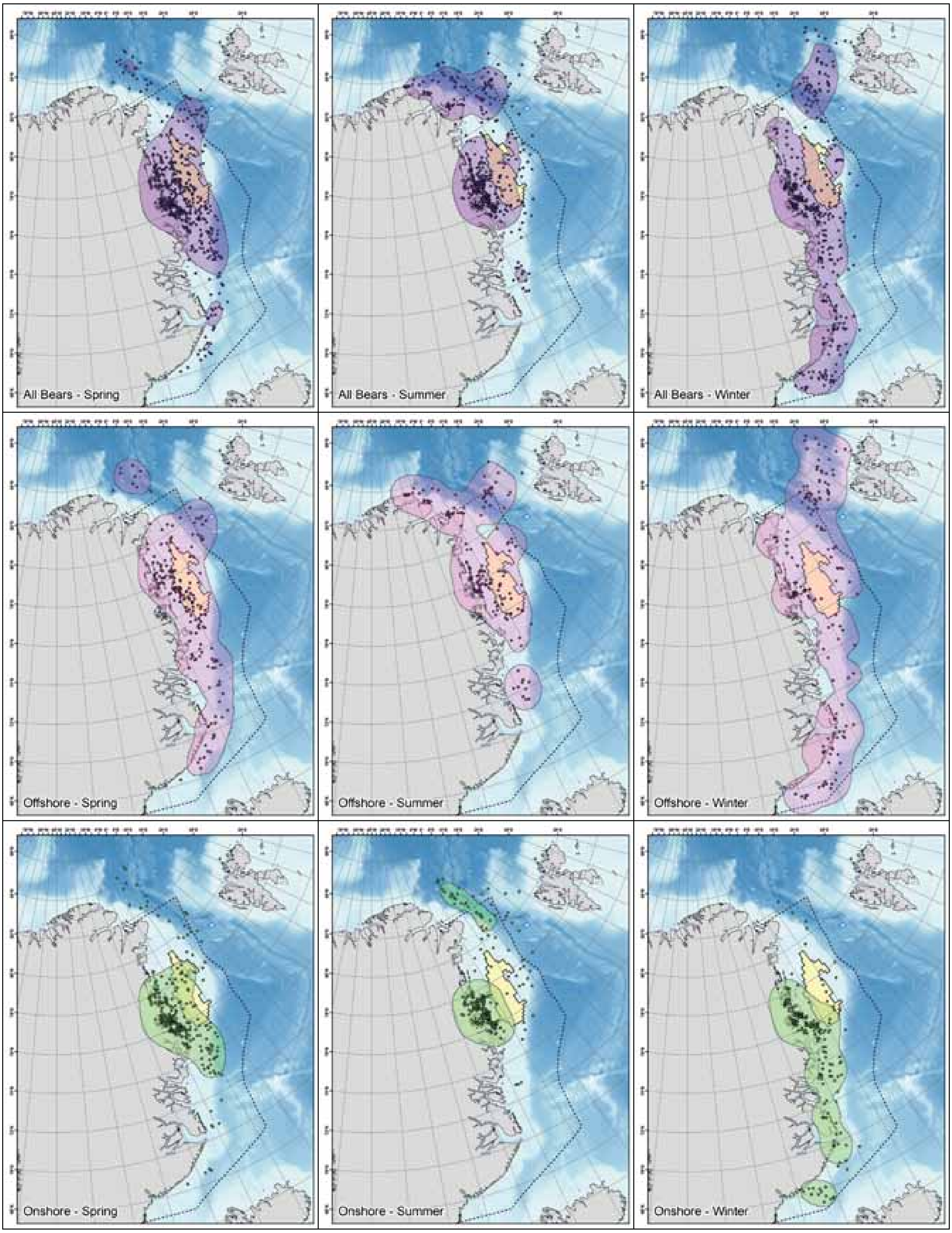


Figure 48. Kernel range sizes in each of three seasons (spring, summer and winter) for all bears (upper panel), offshore collared bears (middle panel) and inshore collared bears (lower panel). The original licence area is shown in yellow and the boundary of the entire assessment area is shown with a dashed line.

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

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

A genetic study revealed significant differences between polar bears from East and West Greenland (Paetkau et al. 1999). Limited exchange between the polar bear subpopulations in these two regions was also indicated by differences in concentrations of mercury in hair and internal organs (Born et al. 1991, Dietz et al. 2000, 2006). Preliminary data presented here support previous findings from movement studies that there is little exchange between the East Greenland and the Svalbard subpopulations (Born et al. 2012).

However, there was only minimal genetic difference between East Greenland and the neighbouring Barents Sea (i.e. Svalbard-Franz Josef Land) subpopulation to the east (Paetkau et al. 1999). Interestingly, in the study by Paetkau et al. (1999), polar bears from East Greenland were grouped with the Chukchi Sea, the Southern and Northern Beaufort Sea and the Barents Sea populations indicating that the East Greenland population is not genetically isolated from these other populations (Paetkau et al. 1999). Recovery in East Greenland of a few individual polar bears that were tagged in the Northern Beaufort Sea and the Barents Sea subpopulations support the notion that the East Greenland polar bear population is not entirely closed (Born et al. 2012).

Size of the East Greenland population

The size of the subpopulation of polar bears in East Greenland is unknown. Plans for an aerial survey in the previous licence area (and part of the assessment area) in spring 2021 will shed more light on densities and abundance in the area. Due to the lack of information on total population size in East Greenland (PBSG 2010) it is not possible to calculate the fraction of the entire subpopulation that may be influenced by oil activities in the assessment area. The habitat used by polar bears basically encompasses all fast ice and offshore pack ice along the entire East Greenland coast. There have been no population inventories covering this vast area and data are sparse (e.g. Aars et al. 2006). A mark-recapture study conducted in the fjords and along the coast between Kong Oscars Fjord and Dove Bugt in 1973–1975 (Vibe 1976a, b) resulted in an estimate of approx. 180 polar bears in the coastal areas between approx. 72° and approx. 77° N (Born & Rosing-Asvid 1989).

Maternity denning sites

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

During the field work in April 2018, a total of 55 polar bears were immobilized and tagged. Of these, 29 were "independent" bears (i.e. only adult and solitary subadult bears) and the remaining 26 bears were dependent cubs, which broke down into 16 cub-of-the-year (COYs) and 10 yearlings. No 2-year-old cubs were captured or sighted. This was a relatively skewed distribution relative to other capture programs and COYs in 2018 made up 29% of the sample. If yearlings and COYs were combined, then 0 or 1 year old cubs made up 47% of the total capture sample suggesting the area is important for adult females with young cubs.

Seven maternal denning sites used by five female bears were identified along the coast in 2007-2010. All these dens were on land. Five of the dens were clustered between 78° 44′ N and 81° 24′ N (i.e. along the shores of the Northeast Water Polynya) while two were on the coast north of Scoresby Sund between 71° and 72° N on Liverpool Land and Traill Ø, respectively. Two female bears denned twice during the study period and in both cases the dens were situated on the shore of the Northeast Water Polynya. Denning for the bears tagged in 2018 cannot yet be determined until collars transmit for at least 1-2 more years.

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

Miscellaneous historical observations of maternity dens and family groups with 0-year-old cubs indicate that maternity dens may occur along the entire East Greenland coast with an apparent tendency of higher densities north of approx. 68° N (Pedersen 1945, Born 1983, Dietz et al. 1985, Born & Rosing-Asvid 1989, Glahder 1995, Born et al. 1997, Sandell et al. 2001, Wiig et al. 2003), where ice and weather conditions are generally more stable than further south (Vibe 1967). Previous information indicates that the following areas are regularly used for denning: Kangerlussuaq, the Blosseville Kyst, the inner parts of the Scoresby Sund fjord complex, the areas between Kong Oscars Fjord and Kejser Franz Joseph Fjord, Shannon, Dove Bugt, the areas between Île de France and Ingolf Fjord, and the coast at the Northeast Water. Adult female polar bears choose the areas between Kong Oscars Fjord and Kejser Franz Joseph Fjord and the coast at the Northeast Water for denning and these are important maternity denning areas.

Amstrup & Gardner (1994) suggested that polar bears that exploit the drifting pack ice until just before den entry have a less predictable choice of denning location than bears living on stable ice. This was also indicated in Wiig et al. (2003) where a female in different years entered maternity dens that were situated more than 500 km apart on the East Greenland coast. It is likely that some polar bears exploiting the dynamic pack ice in the East Greenland Current may choose highly alternating sites for maternity denning and that their choice depends on the extension and density of the pack ice before den entry in that particular year. However, this tendency was not confirmed by the present study but it must be emphasized that sample size was small and the study only covers 1.5 years of tracking.

Larsen et al. (1983) noted that approx. 90% of the tracks that were observed during the FRAM I expedition at approx. 83° N off Northeast Greenland were of females with small cubs. Based on the distance of such tracks from the coast and with the resemblance to the ice situation off the northern coast of Alaska where polar bears use maternity dens in offshore pack ice, Amstrup

& DeMaster (1988) suggested that maternity dens may also be found on the multiyear pack ice in Northeast Greenland. However, this has not yet been confirmed during studies involving tracking of adult female polar bears (Born et al. 1997, Wiig et al. 2003, this study). The data from 2007-2010 support the notion that the East Greenland coast between ca. 72° N and ca. 74° N and between ca. 78° N and ca. 82° N are important maternity denning areas for female polar bears.

Harvest recoveries and the relationship with other polar bear populations

Among 27 tags that were recovered in East and SW Greenland (i.e. in the East Greenland polar bear management unit), 22 (81%) were polar bears that had been tagged in the East Greenland area (Figure 49). The majority of these (n = 15) were bears that were tagged in the central parts of East Greenland between ca. 72° 35′ N and 73° 23′ N between 1993 and 1975. They were shot by hunters in more and less the same area (i.e. between 69° 55′ N and 73° 08′ N) between 1974 and 1980 (Figure 49). Of six bears (3 females, 3 males) tagged north of 72° during 1979-1994, five were shot by hunters between ca. 70° and ca. 73° N in East Greenland. However, one was shot near Narsaq in SW Greenland confirming that bears that occur in SW Greenland belong to the East Greenland population. A 15-year-old male that was tagged in the pack ice on 17 March 2007 off Traill Ø (72° 13′ N, 19° 24′ W) as a part of the present study was shot near Isortoq in SE Greenland (65° 33′ N, 38° 58′ W) on 10 April 2010.

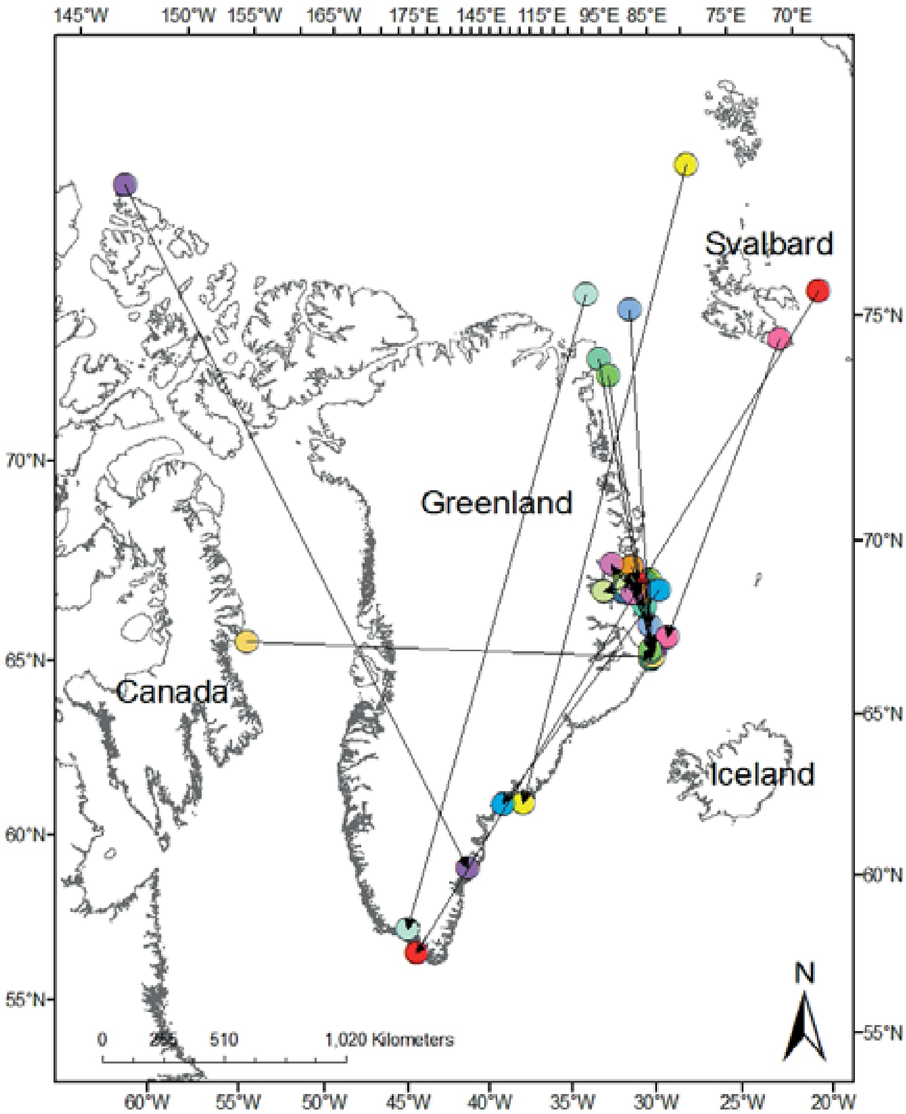


Figure 49. Locations of bears marked in East Greenland and other polar bear management units and recovered in East Greenland between 1967 and 2010; coloured dots are unique for each bear.

Movement of marked bears into the East Greenland region indicates there is likely a limited immigration to the East Greenland subpopulation from other subpopulations. Polar bears that were tagged in other polar bear populations were also recovered in East and Southwest Greenland. Three polar bears (2 males, 1 female) tagged in the Barents Sea population were recovered in SE and SW Greenland (tagging year/recovery year: 1967/1968; 1980/1986; 1989/1991). Furthermore, a female polar bear that was tagged in 1983 in the Baffin Bay population was shot at the entrance to Scoresby Sund in 1992. A male that was tagged in 1993 in the Northern Beaufort Sea population in 1993 was shot in SE Greenland in 1996. This demonstrates that some (but presumably very few) polar bears from other populations migrate to East Greenland (Born et al. 2012).

Five polar bears that were instrumented in the Svalbard area moved west-northwest and had some overlap with East Greenland polar bears in the Fram Strait-northern Greenland Sea during spring and summer. Overlap, as defined as a polar bear tagged in Svalbard entering the 95% seasonal home range of bears from East Greenland, occurred during the spring and summer season, specifically during the months of May, June and July (Figure 50). No overlap during the winter was detected. Hence, factors affecting East Greenland polar bears in their northern and offshore parts of their range may affect the Barents Sea population to an unknown extent.

In addition to the data summarized here there is information from satellite telemetry of migration to East Greenland. In the early 1990s, two polar bears instrumented with satellite transmitters in the Southern and Northern Beaufort Sea, respectively, visited Northeast Greenland (Durner & Amstrup 1995, Durner et al. 2007, 2009). This indicates that some polar bears mainly from the active ice in the rim of the Polar Basin migrate to East Greenland, presumably reflecting the main movement of the drift ice in the Polar Basin and East Greenland. However, given the fact that over the years several hundred polar bears have been tagged in the Southern and Northern Beaufort Sea (e.g. Stirling 2002, Regehr et al. 2006 and references therein), the migration of bears from these areas to East Greenland appears to be negligible.

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

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

Existence of separate populations in the East Greenland and Barents Sea regions has been indicated by the finding of significant differences in prevalence of various cranial traits in East Greenland and Svalbard-Franz Josef Land polar bears (Sonne et al. 2007, Bechshøft et al. 2008a, b, 2009). However there are currently ongoing studies in Southeast Greenland to assess genetic relatedness with Northeast Greenland and to look at sub-structuring.

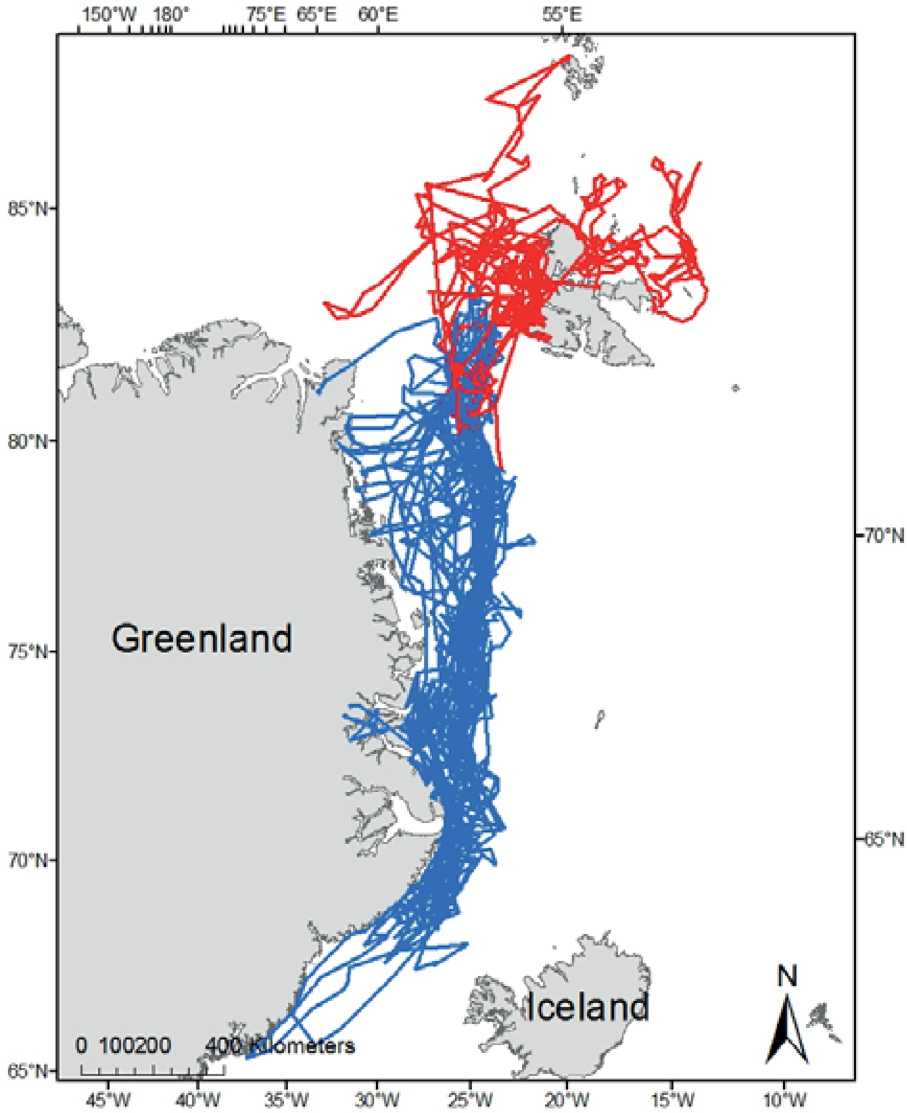


Figure 50. Tracks of polar bears monitored with satellite transmitters in East Greenland (2007-2010, blue) and the Svalbard region (2000-2008, n = 5, red). The polar bears from Svalbard represent a sub-set of polar bears that have been tracked in this region and the five bears from Svalbard were selected for this study because they moved into the assessment area. The map shows that there is some overlap during spring and summer in Fram Strait and the northern Greenland Sea between polar bears from the East Greenland and the Barents Sea populations.

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

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

The catch

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

In East Greenland, the majority of the catch activity takes place within approximately 100 km of the permanently populated areas and generally not far from the coast (Glahder 1995, Born 1983, Sandell et al. 2001). Historically, hunters from the community at the entrance to Scoresby Sund made sled trips on the fast ice in the fjords and along the coast to hunt polar bears as far north as the Dove Bugt (approx. 77° N) (Born 1983, Sandell et al. 2001). Apparently, it was common to make such trips in the 1970s and 1980s, but hunting activity in the areas north of Scoresby Sund decreased during the 1990s (Sandell et al. 2001). Recent studies of traditional ecological knowledge (TEK) of the hunters indicate that these trips have all but ceased and most bears are caught just outside the community, within 50 km, which may reflect a decrease in sea ice around the communities bringing polar bears closer to populated areas (Flora et al. 2019). Hunters interviewed in Traditional Ecological Knowledge surveys have speculated this may be a consequence of sea ice loss bringing bears closer to communities or introduced quotas in 2006 which may have increased the number of bears close to Scoresby Sund (Laidre et al. 2018).

In Greenland, quotas for the polar bear hunt were introduced 1 January 2006. The annual quota for the East Greenland subpopulation for the period 2007–2009 was 54 (30 in Ittoqqortoormiit, 20 in Tasiilaq and 4 in Southwest Greenland). This was raised to 64 in 2011 (35 in Ittoqqortoormiit, 25 in Tasiilaq and 4 in Southwest Greenland; Government of Greenland 2012) and continues today (Anon. 2019) until new scientific advice is available.

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

Future scenario and conservation status

Using 10 of the scenarios by the Intergovernmental Panel of Climate Change (IPCC) of projected decrease of sea ice and resource selection functions (RSF) based on data from satellite telemetry on polar bear habitat preferences including data from East Greenland (1993-1998), Durner et al. (2007, 2009) forecasted that optimal polar bear habitat in East Greenland will decrease substantially during the next 50–100 years. The decrease will be most pronounced during spring and summer. A decrease in sea ice in the southern range of the polar bears will imply that areas with optimal polar bear sea ice habitat in Northeast and North Greenland will become more important. Laidre et al. (2015) also reported that bears in East Greenland were using poorer habitats (reduced ice concentrations and areas closer to open water) in the 2000s compared to the 1990s. Hence, it is projected that the northern parts of the assessment area progressively will be of increasing importance to the East Greenland population of polar bears.

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

Sensitivity and critical habitats

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

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

Polar bears make extensive use of the offshore sea ice in the assessment area throughout the year. New data from bears collared in 2018 support historical data showing that the assessment area, and the previous licence area, is important for bears collared both inshore and onshore. This is important because the inshore area appears to be key habitat for adult females with young cubs (COY and yearlings). Data also support the fact that these females with new cubs (COYs) move into the previous offshore licence area, when cubs are ready to travel in the pack ice. This means the previous licence area is important for reproduction, primarily after females leave their maternity dens in the coastal area to search for food offshore. The bears show a clear preference for areas with dense sea ice and shift their distribution north in the assessment area during the open water season to exploit areas where drift ice remains during summer. The polar bears may den widely scattered along the east coast of Greenland. However, previous satellite telemetry studies have indicated that the coastal areas between ca. 72° N and ca. 74° N and between ca. 78° N and ca. 81° N are traditionally used maternity denning areas. This will be updated with the 2018 data once a few years pass and all collar transmissions are received, and it is important to realize that the dataset presented here (and therefore results) are only partial.

3.8.2 Walrus

Erik W. Born (GINR)

General biology

Walruses are benthic feeders that usually forage where water depths are less than approx. 100 m (Vibe 1950, Fay 1982, Born et al. 2003), although they occasionally make dives to at least 200–250 m depth, both inshore and offshore in Northeast Greenland (Born et al. 2005, Acquarone et al. 2006). Dives to 400-500 m depth have been recorded at Svalbard (Lowther et al. 2015) and in Northwest Greenland (Garde et al. 2018b).

Walruses are gregarious year-round (Fay 1982, 1985). They use terrestrial haul-outs in the vicinity of shallow areas with suitable food, and winter in waters with not too dense ice and predictable access to food (Born et al. 1995 and references therein). In East Greenland such habitat is mainly found north of approx. 73° N (Born et al. 1997). During the mating season (January-April; Born 2001, 2003 and references therein) male walruses engage in ritualized visual and acoustic display under water (Fay et al. 1984, Sjare & Stirling 1996, Sjare et al. 2003).

Distribution

The walruses in East Greenland are distributed across most of the shelf areas within the assessment area (Figure 51). They are more or less segregated by age and sex class for most of the year: there is a tendency that most adult females with young stay year-round in the areas north of approx. 79° N whereas adult males migrate southward along the coast to their traditionally used terrestrial haul-outs, of which the southernmost is located at 74° N (Born et al. 1997, NAMMCO 2009, Born et al. 2010). However, in recent years females with calves have been observed between 74° N and 77° N during summer (Born et al. 1997, Boertmann & Nielsen 2010a, Boertmann et al. 2019a) with an apparent increase since 2001 (Born & Acquarone 2007). This may indicate an expansion of the range of the female portion of the East Greenland subpopulation. Some males venture further south to Scoresby Sund and a few even to Tasiilaq. The seasonal distribution of catches there indicates that walrus stragglers can occur in southeastern Greenland at all seasons with the possible exception of December (Born et al. 1997); however, catch records (1993-2006) show a peak in June-September (Born et al. 1997). At the entrance to Scoresby Sund the catches peak during May-July (see Figure 72). Both here and at Tasiilaq, this seasonal distribution of the catch may reflect both an increased hunting activity during spring and early summer, and an increased occurrence of walruses.

According to inhabitants living in Ittoqqortoormiit (at the entrance of Scoresby Sund), the number of walruses frequenting this area has increased in recent years. This is ascribed to the fact that walruses have been protected since the 1950s in the areas further north (Born 1983).

Today walruses occur most frequently between Clavering Ø and Dove Bugt, where several terrestrial haul-outs are used – the most important ones are on Sandøen, Shannon Island, at Kap Carl Ritter and at Lille Snenæs in Dove Bugt. However, the latter has not been used in recent years, and the walruses tend to give up some of the haul-outs to find new. The reason for this apparent change in area occupancy during the recent decade is unclear (Born et al. in prep.).

North of Dove Bugt, the most important area is the Northeast Water Polynya, where females with calves are numerous in summer, and where many males also seek to for the winter. A terrestrial haul-out used by adult female and subadult walruses was located on southern Lynn Ø in Dijmphna Sund (Born et al. 2009, Born et al. in prep.).

Walruses occur primarily along the coasts but may also occur several hundred kilometres offshore during spring and summer (Dietz et al. 1984, Born et al. 1997). Satellite telemetry has shown that individuals may make what is assumed to be foraging excursions more than 150 km offshore from their haul-outs (Born & Acquarone 2007, Born et al. in prep.), and that adult males also make fall migrations from their summer grounds at 74°-77° N northward to the Northeast Water Polynya; some of them move more or less along the continental shelfbreak (Born et al. in prep.).

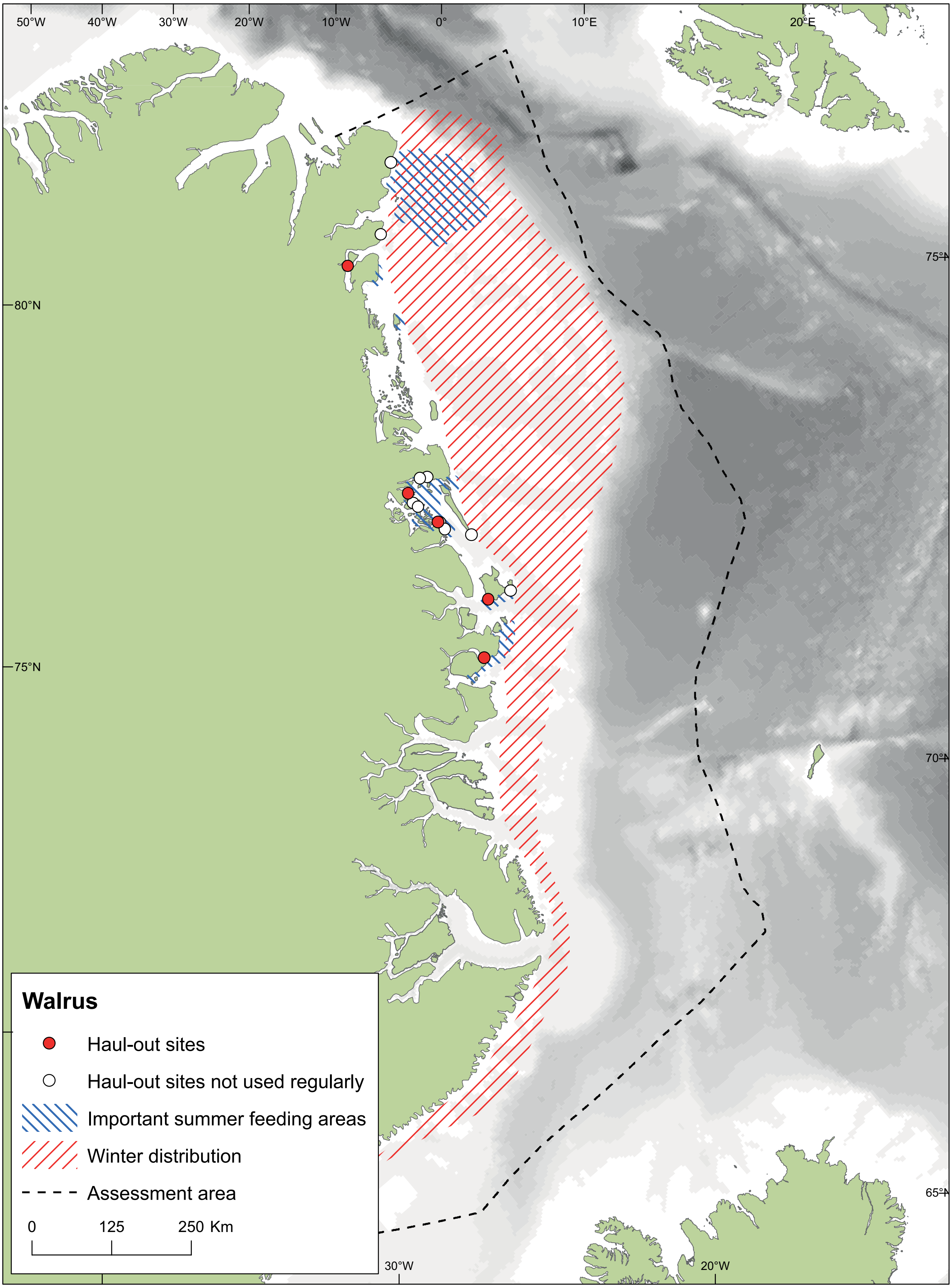


Figure 51. General distribution of walrus in the assessment area. The terrestrial haul-outs are those which have been used regularly in recent years by several individuals. The signature for sites not used regularly only show the main ones; there are many more where only a single individual have been observed once.

Important habitats – terrestrial haul-outs

The traditionally used terrestrial haul-out sites constitute an important element in the life history of walruses and walruses show great site tenacity to these sites during summer (Born et al. 1997, Born & Acquarone 2007).

During the open water season the haul-out at Sandøen is used regularly by a large group of walruses – in 2002 up to at least 40 different individuals (Born & Acquarone 2007). Apparently, the number of walruses using this site has increased since the early 1980s (Born et al. 1997), although sporadic observations indicate that recently the numbers may have diminished somewhat (Boertmann et al. 2019a, b).

During summer, walruses in Northeast Greenland are sexually segregated to a large extent. Adult males are mainly found between 74° N (Clavering Island) and 77° N (northern Dove Bay) whereas the majority of adult females with young and calves stay year round north of 77° N and especially in the Northeast Water Polynya area (Born et al. 1997, 2009) although, as noted above, females with calves have been observed between 74° N and 77° N during summer in recent years.

Tracking of 32 male walruses that were fitted with satellite transmitters on Sandøen and Lille Snenæs between 1994 and 2010, and aerial surveys conducted along the shores of Northeast Greenland north of ca. 74° N in August 2009, provided further information on the terrestrial haul-outs. At least 12 terrestrial sites have been used regularly, although in recent years only five sites (Dijmphna Sund, Lille Snenæs, Kap Carl Ritter, Fredens Bugt and Sandøen; Figure 51) have been used. At many more sites (n = 19) walruses have been located on land at least once. Until recently these sites were used exclusively by males, but since 2009 a limited but increasing number of females and calves have been observed at some of the sites and one site seems to be used exclusively by females and calves (Born et al. in prep.).

Important habitats – wintering areas

Besides the haul-outs, areas where walruses concentrate in winter are important habitats. Various sources (Dietz et al. 1985, Born et al. 1995, 1997, 2005) indicate that walruses winter in the following areas in East Greenland of which many are polynyas: the entrance to Scoresby Sund, the Gael Hamkes Bugt area at Kap Borlase Warren along Wollaston Forland and Sabine Ø, at Shannon Ø, and the southern tip of Store Koldewey as well as in the Northeast Water Polynya. Tracking studies (1994-2010) confirmed three wintering areas, all of which are perennial polynyas (Figure 12): The Northeast Water area, the entrance to Young Sund-Wollaston Forland area, and the entrance to Scoresby Sund (Born et al. in prep.).

It is likely that some walruses also winter scattered along the coast in the shear zone between land-fast ice and the moving pack ice.

Movements

Tracking studies by satellite telemetry have documented long-range movements along the coast of Northeast Greenland. Of 10 adult male walruses tagged with satellite transmitters at Lille Snenæs during summer (1989-1990, 2000-2001), three moved offshore from Dove Bugt during the period of formation of land-fast ice some time during October. They subsequently moved north about 200-300 km offshore to winter in the Northeast Water area (Born & Knutsen 1992, Born et al. 2005, Born et al. in prep.).

Similarly, relatively shortly after having been furnished with transmitters in August 2008, 2009 and 2010 at Sand Ø in Young Sund, six of the 18 tagged male walruses moved far north in Northeast Greenland, traveling along the eastern edge of the continental shelf in the Greenland Sea. Three of these walruses reached the Northeast Polynya from where two transmitted during winter (Born et al. in prep.).

The walruses' mate in winter with an apparent peak in January–April (Born 2001, 2003 and references therein). Because the majority of the adult female walruses in the East Greenland subpopulation stay year-round in the Northeast Water area (Born et al. 1997, Born et al. 2009), this area is likely an important mating ground, and some adult male walruses therefore migrate from their summering grounds to the Northeast Water.

Individual walruses tagged at Sandøen and Lille Snenæs, respectively, occurred along the East Greenland coast between 69° 30′ N (entrance to Scoresby Sund) and 81° 40′ N (Nordostrundingen) covering a stretch of the coast which has a straight line distance of 1300 km (Born et al in prep.). This indicates that walruses occurring in Northeast Greenland constitute one coherent group.

Delineation of populations

Genetic studies indicate that the walruses in East Greenland constitute a separate subpopulation, which has only limited exchange with neighbouring subpopulations in West Greenland and at Svalbard-Franz Josef Land (Cronin et al. 1994, Andersen et al. 1998, 2009, 2017b, Born et al. 2001). Satellite telemetry has supported the notion that walruses in East Greenland and at Svalbard-Franz Josef Land belong to two separate subpopulations as there has been no overlap in the ranges of the walruses that have been tracked in these two areas (Born & Knutsen 1992, Born et al. 2005, Born & Acquarone 2007, Wiig et al. 1996, Freitas et al. 2009).

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

East Greenland subpopulation size

Based on miscellaneous observations, a rough estimate of 500 to 1000 walruses in the eastern Greenland subpopulation was tentatively suggested by Born et al. (1995, 1997). An aerial survey to determine the abundance of walruses in East Greenland was conducted between ca. 74° N and 81° 45′ N during 12-19 August 2009. This resulted in a corrected estimate of walruses in their prime distribution area in East Greenland at 1429 individuals (95% CI: 616-3316 (Born et al. 2009, NAMMCO 2009). Based on the distribution of observations, an estimated 10% of the total stock (primarily males and subadults) were present along the coast south of ca. 77° N and the remaining approx. 90% were in the Northeast Polynya area north of ca. 80° N and west of ca. 9° W (Born et al. 2009).

An aerial survey conducted in 2017 to determine the size of the East Greenland walrus subpopulation north of 74° N resulted in an estimate of total abundance of 350 individuals (95% CI: 277-442). A re-analysis of the 2009 aerial survey data resulted in a corrected estimate of the total stock of 559 (95% CI: 365-856) for that year (Hansen et al. 2018a). However, none of the surveys covered all the haul-out sites simultaneous with offshore areas, and correction factors for undetected walrus were considered inadequate for both surveys. Hence, both abundance estimates are likely negatively biased to an unknown degree due to survey coverage and correction factors (Hansen et al. 2018a).

Back-calculation to original population size (i.e. before foreign sealers initiated their catches in the late 1800s), resulted in estimates ranging between approximately 1500 and 1900 walruses in the pristine East Greenland stock (Born et al. 1987, Witting & Born 2005, Witting et al. 2009).

The catch

The East Greenland subpopulation of walruses is subject to hunting at a limited scale by subsistence hunters living in the areas of Tasiilaq and Ittoqqortoormiit (Born et al. 1997). The catch consists almost exclusively of males although a few subadults and adult females are occasionally killed in the Scoresby Sund area (Born et al. 1997, Witting & Born 2014, Garde et al. 2018a, Greenland Department of Fishery, Hunting and Agriculture (DFHA), Nuuk, in litt., January 2017). After 2006 when quotas took effect (Wiig et al. 2014) the reported annual catch in East Greenland (2007-2018) has averaged ca. 6 (range: 2-10/year; Garde et al. 2018a). About 80% of this catch was taken by hunters from Ittoqqortoormiit (ibid.) which is situated closer to the main distribution area of East Greenland walruses than Tasiilaq. The 2020-quota for the catch in East Greenland (including “struck-but-lost”) is 17 (Anon. 2019).

In the Scoresby Sund area walruses are taken at the entrance to the fjord complex (Born 1983, Sandell & Sandell 1991). They can be caught in all seasons with a peak in May-August (Born et al. 1997, Garde et al. 2018a).

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

Conservation status

Today, walruses are fully protected within the National Park in North and East Greenland, although hunters from Ittoqqortoormiit are allowed to catch walrus there. In 1951 (i.e. before establishment of the national park in 1974), they became protected north of 74° 24′ N and since then the East Greenland subpopulation has apparently expanded its range, suggesting that the numbers have increased (Born et al. 1997, NAMMCO 2009, Wiig et al. 2014).

The population is listed as ‘Near Threatened’ (NT) on the Greenland Red List and the Atlantic population of walrus is assessed as ‘Near Threatened’ (NT) (Kovacs 2016c).

Sensitivity and critical habitats

In particular when hauled out on land, walruses are sensitive to disturbance, including sailing, traffic on land, and flying (Born et al. 1995 and references therein). Based on fieldwork in the assessment area Born & Knutsen (1990) concluded that air traffic should keep a distance of 5 km from walrus haul-outs in order to minimize disturbance. Moreover, the official guidelines to seismic surveys in Greenland identify specific walrus protection areas (‘closed areas’) along the coast near the haul-outs, and ‘areas of concern’ in the offshore areas (Figure 66) (EAMRA 2015).

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

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

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

1. Walruses are highly gregarious, and a spill will likely affect many individuals.
2. Their pronounced thigmotactic behaviour (occurring in groups where individuals have close body contact) on ice and on land makes it likely that oil-fouled walruses will transfer oil to other individuals.
3. In ice-covered waters spilled oil will accumulate in the restricted open waters, where walruses (and other marine mammals) tend to aggregate to breathe and where the risk of being impacted is very high.
4. Because they are benthic feeders, walruses may be more likely to ingest petroleum hydrocarbons than are most other seals. Benthic invertebrates are known to accumulate petroleum hydrocarbons from food, sediments and the surrounding water (see Richardson et al. 1989a).
5. Walruses are stenophagous (i.e. have a narrow food niche) and depend on access to mollusc banks in shallow water. Oil spills in certain feeding areas could deplete the resource and 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. Also, oil spill countermeasure activities have the potential to scare away walruses from their traditional habitats.

The most important areas for walrus in the assessment area are the terrestrial haul-outs and their surrounding waters which are used for foraging. Based on satellite telemetry these surrounding waters may stretch up to ca. 150 km from a haul-out. Based on the distribution of traditionally used haul-outs the inshore and coastal areas between ca. 74° N and ca. 77° N, and the coasts of the Northeast Water Polynya constitute critical walrus habitat during summer. During winter essential critical walrus habitats are the polynyas: (1) The Northeast Water area, (2) the entrance to Young Sund-Wollaston Foreland area (the Sirius Water Polynya), and (3) the entrance to Scoresby Sund.

3.8.3 Seals

Aqqalu Rosing-Asvid (GINR)

The assessment area is home to four seal species. Two species, the ringed seal and the bearded seal, are resident although some individuals perform long migrations outside the assessment area. The other two species, the hooded seal and the harp seal both give birth and moult in the assessment area, but the majority of these seals will perform seasonal migrations out of the assessment area.

Hooded seal

Hooded seals are large seals. Females measure about 2 m and males up to 2.6 m. In summer when they are leanest (after the moult), the full-grown females weigh 150-200 kg, while full-grown males can weigh 250-300 kg. Late in winter just before the breeding season females can have a weight of to 300 kg and the largest males to around 450 kg.

Hooded seals dives deeper than other Arctic seals and will regularly forage below 500 m. The deepest registered dive is 1652 m (Andersen et al. 2013). Adult seals mainly eat large fish and squids, while the young seals eat smaller fish like capelin and polar cod.

Distribution: The Greenland Sea population of hooded seals whelp in the same area as the harp seals (Figure 52), but more dispersed. The position of the whelping grounds varies between years, depending on the distribution of the pack ice, but both the whelping and the moulting areas will normally be within the assessment area. Moulting is also roughly in the same area (in June-part of July), but again the seals can be quite dispersed. Sergeant (1976) assign the moulting area to be on the pack/drift ice between 72° N and 76° N. Outside the whelping and moulting season, most hooded seals migrate eastward. Some hooded seals will reach the Barents Sea, but the majority migrate into the Norwegian Sea. Many of the migrating seals move forth and back between the assessment area and foraging areas in the Norwegian Sea. Tracking studies show that the movements of the pups are very similar to that of the adult seals. Hooded seals will often sleep in the water (Andersen et al. 2014), and they rarely haul-out outside the breeding and moulting season. Surveys outside these periods will therefore only encounter a low fraction of the seals in the survey area (see Figure 56 for seal observations from ship-based surveys).

Population: The hooded seals are believed to have been reduced from more than a million around World War II to around 80,000 when the commercial sealing stopped in 2007. The estimated total 2018 population of hooded seals in the Greenland Sea (based on surveys and model-projections) is 76,623 (95% CI: 58,299-94,947) individuals, and the latest survey estimate of the pup production (2018) was 12,977 (95% CI: 9867-17,067) pups (ICES 2019).

The catch: Norwegian sealers strongly reduced the hooded seal population in the Greenland Sea during the years after World War II. Quotas have regulated the commercial sealing in the Greenland Sea since the 1980s and while the harp seals have doubled in numbers since then, the hooded seals have failed to recover. Therefore, the commercial catches of hooded seals in the Greenland Sea stopped in 2007, and the subsistence hunting on this population is only by hunters from Ittoqqortoormiit, taking on average less than 10 seals/year. So far, however, there has been no sign of a recovery of the population.

Conservation status: The global population of hooded seals is listed as 'Vulnerable' (VU) by IUCN and on the Greenland red list (Kovacs 2016a, Boertmann & Bay 2018), because the population is decreasing (ICES 2019).

Sensitivity and critical habitats: The seals need ice floes for the whelping and moulting. The pups only lactate for 4 days during which they gain 7 kg/day and they start to swim and dive shortly after weaning (Folkow et al. 2010). The position of the main whelping area vary, depending of the distribution of the sea ice. The whelping area (in late March-early April) and the moulting area (June-early July) are areas where a large fraction of the population aggregate, and in these areas the seals are sensitive to both oil spills and disturbance.

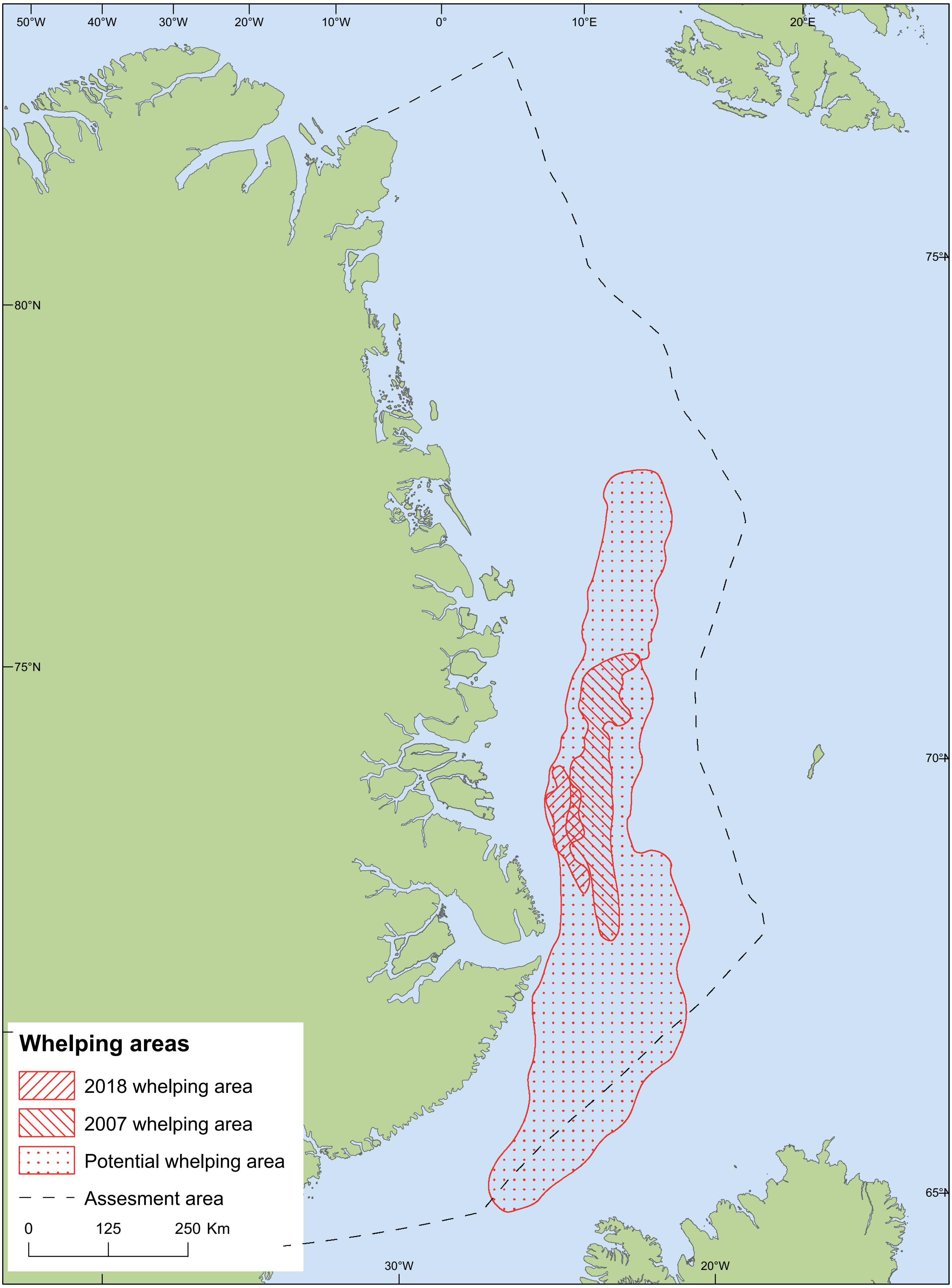


Figure 52. The potential and the actual whelping area in 2007 and 2018 for harp and hooded seals in the Greenland Sea. The potential area is where the whelping has been recorded in recent decades (Øigård et al. 2008, ICES 2019).

Harp seal

Harp seals are medium sized seals; adult males grow to 1.70 m on average and females about 5 cm shorter. After the moult in June they weigh about 80-90 kg but throughout the summer and fall they gain weight and prior to the breeding season in late March they weigh around 130-140 kg.

Capelin and polar cod are the principal prey in most areas, but krill and amphipods (*Parathemisto* spp.) might also be important.

Distribution: Harp seals assemble in large concentrations to whelp and nurse their pups on pack/drift ice in the assessment area more or less in the same area as the hooded seals whelp (Figure 52). They give birth in late March and the lactation period is 10–12 days. After the nursing period, the adult seals stay in the Denmark Strait/Greenland Sea area until the moult in May-early June. There will always be some harp seals in the assessment area (e.g. Figure 56), but after the moult the majority of the seals move northward along the marginal ice zone and in July some have reached the waters north of Svalbard or they will have migrated south of Svalbard and into the Barents Sea. From August to November, the majority of the adult harp seals will be foraging in the Barents Sea but during winter they return to the marginal ice zone in the assessment area. Harp seals rarely haul-out, except during the breeding and moulting seasons.

One of the studies from the *Strategic Environmental Study Program for Northeast Greenland* tracked 20 harp seal pups (Rosing-Asvid & Zinglersen 2018). The longest track recorded lasted 400 days and the study revealed that the pups roughly follow the same route as the adults, implying that the majority of the pups will spend the winter in the Barents Sea. Figure 53 and Table 7 show the seasonal distribution of the tagged pups in different parts of the northeast Atlantic, and. Figure 54 shows examples of harp seal movements tracked through a full year.

Population: The 2018 estimate of abundance (based on surveys and model projections) is 360,400 (95% CI: 258,245-462,556) adult and immature seals and a survey in 2018 resulted in a pup production of 54,181 (95% CI: 38,884-75,949) (ICES 2019).

The catch: Norwegian sealing has previously been substantial in the whelping area, but catches in recent years have been small (<3000). The subsistence hunt along the coasts near the town of Ittoqqortoormiit averages less than 100/yr. Further south in Tasiilaq, about 2000 seals on average are taken annually. However, many of these seals come from the West Atlantic population.

Conservation status: The harp seal is listed as of 'Least Concern' (LC) by IUCN and locally in Greenland (Kovacs 2015, Boertmann & Bay 2018).

Sensitivity and critical habitats: Almost all harp seals concentrate in the whelping and moulting areas in spring (April – early June) and during June-July most of the seals migrate northward close to the marginal zone of the pack ice. Disturbance or oil spills in these areas/periods may have the potential to impact a large proportion of the seals from this population.

Bearded seal

The bearded seal is a large seal. Adults typically grow to 2.30-2.40 m and during summer when they are leanest, they weigh 200-250 kg; late in the winter and during spring they can reach 400 kg. Bearded seals do eat fish like the

Figure 53. Division of the Northeast Atlantic into to the four destination areas for the harp seals tracked from the assessment area. See also Table 7 for the relative distribution in these areas of the seals with an active tag.

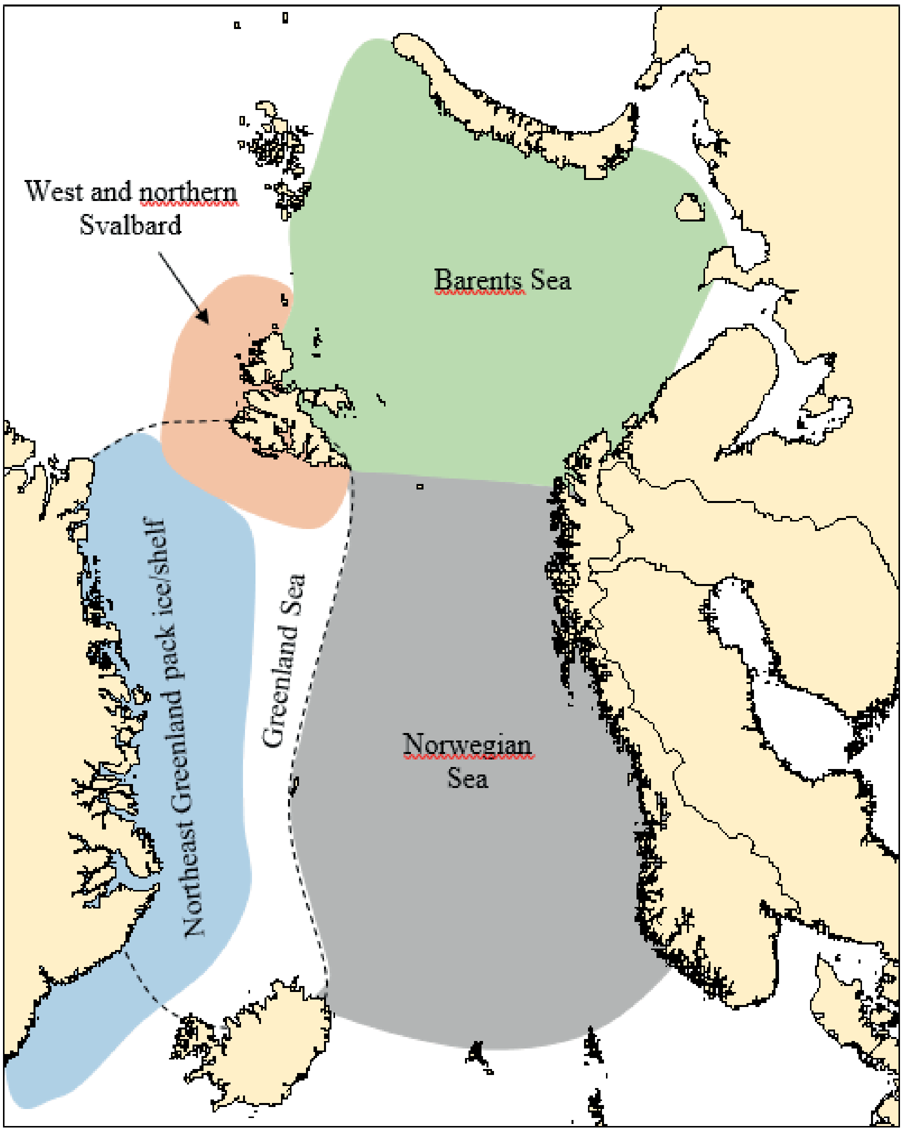


Table 7. Distribution of the 20 tracked harp seals in the four parts of the northeast Atlantic (see also Figure 53).

Relative distribution Seals/month/area	Northeast Greenland pack ice/shelf	West and northern Svalbard	Norwegian Sea	Barents Sea
April (n = 20)	100% (20/20)			
May (n = 20)	80% (16/20)		20% (4/20)	
June (n = 17)	94% (16/17)		6% (1/17)	
July (n = 12)	67% (8/12)	33% (4/12)		
August (n = 10)	30% (3/10)	70% (7/10)		
September (n = 8)	25% (2/8)	75% (6/8)		
October (n = 7)		43% (3/7)	14% (1/7)	43% (3/7)
November (n = 7)		29% (2/7)	14% (1/7)	57% (4/7)
December (n = 7)	29% (2/7)	14% (1/7)		57% (4/7)
January (n = 7)	14% (1/7)	14% (1/7)		72% (5/7)
February (n = 5)	17% (1/6)	17% (1/6)		66% (4/6)
March (n = 5)	20% (1/5)	20% (1/5)		60% (3/5)
April 1 yr. (n = 5)	60% (3/5)		20% (1/5)	20% (1/5)
May 1 yr. (n = 2)	100% (2/2)			
Mean all months (%)	**45**	**23**	**5**	**27**

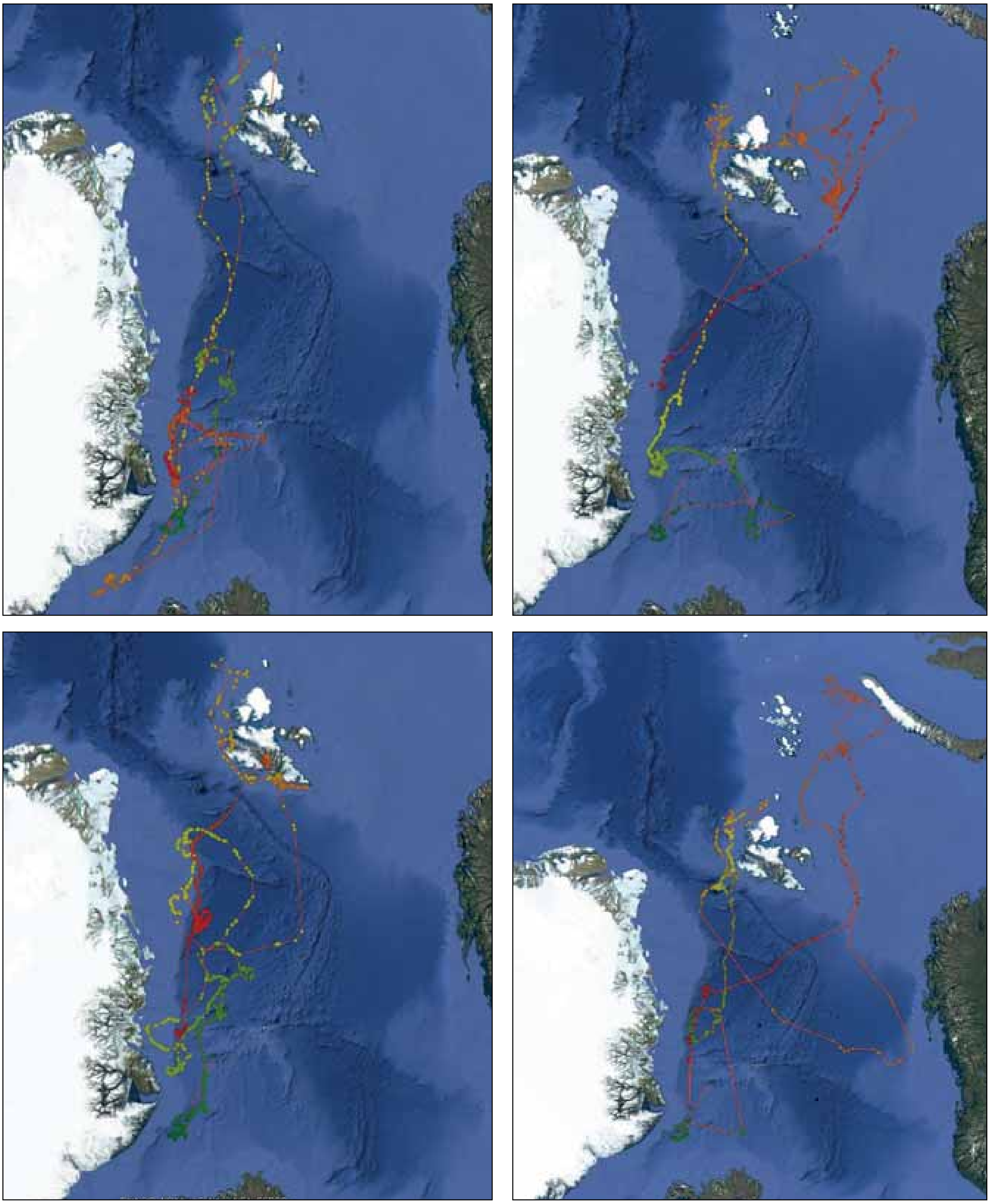


Figure 54. Four examples of GPS-tracks of harp seals tracked for a full year cycle (green dots starts the tracks and red dots end them).

other seal species, but a significant part of their diet consists of benthic invertebrates found in waters down to 100 m depth (Burns 1981, Gjertz et al. 2000).

Distribution: Bearded seals occur throughout the assessment area, but not in high densities compared to the other seal species. They can maintain breathing holes, but normally they avoid thick ice in favour of dynamic drift ice where cracks and leads give access to open waters. They give birth in late April – early May on drift ice or in other areas with sea ice and access to open water; the lactation period is 12–18 days (Burns 1981). Many bearded seals are likely to be resident in the assessment area but there have not been tagging studies to verify this. Young seals seem to stray more than the adults do and a pup tagged in Svalbard swam to the coastal areas in the assessment area (Gjertz et al. 2000). Bearded seals regularly haul-out throughout the summer (June-August) and summer surveys will therefore often provide a good indication of bearded seal densities.

Population: There are no population estimates for bearded seals in the assessment area.

The catch: The annual catch in the assessment area (by hunters from Ittoqqortoormiit) is approx. 40 seals/year, with a peak during summer (Piniarneq).

Conservation status: The widespread distribution of bearded seals is a good protection against overexploitation (Anon. 1998). Both the international and the Greenland Red List list bearded seals as ‘Least Concern’ (LC) (Kovacs 2016b, Boertmann & Bay 2018).

Sensitivity and critical habitats: Bearded seals vocalize very often, especially during the breeding season in spring (Burns 1981); they may therefore be vulnerable to acoustic disturbance (noise) (Wiig et al. 1996). Their feeding habits also make them vulnerable to oil-polluted benthos just like the walruses.

Ringed seal

Ringed seals are the smallest of the seals in the assessment area. Adult seals will typically be 1.20-1.45 m long and weigh 50-110 kg during winter when they are fattest. The dominating prey in high Arctic waters will typically be Arctic cod, polar cod and amphipods (*Parathemisto* spp).

Distribution: Ringed seals prefer to be in areas with sea ice and they are common and widespread in the assessment area, both in the fjords and in the pack ice off the coast. They can maintain breathing holes in thick winter ice and they give birth in lairs made in snowdrifts associated with a breathing hole. The pups are born in late March – early April and lactation lasts about 6-7 weeks (Hammill et al. 1991). They need stable sea ice and snow accumulation for the birth-lairs and coastal fast ice is often the preferred breeding habitat (McLaren 1958), but they do also breed in consolidated pack ice (Finley et al. 1983).

Ringed seals are in the water for most of the time, except during the peak of the moult in June, when they haul-out on the ice for most of the day. June surveys for ringed seals on the fast-ice in Scoresby Sund and Kong Oscars Fjord (in the southern part of the assessment area), estimated the density of visible ringed seals to be 2.00 and 1.04 seals/km^2, respectively (Born et al. 1998).

As part of the *Strategic Environmental Study Program for Northeast Greenland* 20 ringed seal caught close to the licence areas were tagged with satellite-linked data-loggers (Rosing-Asvid & Dietz 2018). The seals were tagged in late August and during fall they split up in one group that became very stationary (2 pups, 8 juvenile and 3 adults) and a group (3 pups, 3 juvenile and one adult) that seemed to be on the move throughout the tracking period (up to 248 days – late August to late April; Figure 54). Some of the stationary seals stayed within a radius of 1 km from fall to spring. They stayed in relative shallow waters where strong currents probably helped them in their effort to maintain breathing holes throughout the winter. The migrating seals explored the entire shelf area and they dove much deeper than the stationary seals. The general direction of these seals was southward and therefore only a few tracks into the licence areas were observed. One seal swam to the southern tip of Greenland and from there to Labrador (Canada) and then southward to Newfoundland. This is probably the longest recorded track of a ringed seal.

The catch: The annual catch of ringed seals in the assessment area (by people from Ittoqqortoormiit) is approx. 1500 seals. However, many of the more than 10,000 seals caught annually in Southeast and in Southwest Greenland are likely to be juvenile seals originating from the assessment area. One of the tagged seals was shot near Ittoqqortoormiit, and others passed close by other settlements where the seals are hunted.

Conservation status: The widespread distribution of ringed seals is a good protection against overexploitation (Anon. 1998) and both the global and the Greenland Red List note ringed seals as of 'Least Concern' (LC) (Boveng 2016, Boertmann & Bay 2018).

Sensitivity and critical habitats: During the breeding period ringed seals depend on stable sea ice where they can establish territories, whelp and nurse their pup. Some areas usually have higher concentrations of birth layers than others do, but generally, this species is widespread. Based on the current knowledge there are no specific areas that are especially critical or important.

3.8.4 Baleen whales

Fernando Ugarte (GINR)

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

Bowhead whales are associated with cold polar water and use the assessment area year round.

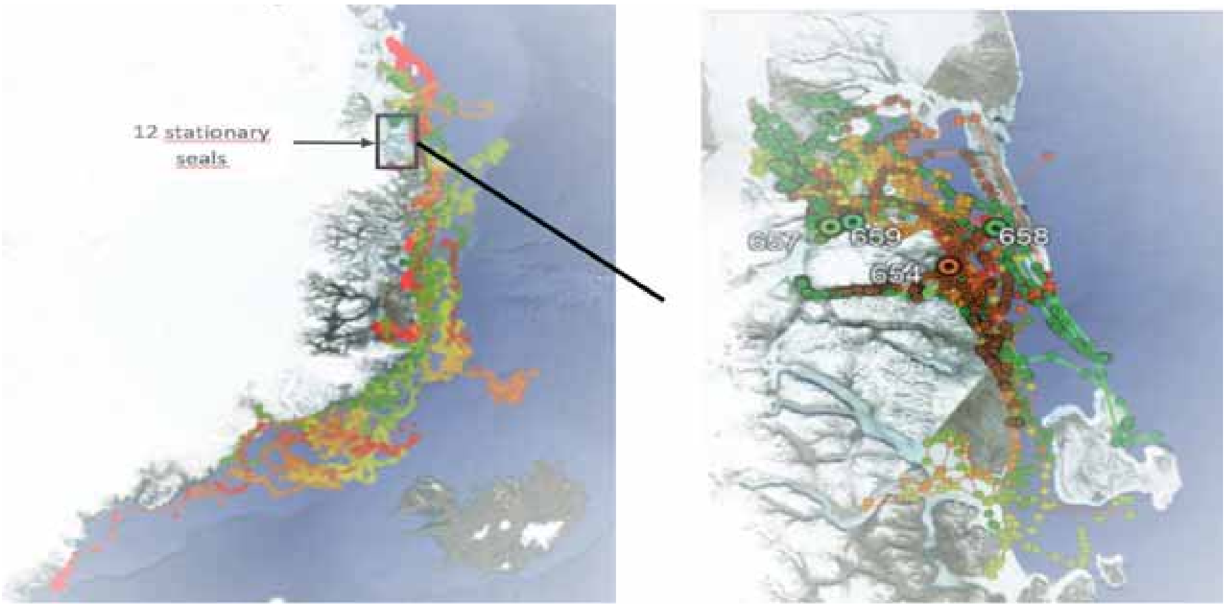


Figure 55. Left: Tracks from the seven ringed seals that left the tagging area (five were tagged within the black square and two a little further down the coast). Right: Tracks from 12 ringed seals that were all tagged and stayed within the black square shown on the left figure.

Rorquals migrate between southerly calving and mating grounds where they stay during winter, and northern feeding grounds where they spend the summer. Their summer distribution includes parts of the North Atlantic, including the Greenland Sea. However, until recently, little information on these whales has been available from the assessment area (Table 5).

The seismic surveys etc. 1994-2017 revealed many rorquals in the assessment area (Figure 56) and the aerial and ship-based surveys in 2017 (part of the *Strategic Environmental Study Program for Northeast Greenland*) also recorded baleen whales.

Climate change will likely impact the migratory species in terms of distribution changes due to geographic shifts in the locations of frontal and upwelling areas that concentrate their food. Such oceanographic changes are likely to affect most marine mammals, but they are currently very difficult to predict (Kovacs & Lydersen 2008). In the assessment area, new habitats for these migratory whales may open when the ice-edge retreats during the summer months, and the area may become more important than at present for these species.

Baleen whales produce distinctive low frequency calls which makes them able to communicate over very long distances and that can be detected over tens to hundreds of kilometres (Širović et al. 2007, Mellinger et al. 2007, Figure 57). These calls overlap on frequency with the noise from seismic sound sources, and masking may occur. Documented reaction of baleen whales to seismic surveys and/or drilling activities include increased calling, shift of the frequency of their calls and displacement (e.g. Ljungblad et al. 1988, Patenaude et al. 2002, Stone & Tasker 2006, Di Iorio & Clark 2010, Castellote et al. 2010). See also Chapter 7.2.1.

One of the studies of the *Strategic Environmental Study Program for Northeast Greenland* was Passive Acoustical Monitoring (PAM) during 2016 to 2018 (Videsen et al. 2019). However, only few results are currently available (Box 3.12).

Bowhead whale

The bowhead whale occurs regularly in the assessment area but has been considered rare. However, the number of sightings has increased since the mid-1980s (Gilg & Born 2005, Boertmann et al. 2009b, Wiig et al. 2010). During the 2008 and 2009 aerial surveys five bowheads were observed in July-August 2008 and a female with a calf were seen in July 2009 (Boertmann et al. 2009). At least 11 different individuals were seen in the Northeast Water Polynya during a GINR aerial survey for walrus in August 2009. The sightings in 2009 made it possible to estimate the abundance in the Northeast Water Polynya, and the result was 102 (95% CI: 32-329) whales (Boertmann et al. 2015a). Similar high numbers were recorded along the ice edge between 76° and 78° N (de Boer et al. 2019) in the springs of 2015 to 2018. The surveys in 2017 (as part of the *Strategic Environmental Study Program for Northeast Greenland*) located 301 (95% CI: 127-769) whales in winter and 318 (95% CI: 110-956) whales in summer in the Northeast Water Polynya (Hansen et al. 2019a).

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

In East Greenland bowhead whales have in recent years been recorded between the Blosseville Kyst and the Northeast Water (Gilg & Born 2005, Boert-

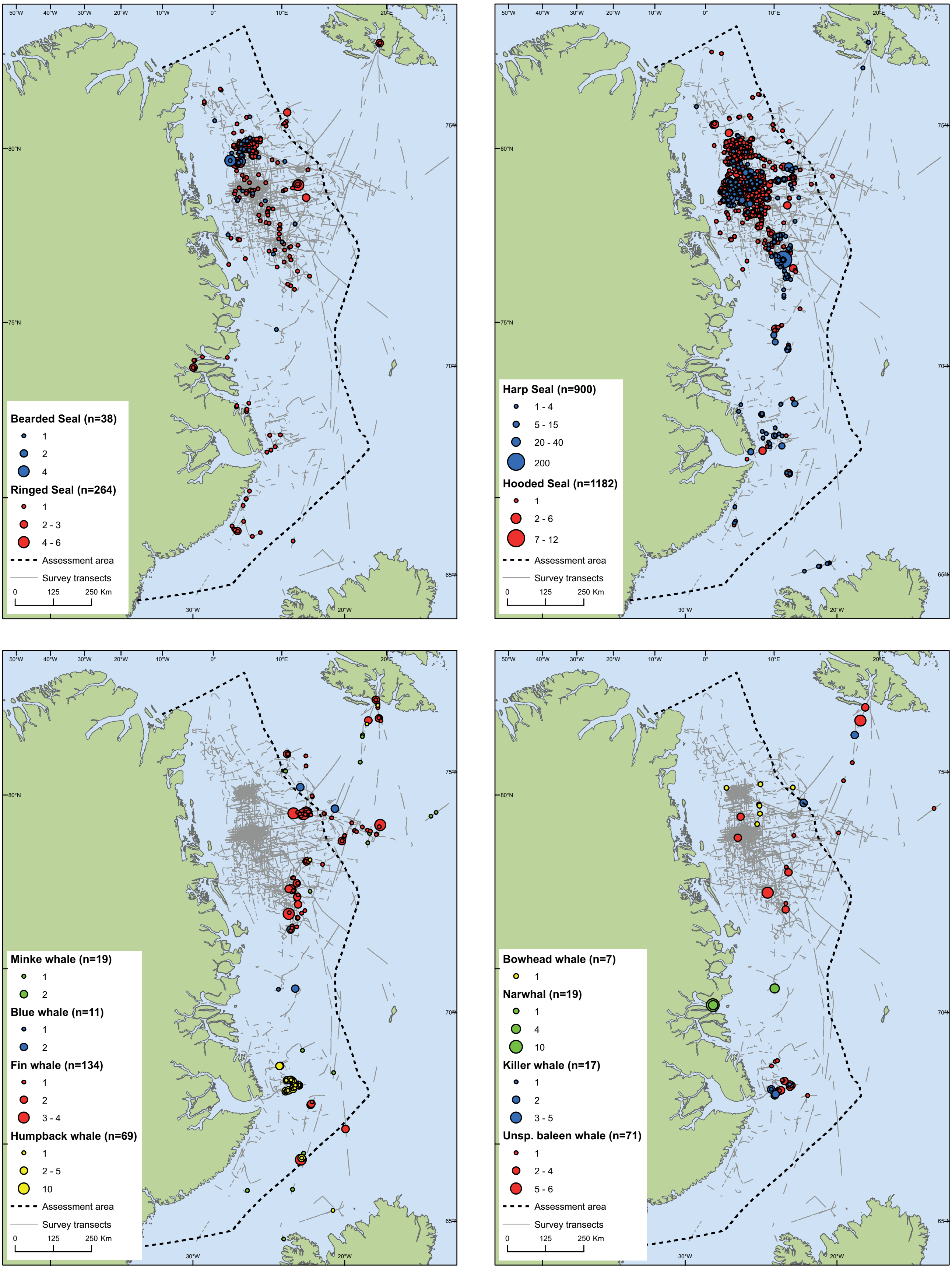


Figure 56. Marine mammal observations during seismic, research and fishery surveys in 1994, 1995, 2005, 2006 and 2009-2017 (aggregated over all years). The unspecified baleen whales observed on the shelf north of 70° were most likely bowhead whales.

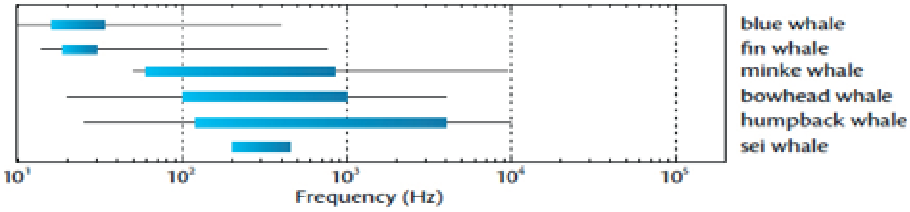


Figure 57. Known frequency ranges used by the baleen whales occurring in the Greenland Sea assessment area. The thick bars show the range of the most common types of vocalisations, while the thinner lines show recorded extremes of frequency (adapted from Mellinger et al. 2007).

mann et al. 2009b, 2015, Hansen et al. 2019a), usually along ice edges or in the marginal ice zone. Their winter quarters are probably in the Fram Strait, where a satellite tracked individual spent the winter (Lydersen et al. 2012). One of the studies in 2017 (part of the *Strategic Environmental Study Plan for Northeast Greenland*) included satellite tracking of bowhead whales. Eight whales were tagged north of Jan Mayen in June 2017 and tracked for 87 to 546 days. The tracks of the whales showed that the East Greenland shelf was used extensively, but also that there was a connection to an area north of Franz Josef Land and to the island Ostrov Ushakova further east. Only one whale visited the northern part of Svalbard, which it passed *en route* to Franz Josef Land. It returned to Northeast Greenland in December where it followed a route far north of Svalbard (~180 km) before returning to Franz Josef Land after a few days of stay in Northeast Greenland. This whale spent considerable time at Ostrov Ushakova before moving west into the Barents Sea in November 2018. The rest of the whales stayed on the East Greenland shelf for the duration of the tracking period and only one whale went south along the East Greenland coast towards the former whaling ground ('Southern Whaling Ground') off the coast of Liverpool Land (approx. 71° N).

An acoustic recorder deployed for several years in the western Fram Strait, on the shelfbreak and inside the assessment area, recorded signals from bowhead whales almost throughout the four years of recording, however with large variation between seasons (Ahonen 2017). The sound production peaked in the winter from October to April.

The studies of the *Strategic Environmental Study Program for Northeast Greenland* also included the deployment of a passive acoustic recorder (PAM) in 2016 to 2018. This also documented the presence of bowhead whales on the shelf within the assessment area as well as a seasonal shift between on-shelf areas in summer and autumn, and shelfbreak areas in winter (Videsen et al. 2019).

Conservation status: Bowhead whales have a high conservation value due to the rarity of the species. The Spitzbergen stock of bowhead whales was almost exterminated by two centuries of whaling (from 1611), and only a few individuals remained – until 1990s estimated at a few tens (Gilg & Born 2005). However, the recent sightings indicate that a recovery is occurring, and the "few tens" is far from current anymore. Bowhead whale (the Spitzbergen stock separately) is considered as 'Endangered' (EN) on the global Red List and as Vulnerable (VU) on the national Red List (Cooke & Reeves 2018, Boertmann & Bay 2018).

Sensitivity and critical habitats: Bowheads are sensitive to disturbance (noise) and may avoid areas with drilling and seismic surveys; Blackwell et al. (2015) showed that they change their calling pattern when approached by a seismic survey. Local populations may be displaced or reduced by increased traffic and oil activities (Wiig et al. 1996). Bowhead whale sensitivity to oil spills is unknown, but it has been speculated that bowheads are especially vulnerable to fouling of their baleen, due to their skim feeding habits (Lowry 1993). The official guidelines to seismic surveys in Greenland designate specific 'areas of concern' for bowhead whale in summer and autumn, including almost the entire Greenland Sea assessment area (EAMRA 2015).

The recent observations seem to confirm the old whaling grounds as especially important habitats (Gilg & Born 2005, Boertmann et al. 2009b, 2015 Lydersen et al. 2012) – one of them within the assessment area: the 'south fishing ground' or 'southern whaling ground' situated in the marginal ice zone off East Greenland between 72° and 75° N (Ross 1993). Also, based on the many individuals estimated in 2009 and 2017, the Northeast Water Polynya seems

Box 3.12

Passive acoustic monitoring of marine mammals and noise in the Northeast Greenland assessment area.

Simone Vidensen (GINR), Tenna Boye (GINR), Peter T. Madsen (AU), Kristian Beedholm (AU) & Malene Simon (GINR)

In September 2016 and 2017 a total of nine passive acoustic data loggers (Aural M2s) were moored to the seabed at various positions covering the oil licence area within the Greenland Sea (Figure 1). Three operated in 2016-2017 and three other from 2017 to 2018. One was lost and the last two were retrieved too late for inclusion in this report.

Three of the analysed recorders were positioned on the bank closer to shore whereas another two were positioned further off shore close to the shelf break and the last one positioned further north (Figure 1).

Both abiotic and biological sounds contributed to the soundscape in each location. Seismic noise was represented mainly in the 20 Hz and 63 Hz bands while noise from the ice covered all frequency bands. Bowhead whales mainly produced song in the 500 Hz and 1000 Hz band. Bearded seals produced trills that also dominated in the 1000 Hz band. Narwhal clicks could be detected in the 4000 Hz band while sperm whale clicks were visible in the frequency bands between 1000 Hz and 4000 Hz.

There was a clear time dependent shift in the distribution of the marine mammal species. Bowhead whales, narwhals and sperm whale were all registered on the recorders close to shore during summer and fall. However, from fall to spring their detections shifted to the recorder near the shelf break. The formation of fast ice likely forces these three species further off shore. Bowhead whales were especially detected on N7 and NE1 and narwhals year-round on NE4, NE5 and NE7. Bearded seals were only heard just prior to and during their mating season (February-July) which was expected as they call very little outside this season. They were detected on all recorders but were especially loud at a location in the middle of the licence area, meaning that this area plausibly serves as good a mating area.

The seismic noise (from airguns) recorded at NE1, NE2 and NE3 in the autumn of 2016 derived from a seismic survey on the Northeast Greenland shelf, while the recorded seismic noise at other times derived from surveys taking place far away, at least outside Greenlandic waters, as no seismic surveys were carried out in Greenland that year.

Table 1 and 2 below show the temporal distribution of recordings of different species of marine mammals and noise from seismic surveys.

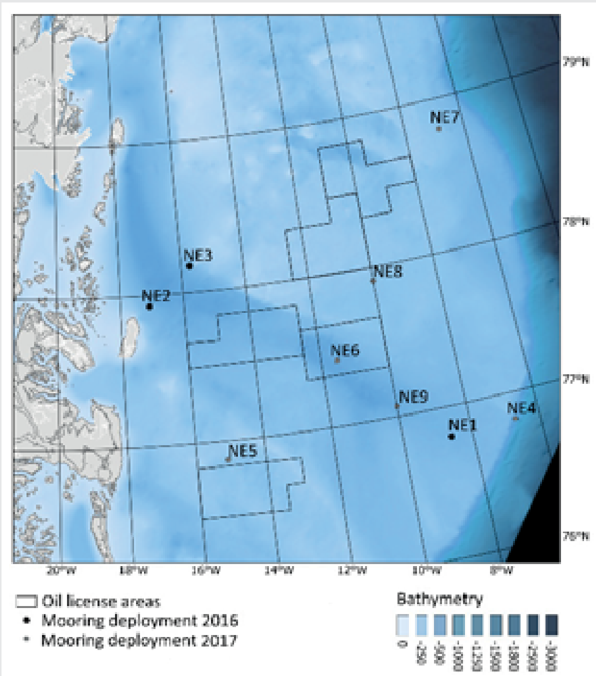


Figure 1. Location of nine passive acoustic data loggers deployed in 2016 and 2017.

to be especially important; the area of importance may include the ice edge between the polynya and Île de France since a female with a calf was observed here in 2009 (Boertmann & Nielsen 2010a, b). The observations reported by de Boer et al. (2019) indicate that also the shelfbreak between 76° and 78° N is an important habitat in spring (May/June).

Minke Whale

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

Table 1. The presence of selected marine mammals and seismic surveys in the recordings of three acoustic recorders deployed in 2016.

Year and month	NE1					NE2					NE3				
	Seismic	Sperm whale	Narwhal	Bowhead whale	Bearded seal	Seismic	Sperm whale	Narwhal	Bowhead whale	Bearded seal	Seismic	Sperm whale	Narwhal	Bowhead whale	Bearded seal
August 16	+	-	-	-	-	+	+	+	-	-	+	+	+	-	-
September 16	+	-	-	-	-	+	+	+	+	-	+	+	+	+	-
October 16	+	+	+	+	-	-	+	-	+	-	-	+	+	+	-
November 16	+	+	+	+	-	-	+	+	-	-	-	-	-	-	-
December 16	-	+	+	+	-	-	-	-	-	-	-	-	-	-	-
January 17	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-
February 17	-	-	+	+	+	-	-	-	-	-	-	-	-	-	+
March 17	-	+	+	+	+	-	-	-	-	-	-	-	-	-	+
April 17	-	-	-	+	+	-	-	-	-	-	-	-	-	-	+
May 17	+	-	-	+	+	-	-	-	-	-	-	-	-	-	+
June 17	+	+	-	-	+	-	-	-	-	+	-	-	-	-	+
July 17	+	+	+	-	-	-	+	+	+	+	-	+	+	-	+
August 17	+	+	+	-	-	-	+	+	-	-	-	+	+	-	-
September 17	+	-	-	-	-	-	+	+	+	-	-	+	+	-	-

Table 2. The presence of selected marine mammals and seismic surveys in the recordings of three acoustic recorders deployed in 2017.

Year and month	NE4					NE5					NE7				
	Seismic	Sperm whale	Narwhal	Bowhead whale	Bearded seal	Seismic	Sperm whale	Narwhal	Bowhead whale	Bearded seal	Seismic	Sperm whale	Narwhal	Bowhead whale	Bearded seal
September 17	+	+	+	-	-	+	+	+	-	-	+	-	-	-	-
October 17	+	+	+	-	-	-	+	+	+	-	+	+	+	+	-
November 17	+	-	+	-	-	-	+	+	+	-	-	-	+	+	-
December 17	-	-	+	-	-	-	-	+	-	-	-	-	+	+	-
January 18	-	-	+	-	-	-	-	-	-	-	-	-	+	+	-
February 18	-	-	+	-	-	-	-	+	-	-	-	-	+	+	+
March 18	-	-	+	-	+	-	-	+	-	+	-	-	+	+	+
April 18	+	-	+	+	+	-	-	+	-	+	-	-	+	+	+
May 18	+	-	+	-	-	-	+	+	-	+	+	-	+	-	+
June 18	+	-	-	-	-	-	+	+	-	+	-	-	+	-	+
July 18	+	-	+	+	-	-	+	+	-	+	+	+	+	-	-
August 18	+	+	+	-	-	+	+	+	-	-	+	+	+	-	-
September 18						+	+	-	-	-					

Minke whales feed on a large variety of prey, including small schooling fish and krill, and migrate seasonally from boreal, Arctic and sub-Arctic waters in summer to warmer waters in winter. Summer feeding grounds extend from northern Europe and North America, including Iceland and Greenland, into the ice edge. Winter breeding grounds are unknown but may include tropical waters off the Caribbean and West Africa. Some individuals remain at high latitudes during winter.

Distribution and stocks: The occurrence of minke whales in the assessment area is unknown. At least a few were seen during a seismic survey in 2006 and as far north as 75° N; all to the east of the drift ice (Figure 56). Furthermore, minke whales have been observed by GINR researchers (unpublished) working with other species at the ice edge within the assessment area during spring, and one was observed in the Northeast Water in May 1993 (Kapel & Berg 1994). No minke whales were observed during the surveys in 2017.

For management purposes, the International Whaling Commission (IWC) recognizes four different stocks of minke whales in the North Atlantic (Figure 58). These management regions were established based on studies of catch statistics, biological characteristics and tagging. Newer molecular studies tend to confirm the established subdivisions (Andersen et al. 2003, Born et al. 2007). The assessment area includes parts of both the Northeastern (northern half) and Central management areas (southern half).

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

There is no single estimate for the number of minke whales in the Central Stock. However, the Scientific Committee of the IWC agreed in 2008 (IWC 2008a) that the best estimates available for three sub-areas of the central stock were 24,900 (CV 0.45), 10,700 (CV 0.229) and 23,600 (CV 0.26), respectively. Surveys in 2015 covering the innermost 50 km of the shelf off East Greenland north to 71° N and in the north Atlantic around Iceland and the Faroe Islands resulted in estimates of 2762 (95% CI: 1160-6574) and 42,515 (95% CI: 22,896-78,942) whales respectively, although only one were observed inside the assessment area (Hansen et al. 2018b, Pike et al. 2019).

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

Conservation status: The population occurring in the assessment area has a favourable conservation status. Both the global and the Greenland Red Lists categorise the minke whale as of 'Least Concern' (LC) (Cooke 2018a, Boertmann & Bay 2018).

The catch: The quota for minke whales in Greenland was raised from 12 to 20 minke whales per year in 2019 (IWC 2018). From 2009 to 2018, an average of

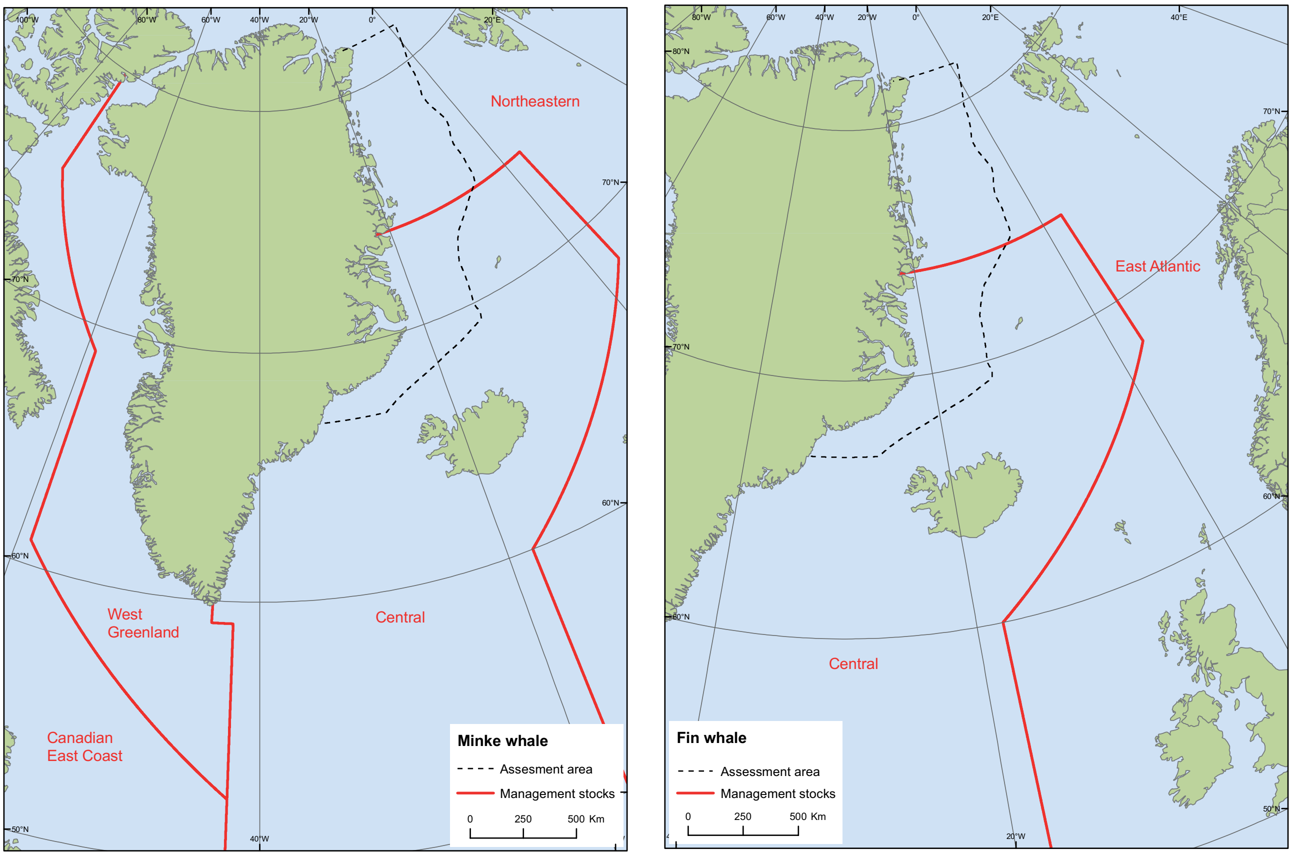


Figure 58. The delimitation of minke and fin whale stocks. Left: The four management stocks of minke whales in the North Atlantic; two of them overlap the assessment area, but only whales from the central stock are frequent within the assessment area. Right: The two fin whale stocks in the Northeast Atlantic: Central and East Atlantic.

eight minke whales were caught yearly in East Greenland (NAMMCO 2019a). The majority of these were taken in Tasiilaq.

Sensitivity and critical habitats: Minke whales produce a variety of vocalisations, using frequencies varying from a few kHz down to 60 Hz (Rankin & Barlow 2005). Underwater sound related to oil exploration and extraction may mask sounds and reduce the range at which whales can communicate by sounds (cf. the description for fin whale). No specific areas or habitats within the assessment area can be identified as critical to the minke whale.

Sei whale

Sei whales are on average 14 m long and weigh 20-25 tonnes. They are very similar in appearance to fin whales, and usually only experienced observer can tell these two species apart. Sei whales feed on small fish, krill, squid and copepods. Their distribution is worldwide, from subtropical or tropical waters to high latitudes of the sub-Arctic or sub-Antarctic. It is assumed that most populations move seasonally between high latitudes in summer and tropical waters in winter (IWC 2008b).

Distribution: The distribution of sei whales is poorly understood. They occur in apparently unpredictable patterns, usually far offshore and can be seen in an area regularly for several years, after which they may largely disappear. Although they occur in polar areas, sei whales seem to be more restricted to mid-latitude temperate zones than other rorquals (Jefferson et al. 2008).

A ship survey in Southeast and West Greenland encountered sei whales frequently in the same areas as fin whales (Heide-Jørgensen et al. 2007). The survey was carried out in September 2005, and the resulting estimate was 729 sei whales (95% CI: 226–2358) in Southeast Greenland (south of the assessment area).

Sei whales in East Greenland belong to a large, oceanic population of the mid-Atlantic, and it has no pronounced site fidelity. Sei whale use of the assessment area is probably limited to the southern part. No sei whales were observed during the surveys in 2017.

Conservation status: After protection in the 1970s and 1980s, this species has been subject to relatively little research and the extent to which stocks have recovered is uncertain. Sei whales are currently classified as 'Endangered' (EN) on the global as well as the Greenland Red Lists (Cooke 2018b, Boertmann & Bay 2018).

Sensitivity and critical habitats: Oil activities that can potentially impact whales include seismic exploration, exploration drilling, ship, helicopter and aircraft noise, discharges into the water, dredging and marine construction. No specific areas or habitats within the assessment area can be identified as critical to the sei whale.

Blue whale

Blue whale is the largest animal in the world, with an average length of 25-26 m and average weight of 100-120 tonnes, females being larger than males.

They are globally distributed from the equator to polar waters, moving to high latitudes for feeding during summer and to low latitudes for breeding during winter. Their main prey is krill (*Euphausia* spp.).

Distribution: Blue whales occur frequently in the waters between Iceland and Greenland (south of the assessment area), and blue whales were also observed in the assessment area during the seismic surveys (Figure 56). In 2017, blue whales were observed at two occasions during the aerial survey for seabirds in late August (Boertmann et al. 2018): two between 77° and 78° N and three between 75° and 76° N, both observations on the shelfbreak to the east of the drift ice. Heide-Jørgensen et al. (2001) satellite tagged a blue whale and tracked it for three weeks when it moved along the shelfbreak of the assessment area between 78° and 68° N.

However, the 2017 observations, and a recent unconfirmed observation of a concentration of blue whales east of Scoresby Sund, indicate that the shelfbreak may be an area where blue whales feed (NAMMCO 2019a). Surveys in 2015 covering the innermost 50 km of the shelf off East Greenland north to 71° N (southern part of the assessment area) and in the north Atlantic around Iceland and the Faroe Islands resulted respectively in one sighting in the southern part of the assessment area and in an estimate of 3000 (95% CI: 1377-6534) whales (Hansen et al. 2018b, Pike et al. 2019).

Their best known feeding grounds in the North Atlantic are in eastern North America (St. Lawrence Bay, Newfoundland, Labrador) and in the Denmark Strait area, including waters of the southernmost part of the assessment area (east of the drift ice).

Conservation status: The population in the North Atlantic is roughly estimated at 1500 individuals. Blue whales are categorised as 'Endangered' (EN) on the global Red List (Cooke 2018c), and this is followed by the Greenland Red List (Boertmann & Bay 2018).

Sensitivity and critical habitats: Blue whales produce distinctive calls with low frequency and high intensity that can be detected over hundreds of kilometres (Širović et al. 2007). Blue whales synchronise their call sequences and display very fine pitch discrimination and control over their calling frequency (McDonald et al. 2009). The physical characteristic of their synchronous calls might allow blue whales to use the Doppler shift to navigate and to acquire information about the direction to other calling whales (Hoffman et al. 2010). Low frequency sounds may effectively mask blue whale calls, thus interfering with their social activities and/or navigation. Indeed, Di Iorio & Clark (2010) documented that blue whales changed their vocal behaviour during a seismic survey. They found that blue whales called more on seismic exploration days than on non-exploration days, and concluded that the observed response represents a compensatory behaviour to the elevated ambient noise from seismic survey operations. Due to their low population densities and their ability to communicate acoustically over very large distances, blue whales are expected to be sensitive to low frequency acoustic pollution. However, Dunn & Hernandez (2009) acoustically tracked blue whales that were at 42-90 km from operating airguns and, at these relatively large distances, were unable to detect changes in the behaviour of the whales.

No particular important areas are known for blue whales within the assessment area. However, the few observations indicate that blue whales feed in areas of the shelfbreak although there is no knowledge about the predictability and distribution of such feeding areas.

Fin whale

Fin whales are probably the most numerous and widespread baleen whales within the assessment area, although they are usually found outside the cold East Greenland current.

Fin whales favour prey items such as krill (*Euphausia* spp.) and small schooling fish, including herring and capelin. During summer they feed at high latitudes and are believed to migrate south to unknown breeding grounds during the winter. However, satellite tracking (Mikkelsen et al. 2007) indicate that at least some individuals remain at high latitudes in the North Atlantic year-round. Passive acoustic monitoring in the Davis Strait showed that fin whales remained in the feeding grounds until the arrival of sea ice in late December (Simon et al. 2010).

Distribution and stocks: Fin whales occur in the assessment area mainly to the east of the drift ice, and mainly in the summer and autumn (Figure 56). During the 2017 surveys, fin whales were observed 14 times (in total 17 individuals) all at, or to the east of, the shelfbreak; the northernmost observation was at 77° N.

A Norwegian study using passive acoustic monitoring through several years in the western Fram Strait (at 78° 50′ N and inside the assessment area) detected fin whales in the period September to March, indicating that some individuals stay at high latitudes in winter (Ahonen et al. 2017).

For management purposes, the International Whaling Commission (IWC) and the North Atlantic Marine Mammal Commission (NAMMCO) recognize two major fin whale stocks in the Northeast Atlantic: the Central North Atlantic and the Eastern North Atlantic (Figure 58). The ranges of these two stocks overlap with the assessment area. They may, however, form a single population comprised of individuals that move over very large areas.

The population in the North Atlantic was in 2006 estimated at 48,016 (CV 0.23, 95% CI: 30,709; 875,078) individuals. The Iceland/Faroese survey area accounted for 58% of this estimate, while the Norwegian and Greenland survey areas accounted for 36% and 6% respectively (NAMMCO–IWC 2006, NAMMCO 2019a). There are also indications of an increased population from the 1980s to 2001 followed by a stabilisation by 2007 (Pike et al. 2008). A northward shift in distribution also seems to have occurred.

Since 1987 NAMMCO has coordinated a series of international surveys of marine mammals in the North Atlantic that cover a small southern portion of the assessment area, east of Scoresby Sund, where several fin whales are regularly observed (Lockyer & Pike 2013). That they also occur further north is evident from the seismic surveys (Figure 56) and the 2017 surveys. Surveys in 2015 covering the innermost 50 km of the shelf off East Greenland north to 71° N (southern part of the assessment area) and in the north Atlantic around Iceland and the Faroe Islands resulted in estimates of 6440 (95% CI: 3901-10632) and 36,773 (95% CI: 25,811-52,392) whales respectively (Hansen et al. 2018b, Pike et al. 2019).

Conservation status: The Fin whale globally has an unfavourable conservation status and is categorised as Vulnerable (VU) on the global Red List (Cooke 2018d). However, the European population (including the Greenland Sea) is assessed at Near Threatened (Cooke 2018d), and it is listed as of 'Least Concern' (LC) on the Greenland Red List (Boertmann & Bay 2018).

The catch: Fin whales are not hunted in the assessment area.

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

Rorquals, including fin whales, produce low frequency calls, many of which are species-specific and can be detected over tens to hundreds of kilometres (Mellinger et al. 2007). A study of the acoustic behaviour of fin whales during seismic surveys in the Mediterranean showed that fin whale vocalisations changed in the presence of air gun events: the 20-Hz pulse duration were shortened, bandwidth decreased, and centre and peak frequencies decreased (Castellote et al. 2010). Furthermore, bearings to singing whales indicated that whales moved away from the airgun source and out of the area for a time period that extended well beyond the duration of the airgun activity. The authors concluded that fin whales modify their acoustic behaviour to compensate for increased ambient noise and, under some conditions, they will leave an area for an extended period (Castellote et al. 2010).

No particularly important areas are known for fin whales within the assessment area. However, the few observations indicate that fin whales feed in areas of the shelfbreak although there is no knowledge about the predictability and distribution of such feeding areas.

Humpback whale

Humpback whales are on average 12-14 m long and weigh 25-30 tonnes. They feed on a variety of small schooling fish and krill. Humpbacks are widely distributed and occur seasonally in all oceans from the Arctic to the Antarctic. Humpbacks migrate between mid- and high-latitude summer feeding grounds and tropical or subtropical winter breeding and calving grounds. Known calving grounds for humpbacks from the North Atlantic are in the Caribbean and around the Cape Verde islands (Wenzel et al. 2009 and references therein).

Distribution: There are no in-depth studies of ecology, distribution or abundance of humpback whales in East Greenland, and the importance of the assessment area for this species is not known. A ship-based survey off East Greenland in 2005, south of the assessment area, detected humpback whales in potential association with capelin aggregations (Heide-Jørgensen et al. 2007). The seismic surveys etc. 1994-2017 in the assessment area, particularly the 2006 survey, encountered many humpback whales, mainly to the east of the Scoresby Sund entrance and on the shelfbreak, and even as far north as 75° N (Figure 56). The 2017 surveys in late August only observed three humpback whales, between 75° and 76° N and to the east of the shelfbreak (Boertmann et al. 2018).

Humpback whales in the North Atlantic show high levels of site fidelity with occasional long-distance movements between four main feeding aggregations (Figure 59) in the Gulf of Maine, eastern Canada, West Greenland and the eastern North Atlantic (Stevick et al. 2006). Distances between re-sightings of individually recognizable whales suggest that humpback whales from the eastern North Atlantic feeding aggregation move over very large distances between feeding grounds, such as from Iceland to Norway (Stevik et al. 2006). Surveys in 2015 covering the innermost 50 km of the shelf off East Greenland north to 71° N (southern part of the assessment area) and in the north Atlantic around Iceland and the Faroe Islands resulted in estimates of 4223 (95% CI: 1845-9666) and 9867 (95% CI: 4854-20,058) whales respectively (Hansen et al. 2018b, Pike et al. 2019).

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

Conservation status: Whaling has seriously depleted all humpback whale stocks, and humpback whales were protected on a worldwide basis in the 1980s and have been recovering since then. The population occurring in the assessment area has a favourable conservation status as it is abundant and increasing. The number of humpback whales around Iceland has increased at a rate as high as 11% per year (Sigurjónsson & Gunnlaugsson 1990). Humpback whales are listed as of 'Least Concern' (LC) on both the global and the Greenland Red Lists (Cooke 2018e, Boertmann & Bay 2018).

Sensitivity and critical habitats: Humpback whales are well known for the long and complex songs produced by males in the breeding grounds (review of humpback whale song in Parsons et al. 2008). Most knowledge about the sound produced by humpback whales in their feeding grounds comes from a few studies in the North Pacific (D'Vincent et al. 1985, Thompson et al. 1986) and the Gulf of Maine (Stimpert et al. 2007), where social feeding calls, as well as click-like sounds have been described. Humpback whale sounds are low- to mid-frequency (Figure 57), usually 30 Hz to 8 kHz, although up to 24 kHz may be reached. Peak frequencies tend to be around 315 Hz and 630 Hz (Parsons et al. 2008).

The few observations indicate that there are areas on the shelfbreak, where humpback whales congregate and feed, for example to the east of Scoresby Sund. However, there is no knowledge about the predictability and distribution of such areas.

Figure 59. The main feeding aggregations of humpback whales in the North Atlantic: Gulf of Maine, Eastern Canada, West Greenland, Southeast Greenland and eastern North Atlantic.

3.8.5 Toothed whales

Fernando Ugarte (GINR)

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

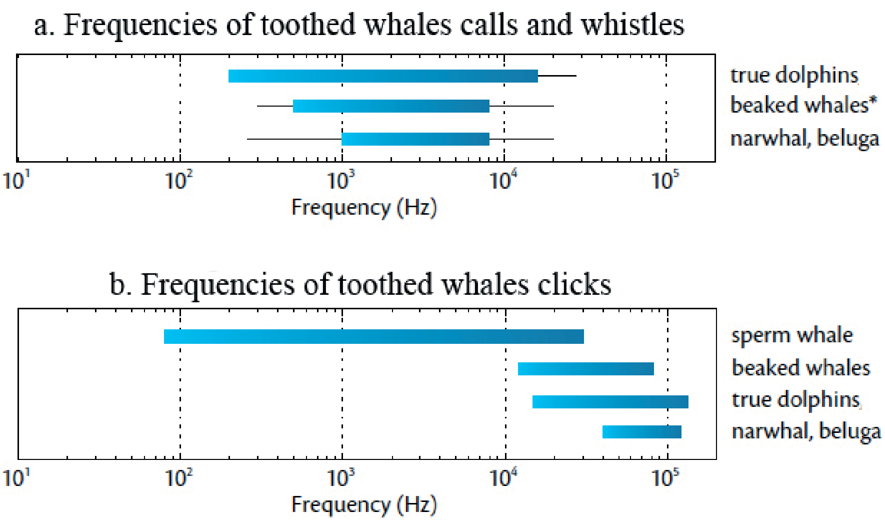


Figure 60. Known frequency ranges of pulsed calls and whistles (a) and echolocation clicks (b) made by toothed whales in the Greenland Sea assessment area. True dolphins (family Delphininae) include killer whale, pilot whale and white-beaked dolphin. Beaked whales (family Ziiphidae) include bottlenose whale. Narwhal and white whale are also included. See legend in Figure 57 (adapted Mellinger et al. 2007).

Besides the five widely spread species of toothed whales mentioned above, there is one exclusively Arctic toothed whale found in the assessment area: the narwhal. This is a North Atlantic Arctic species found in the assessment area year-round. There is a second Arctic toothed whale, the white whale, which has a nearly circumpolar distribution that includes all Arctic waters except for East Greenland. The white whale is a rare visitor to the assessment area and not treated further here, but it can be mentioned that a single individual was observed during the aerial whale survey in August 2017.

All toothed whales produce clicks for echolocation[1] and communication. In addition, killer whales produce pulsed calls comprising clicks in very rapid succession, and narwhals, white-beaked dolphins, pilot whales and killer whales produce whistle-like sounds. Pulsed calls serve several purposes, including long-range communication and transmission of information about kinship and group cohesion. Whistles are important during short-range social contact. Figure 60 shows the frequency ranges of echolocation clicks, calls and whistles produced by toothed whales in the assessment area.

Long-finned pilot whale

Distribution: The long-finned pilot whale occurs in temperate and subpolar zones and ranges in the North Atlantic from southern Baffin Bay, off East Greenland across Iceland and the Faroe Islands to mid-Norway and south to North Carolina, the Azores, Madeira, and Mauritania (e.g. Jefferson et al. 2008). Greenlandic catch statistics (APNN, unpublished data) show that pilot whales may occur as far north as Ittoqqortoormiit on the east coast in late summer and early autumn. However, they apparently avoid ice-covered waters and will only come close to the coast in years with very little ice (Heide-Jørgensen & Bunch 1991).

Pilot whales were not observed during the seismic surveys etc. 1994-2017 nor during an aerial survey in the southern part of the assessment area in 2015 (Hansen et al. 2018b).

Population: The pilot whales occurring in the assessment area (and the rest of Greenland) are likely to represent vagrants from a single North Atlantic population of which numbers several 100 thousand individuals (NAMMCO 2019a).

Biology: Long-finned pilot whales are social and generally found in groups of 20 to100 individuals. In the western North Atlantic, they concentrate in areas

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

over the continental slope in winter and spring and move over the shelf in summer and autumn (Jefferson et al. 2008).

Diet consists primarily of squid, but also small to medium-sized fishes are taken, such as cod and herring.

The catch: Pilot whales are caught by hunters from Tasiilaq and occasionally in Ittoqqortoormiit. According to catch reports (Flora et al. 2019, NAMMCO 2019a), during the 10-year period from 2006-2015, there were an average of 3 pilot whales caught in East Greenland per year. It seems like this number has greatly increased in recent years, with 27 pilot whales reported caught in 2016 and 66 in 2017 (ibid.). Several pilot whales were taken in Tasiilaq in 2018, although catch statistics were not available at the time of writing this report.

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

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

White-beaked dolphin

Distribution: White-beaked dolphins inhabit the North Atlantic Ocean in the cold temperate zone to subpolar waters. In the Northeast Atlantic they reach into the Arctic waters in the Barents Sea, around Spitsbergen and to East Greenland at approx. 74º N. They are the most common dolphin off south-eastern Greenland, in Denmark Strait and the seas around Iceland (Reeves et al. 1999, Kinze 2009, Flora et al. 2019).

No white-beaked dolphins were reported by the seismic surveys etc. 1994-2017 in the assessment area, and only one group was observed during an aerial survey in the southern part of the assessment area (Hansen et al. 2018b).

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

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

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

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

The catch: In Greenland, white-beaked dolphins are caught for subsistence. There are no catch statistics for this species prior to 2005. From East Greenland, catches of white-beaked dolphins were reported only from Tasiilaq, south of the assessment area and, as with pilot whales and killer whales, there is a recent increase of reported catches, with yearly averages of 3 dolphins caught in 2005 - 2009 and 34 in 2010 - 2017 (Flora et al. 2019, NAMMCO 2019a).

Conservation status: The global Red List status of the white-beaked dolphin is 'Least concern' (LC) (Kiszka, & Braulik 2018), which also is the case in Greenland (Boertmann & Bay 2018).

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

Killer whale

Biology: Killer whales are top predators that occur in all oceans but tend to concentrate in colder regions with high productivity. They feed on prey items that vary in size from herring to adult blue whales. There are different ecotypes of killer whales, and examples of such ecotypes include killer whales that feed seasonally on South American sea lion and southern elephant seal pups in Patagonia (Lopez & Lopez 1985), herring in Norway and Iceland (Simon et al. 2007), various sharks in New Zealand (Visser 2005) and bluefin tuna in the Gibraltar Strait (Guinet et al. 2007). In some areas, up to three different ecotypes may occur (Ford & Ellis 2006, Baird & Dill 1995, Herman et al. 2005, Pitman & Ensor 2003). Sympatric ecotypes (i.e. with overlapping ranges) seldom interact and do not interbreed.

Killer whales are typically found in groups of 3-30 animals, but group size may occasional exceed 100 individuals. Large groups are temporary associations of smaller, more stable groups with long-term associations and limited dispersal (review in Baird 2000).

Killer whale populations tend to be small, often numbering in the hundreds rather than thousands (e.g. Bigg et al. 1990, Similä & Ugarte 1997, Ford & Ellis 2002, Visser 2001). Based on genetic analyses of killer whales from several locations in the North Pacific, Hoelzel et al. (2007) suggested that killer whale populations in the North Pacific had small effective population sizes and that there was ongoing low-level genetic exchange between populations.

As estimated in 2001, 15,000 killer whales occur in the Northeast Atlantic (95% CI: 6600 – 34,000; NAMMCO 2019a), but high concentrations are found only seasonally in Iceland and Norway. An unknown proportion of Icelandic killer whales, and the majority of Norwegian killer whales, belong to a Scandinavian ecotype of herring-eating killer whale (Simon et al. 2007), forming at least two separate populations that migrate along with major herring stocks: the Icelandic summer-spawning herring and the Norwegian spring-spawning herring (Sigurjónsson & Leatherwood 1988, Similä et al. 1996).

Killer whales that feed on marine mammals occur at least in Tasiilaq, south of the assessment area, and herring feeding killer whales may occur in the southern part of the assessment area, where the summer spawning Icelandic herring stock occurs.

Killer whales from Norway, Iceland and East Greenland are genetically indistinguishable (Foote et al. 2013).

Distribution: There is very little information about killer whales in East Greenland. Norwegian small-type whalers caught 136 killer whales south of the assessment area between 1959 and 1972 (Øien 1988).

Heide-Jørgensen (1988) reviewed published and unpublished information available on killer whales in Greenland and carried out a questionnaire-based investigation of sightings of killer whales. Observations were reported from almost all areas of Greenland, except for the assessment area north of Scoresby Sund, where survey effort was low. But killer whales seemed to be rare in the coastal areas. Before 2010, killer whales have been reported off the pack-ice belt in East Greenland and on rare occasions during ice-free summers in Scoresby Sund. During the seismic surveys etc. 1994-2017 off Northeast Greenland only few killer whales were reported (Figure 56) and none were seen during the aerial and ship-based surveys in 2017 (part of the *Strategic Environmental Study Program for Northeast Greenland*). Since 2010, killer whales have been caught every summer in the Tasiilaq area (Foote et al. 2013, Lennert & Richard 2017, Dietz et al. 2019, Jourdain et al. 2019, Flora et al. 2019).

Conservation status: Killer whales are listed as 'Data Deficient' (DD) in the Red Lists, both globally and nationally (Reeves et al. 2017, Boertmann & Bay 2018).

The catch: Killer whales are hunted in Greenland, partly for human subsistence and partly to feed sled dogs, but also because the hunters consider them as competitors. Between 1996 and 2006, killer whales were reported taken on two occasions in East Greenland off Tasiilaq (2 whales in 2003 and 2 in 2004) south of the assessment area (NAMMCO 2019a). The average yearly reported catches in the same area from 2009-2017 was six killer whales (NAMMCO 2019a, Dietz et al. 2019; Flora et al. 2019). There are no reports of killer whales caught in the assessment area.

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

Narwhal

Biology: Narwhals are high Arctic mammals that feed primarily on Greenland halibut, other species of Arctic fish, shrimp and squid. Narwhals undertake regular migration between shallower summer grounds in fjords, where they apparently do not feed, and wintering grounds in deep and densely ice-covered waters, where they feed (Figure 61). They are gregarious, occurring usually in groups comprising a few to more than 100 individuals.

Distribution: Narwhals occur throughout the assessment area (Dietz et al. 1994), in winter primarily in the wide drift ice belt off the coast, and narwhals have been tracked from Scoresby Sund to winter habitats over the shelfbreak off the Blosseville Kyst (Heide-Jørgensen et al. 2015). In summer narwhals occur along the coast, ice edges and in the fjords.

The surveys in 2017 and 2018 recorded narwhals at several sites, and especially in Dove Bay many were seen (Figure 62). In the Scoresby Sund fjord complex, tagging and tracking studies have been carried out for several years, some as part of the *Strategic Environmental Study Program for Northeast Greenland* (Figure 63) and they focused on the effects of seismic noise (Box 3.13).

Population: Three systematic surveys have been carried out in the assessment area. In 1983 and 1984 narwhal abundance was estimated in Scoresby Sund

Figure 61. The general distribution of narwhal.

Figure 62. Distribution of narwhals observed in Dove Bugt during systematic transect surveys in 2017 (blue) and 2018 (yellow).

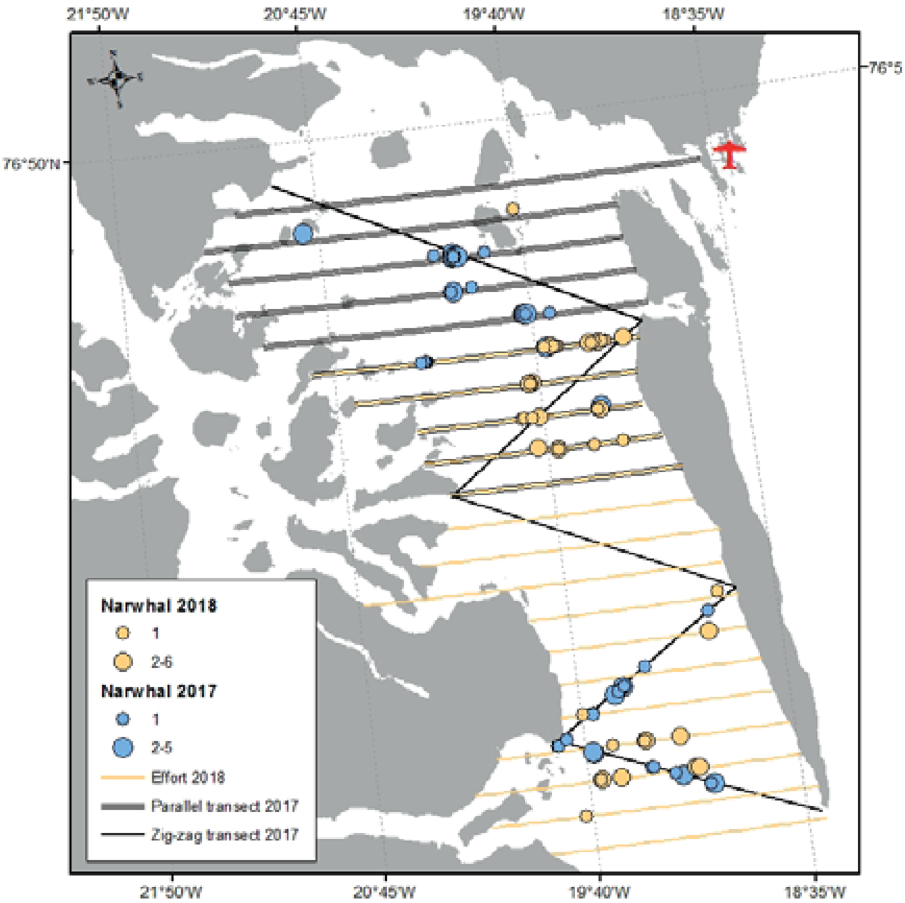
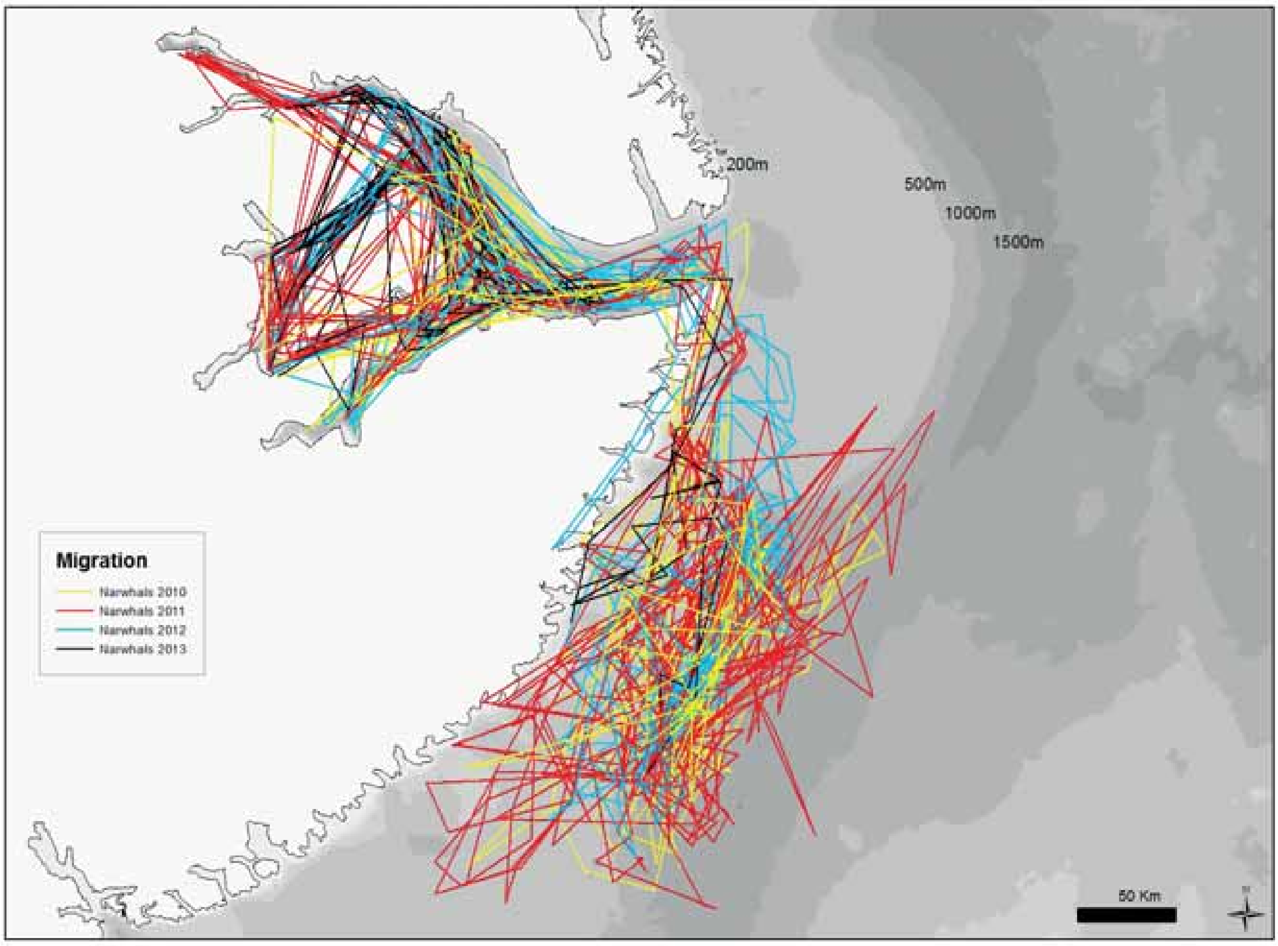


Figure 63. Results of satellite tracking of narwhals in 2010-2014 (Heide-Jørgensen et al. 2015).



and adjacent waters to be 300 and 102, respectively, based on aerial censuses (Larsen et al. 1994). The latest aerial survey in the areas available to hunters in East Greenland was carried out in August 2008 when the number of narwhals in the surveyed areas of East Greenland (Scoresby Sund and south to Tasiilaq) was estimated at 6444 (95% CI: 2505–16,575) (Heide-Jørgensen et al. 2010a).

In 2017 and 2018 narwhal abundance was estimated in three parts of the assessment area (Hansen et al. 2019a): Northeast Water in August 2017: 135 (95% CI: 42-433), Greenland Sea August 2017: 2261 (95% CI: 1008-5071) and Dove Bugt in both 2017 and 2018: 2387 (95% CI: 977-5832) and 1087 (95% CI: 494-2379) respectively. The total abundance estimate in the assessment area in 2017 was 4783 (95% CI: 2633-8687).

The population in the Scoresby Sund fjord complex was assessed at 467 (95% CI: 232-977) in August 2016 (JWG 2017).

The narwhals in East Greenland are, like the whales in Baffin Bugt, probably divided into several subpopulations separated in their summer grounds. Current research by GINR aims at investigating the population structure and abundance of narwhals in East Greenland.

The catch: Narwhals are important quarry for the hunters in both Ittoqqortoormiit and Tasiilaq, because narwhal skin ('mattaq') and male tusks can be traded at considerable prices. The Ittoqqortoormiit hunters catch narwhals in the large Scoresby Sund fjord complex and along the northern part of the Blosseville Kyst. Hunters from Tasiilaq travel to Kangerlussuaq and the southern Blosseville Kyst (Born 1983, Glahder 1995, Flora et al. 2019). Catch statistics show an increasing harvest in the assessment area, from 19 animals/year as an annual average in the period 1997–2003 to between 30 and 93 animals/year from 2004-2006. However, the catch statistics for East Greenland most likely underestimate the real catch. Since 2009, catches of narwhals in East Greenland have been regulated by quotas. The East Greenland quota for 2019 was 66 whales, of which 50 were allocated to Ittoqqortoormiit and 16 to Tasiilaq. This quota is higher than the biological advice, and the harvest of narwhals in East Greenland should be reduced to zero in all three management areas (NAMMCO 2019b, GINR 2019).

Conservation status: The narwhal population in the northern part of the assessment area probably has a favourable conservation status, because the narwhals are fully protected within the National Park of North and Northeast Greenland. South of the national park, the populations are hunted, and declines have been noted between 2008 and 2016 (JWG 2017).

The global Red List classifies the narwhal (entire population) as 'Least Concern' (LC), while the east Greenland population on the national Red List is assessed as 'Endangered' (EN) due to the documented decline (Lowry et al. 2017, Boertmann & Bay 2018).

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

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

Box 3.13

Short-term effects of seismic impulses on narwhals

O. Tervo (GINR) & M.P. Heide-Jørgensen (GINR)

The sensitivity of narwhals to seismic exploration was studied in two experiments in august 2017 and 2018 in Scoresby Sund, East Greenland. The study exposed 9 narwhals instrumented with satellite transmitters and behavioral-physiological-acoustic sensors to seismic sound (Figure 1). The data were compared for periods with and without seismic activity and with different distances to the seismic sound source. Initial analysis showed a cessation of foraging activity measured as the absence of foraging related vocal signals and a change to diving in the upper water column (< 50 m) when seismic activity was <=15 km from the whales (Table 1 and Figure 2).

At that distance one reaction was to freeze and remain at the upper part of the water column and significantly reduce the vocal activity compared to the undisturbed situation. The whales in this category also showed a reduced level of activity measured with three different metrics (stroking, and two units of overall dynamic body acceleration). The second reaction was a flee response where the whales increased their swim speed, presumably to avoid the source of the disturbance while remaining at the upper part of the water column and reducing their vocal activity to include only calls. The whales also tended to approach the coast when exposed to seismic activity.

These behavioral results together with direct measurements of changes in physiological responses (breathing rates, heart rates associated with level of exertion), enable quantification of the energetic costs related to sound disturbances. Together, these can further on be used to asses both short-term and long-term effects of seismic activity on narwhals on individual to population scales.

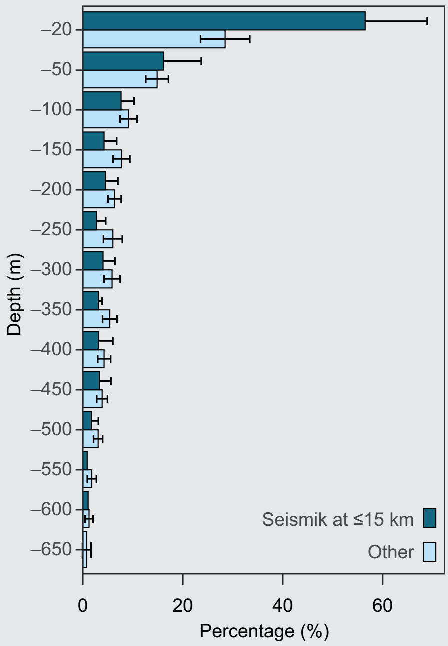


Figure 2. Average percentage of time spent at different depth bins during seismic exposure at <=15 km distance (black) and on all other occasions (white). Error bars indicate one Standard Deviation. Depths > -20 m are removed. Data includes two animals from 2017 and five animals from 2018.

Table 1. Average percentage of buzzes (a vocalization type related to foraging) produced during 1) seismic exposure at <= 15 km distance and 2) on all other occasions. Data includes two animals from 2017 and three animals from 2018.

Category	Mean (%)	SD (%)
Seismic <= 15 km	4.9	7.2
Other	97.1	5.8

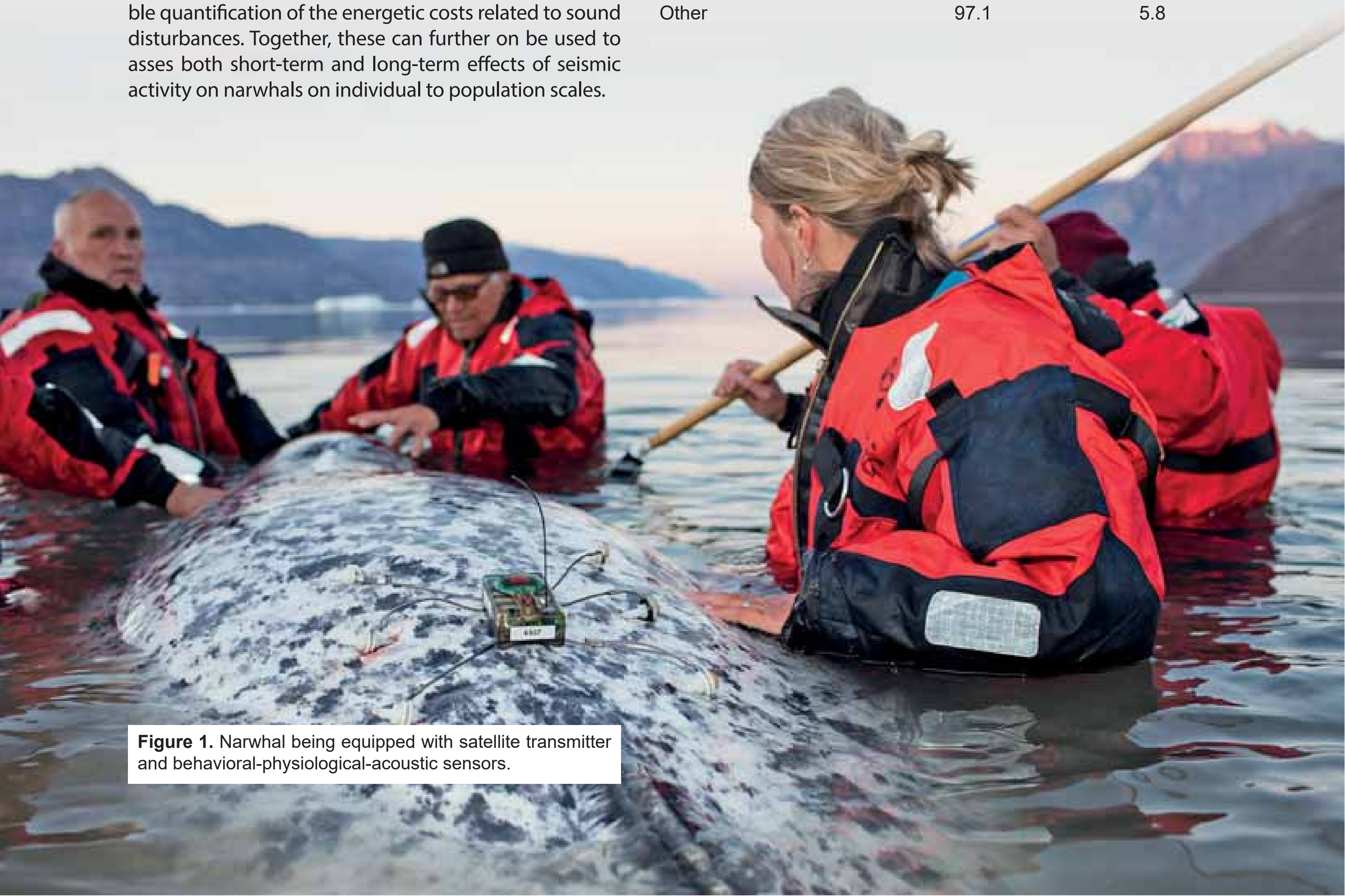


Figure 1. Narwhal being equipped with satellite transmitter and behavioral-physiological-acoustic sensors.

Inuit hunters catch narwhals from kayaks, with nets or by spotting them first from high vantage points, instead of looking for them with boats because narwhals are skittish and avoid engine sounds (Heide-Jørgensen & Laidre 2006). Accordingly, narwhals are believed to be sensitive to noise from seismic surveys, and drilling (Heide-Jørgensen et al. 2013, Finley et al. 1990). Increased traffic and oil activities may cause displacement from critical habitats and reduction in the population. This assumption is supported by the fact that narwhals react strongly to the sound of icebreakers (Finley et al. 1990). The official guidelines to seismic surveys in Greenland designate specific narwhal protection areas (Figure 66), including 'closed areas' (e.g. Dove Bugt in the assessment area) and 'areas of concern' June to November, covering largely the western half of the assessment area (EAMRA 2015).

The effects of seismic shooting on narwhal behaviour and physiology were studied for the first time in 2017, as one of studies of the *Strategic Environmental Study Program for Northeast Greenland* (Box 3.13).

Sperm whale

Biology: With males reaching lengths of 18 m and weights of 50 tonnes, sperm whales are the largest toothed whale. On average, male sperm whales are 15 m long and weigh 45 tonnes, while females are 11 m long and weigh 20 tonnes. As in the case of bottlenose whales, sperm whales are found in deep waters, often seaward of the continental shelf and near submarine canyons.

Sperm whales forage on a wide variety of deep-sea cephalopods and fish. Prey size ranges from a few centimetres long fish to 3-metre long sharks and even giant squids that weigh up to 400 kg (reviews in Rice 1989 and Whitehead 2003). Sperm whales in the Northeast Atlantic feed heavily on the deep-water squid, *Gonatus fabricii* (Santos et al. 1999), favouring mature squid with mantle length of approx. 19 to 26 cm (Simon et al. 2003). Male sperm whales off northern Norway tagged with multi-sensor instruments were feeding both at shallow depths of about 117 m and at the sea bottom at depths down to 1860 m, showing that male sperm whales have flexible feeding habits (Teloni et al. 2008). In some areas, sperm whales take fish from long-line fisheries (e.g. Roche & Guinet 2007) or approach trawlers in search of discarded fish (e.g. Karpouzli & Leaper 2003).

Stomach samples from sperm whales caught between Iceland and Greenland were dominated by fish, squid being a secondary food item (Roe 1969, Martin & Clarke 1986). The most important fish species in the diet was lumpfish, but redfish, anglerfish and Atlantic cod were also common.

Distribution: Sperm whales are found in all oceans, from the ice edges to the equator. Females and calves remain in tropical and sub-tropical waters year-round, while males segregate to high latitudes at the onset of puberty, aged between 4 and 15 years (Best 1979, Mendes et al. 2007). The larger males, in their late twenties or older, occasionally migrate to lower latitudes in search of mating opportunities. When in lower latitudes, males move between different groups of females and their offspring, sometimes engaging in physical combat with other males (Whitehead & Weilgart 2000). Surveys in the waters around Iceland and the Faroe Islands in 2015 resulted in an abundance estimate of 23,166 (95% CI: 7699-69,709) whales.

Based on ship surveys in July 2001, the estimated number of sperm whales between East Greenland and the Faroe Islands was 11,185 (CV 0.34; Gunnlaugsson et al. 2002). There was dense sea ice in East Greenland at the time of that survey, and thus coverage of the assessment area was very poor. Most of the sightings of sperm whales were in the Denmark Strait close to the southern part of the assessment area, or south, east and northeast of Iceland. There were no sperm whales seen in the proximity of the assessment area north of approx. 68° N. In Svalbard, sperm whales have been observed at the ice edge as far north as 80° N (Øien 2009).

No sperm whales were observed by the seismic surveys etc. 1994-2017 or during aerial surveys covering the southern part of the assessment area in 2015 (Hansen et al. 2018b).

The International Whaling Commission considers that all sperm whales in the North Atlantic belong to a single stock (Donovan 1991). This assumption is supported by genetic analyses (Lyrholm & Gyllensten 1998).

Conservation status: Sperm whales were the target of commercial whaling for over two centuries. By the second half of the 20th century sperm whales were still numerous, but several populations were depleted. Commercial whaling of sperm whales stopped with the moratorium on whaling at the end of the 1980s. Nowadays, sperm whales are not caught anywhere in the North Atlantic. Both on the global and the Greenland Red List, sperm whale is listed as 'Vulnerable' (VU) (Taylor et al. 2008, Boertmann & Bay 2018).

Sensitivity and critical habitats: Sperm whales are often found feeding in deep underwater canyons and off the steep continental slopes. But such feeding areas have not been identified in the assessment area. Sperm whales are occasionally seen close to Kulusuk, in the Tasiilaq area (Flora et al. 2019, GINR, unpublished information, R. Dietz, pers. comm.).

The echolocation clicks of sperm whales have the most intensive sound recorded from any animal (Møhl et al. 2003) and, therefore, sperm whales may be more tolerant to loud noises than other whales.

During a controlled exposure experiment in the Gulf of Mexico, sperm whale horizontal movements were not noticeably affected by a seismic survey, but foraging effort diminished when airguns were operating (Miller et al. 2009). The results of this study may not be representative for other parts of the world because these particular sperm whales lived in an area with heavy shipping traffic and a long history of oil activity; therefore the whales may have habituated to anthropogenic noise and stronger reactions may be expected elsewhere.

Northern bottlenose whale

Biology: Next to the sperm whale, the northern bottlenose whale is the largest toothed whale in the North Atlantic, with adult females measuring up to 9 m in length and males up to 11 m. They are found in deep waters, often seaward of the continental shelf and near submarine canyons, from the ice edges south to approximately 30° N. They have a fission-fusion social system (i.e. live in groups that join and split), with group sizes from about 4 to 20 animals. Groups may be segregated by age and sex and males may form long-term companionships with other males (Wimmer & Whitehead 2004).

The main prey of the bottlenose whale is squid (*Gonatus* spp.), but prey items also include fish (herring, redfish, etc.), and invertebrates, such as sea cucumbers, starfish and prawns (Hooker et al. 2001). Prey is often caught near the bottom at depths greater than 800 m (Hooker & Baird 1999). Bottlenose whales are known to take Greenland halibut from long-line fisheries.

Northern bottlenose whales have only been studied in detail in an area surrounding the Gully, an underwater Canyon off Nova Scotia, at the southern end of the species' range. Based on boat surveys, photo-identification and molecular analyses, it has been established that these northern bottlenose whales live in a small population of about 150 animals that is rather stationary and isolated from other populations (Wimmer & Whitehead 2004, Whitehead & Wimmer 2005, Dalebout et al. 2006).

Distribution: Northern bottlenose whales are the most frequently observed cetaceans around the Jan Mayen Ridge (Gunnlaugsson & Sigurjónsson 1990), just east of the assessment area.

No bottlenose whales were seen during the seismic surveys etc. 1994-2017, and none during an aerial survey of the southern part of the assessment area in 2015 (Hansen et al. 2018b).

The catch: Northern bottlenose whales were the target of Norwegian whaling during two periods. The first period was from 1882 to the 1920s, when somewhere in the region of 60,000 northern bottlenose whales were taken. Approximately 5800 whales were taken during the second period, from 1930 to 1973 (NAMMCO 1995). Norwegian catches were spread over much of the Northeast Atlantic, including the Greenland Sea and the Denmark Strait and, after 1959 some bottlenose whales were taken in West Greenland and eastern Canada (Figure 64).

Scottish sealers and whalers took approximately 1961 bottlenose whales from 1856 to 1970, including catches in both the Davis Strait and the Greenland Sea (Thompson 1928, in NAMMCO 1995). Most of these catches (1787) were from the period 1877-1892.

Northern bottlenose whales are not taken by Greenland hunters.

Conservation status: The Red List status of the northern bottlenose whale is 'Data Deficient' (DD) on the global list, and 'Not applicable' (NA) on the Greenland list (IUCN 2011, Boertmann 2018).

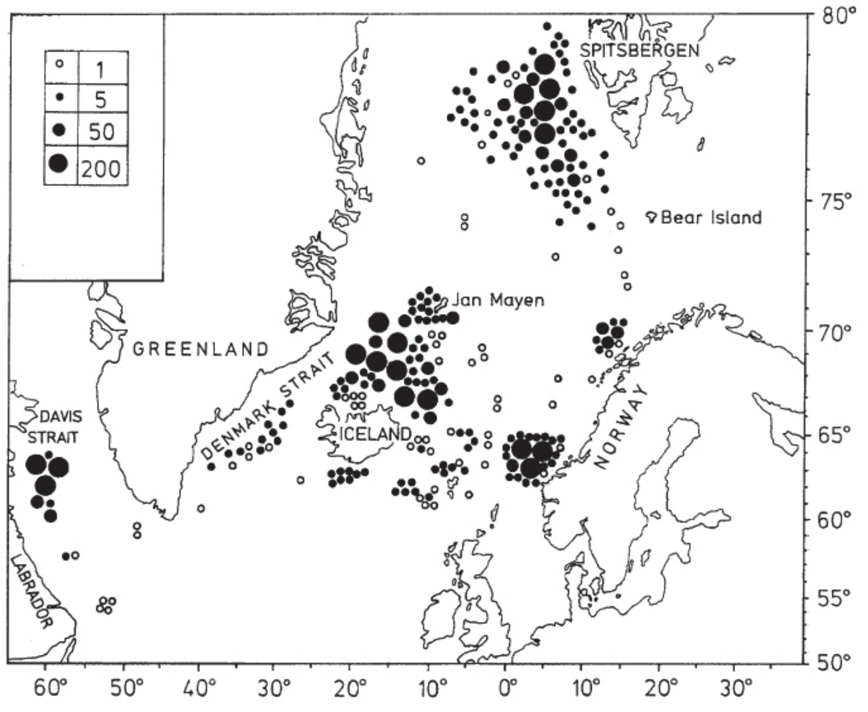


Figure 64. Localities of northern bottlenose whales caught by Norwegian whalers in the period 1938-1972 (modified from Benjaminsen & Christensen 1979).

Sensitivity and critical habitats: Bottlenose whales are often found feeding in deep, underwater canyons and off the steep continental slopes, but feeding grounds for bottlenose whales have not been found in East Greenland waters.

Hooker et al. (2008) found increasing levels of persistent contaminants and CYP1A1 protein expression in biopsy samples from bottlenose whales following the onset of gas and oil development in Eastern Canada. The authors conclude that the change in contaminant levels over time in these whales was likely to reflect a temporal change in contaminant levels in the water and/or in prey species, and speculated that the proximity of oil and gas drilling activities may have influenced contaminant patterns through remobilization of persistent contaminants from sediments on the seabed.

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

See text about toothed whales and acoustic disturbance above.

3.8.6 Important areas for marine mammals

Fernando Ugarte (GINR) & David Boertmann (AU)

The marine mammals of the assessment area are dependent on open waters: seals and whales for breathing, polar bears partly for feeding. Therefore, recurrent and predictive open waters among otherwise ice-covered areas are critical to the marine mammals in the assessment area. The ice edges, the polynyas (Figure 12) and the lead zones are such critical areas. Particularly the Northeast Water is extremely important to walruses, narwhals, bowhead whales, polar bears and probably also to ringed and bearded seals. The Sirius Water Polynya (off Wollaston Forland) is also very important to walruses, polar bears and bowhead whales. The third large polynya, at the entrance to Scoresby Sund, is of similar importance to marine mammals as the Northeast Water (seals, walrus, narwhal, polar bear), and was the basis for the establishment of the town of Ittoqqortoormiit. The marginal ice zone in the Greenland Sea is habitat for bowhead whales, narwhals (mainly in winter) and for polar bears and walruses and serve as whelping and moulting area for harp and hooded seals (see below). It is, however, difficult to designate and delimit specific important areas in this zone, mainly due to the highly dynamic position, extent, and inter-year variability of the drift ice and MIZ. Finally, some of the fast ice edges also seem to be important, especially the edge of the semi-permanent ice shelf between the Northeast Water and Île de France (Norske Øer ice barrier). The ship-based surveys recorded most harp and hooded seals in the previous licence areas (Figure 56).

The studies of the *Strategic Environmental Study Program for Northeast Greenland* in 2017 also revealed several aggregations of both seabirds and marine mammals along the shelfbreak as well as areas of high primary production. However, as the survey was a single year occurrence, there is no information on the variation and predictability of these areas, and this issue should be studied further. But at least one area between 76° and 78° N has shown to be utilised by a large aggregation of bowhead whales each year in June in the period 2015-1018.

Polar bear denning areas are widespread on land along the coast, and it is not possible to point out specific important coastlines for this very sensitive element in polar bear ecology. There seems to be a tendency for higher densities of maternity dens north of approx. 68° N, and known regular denning areas include Kangerlussuaq; the Blosseville Kyst; the inner parts of the Scoresby Sund fjord complex; the areas between Kong Oscars Fjord and Kejser Franz Joseph Fjord; Shannon; Dove Bugt; the areas between Île de France and Ingolf Fjord; and the coast at the Northeast Water. The tracking results reported in Chapter 3.8.1 identified several denning sites in the northern part of the assessment area. Several mother and cub groups were observed during the polar bear fieldwork in 2018, indicating that the area around Station Nord, including the licence area, is important for polar bear reproduction.

Polar bears are dependent on ice cover, preferring relatively dense sea ice at the continental shelf where there are high concentrations of ringed seals, their main prey. Expected changes of ice cover due to global warming will inevitably have an effect on the distribution and abundance of polar bears and seals.

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

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

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

Along the coast of East Greenland, narwhals spend the summer months in coastal waters: especially some of the fjords on the Blosseville Kyst, the inner parts of Scoresby Sund fjord complex, Dove Bugt and the Northeast Water are important habitats.

4 Protected areas and threatened species

David Boertmann (AU)

4.1 International nature protection conventions

According to the Convention on Wetlands (the Ramsar Convention), Greenland has designated twelve areas to be included in the Ramsar list of Wetlands of International Importance (Ramsar sites). These areas are to be conserved as wetlands and should be incorporated in the national conservation legislation; however, only one in Disko Bugt has been incorporated as a protected area so far. Four of the Ramsar sites are found within the assessment area. (Link to Ramsar site 389, Link to Ramsar site 2021, Link to Ramsar site 390, Link to Ramsar site 391). These are all designated due to the presence of geese in internationally important numbers, i.e. more than 1% of the flyway population (Egevang & Boertmann 2001).

4.2 National nature protection legislation

The major part of the land and fjord areas adjacent to the assessment area is designated as national park – The National Park in North and East Greenland (Figure 65), with strict protection of nature and environment. However, it is allowed to explore for petroleum and minerals within the national park and inhabitants of Ittoqqortoormiit are allowed to hunt there by means of dog sledge (Boertmann 2005, Aastrup et al. 2005). Management of the park is under revision, and zoning with varying management and protection is an option which is discussed.

There are four sites protected according to the Bird Protection Order within the assessment area: Kap Brewster, Raffles Ø, Sandøen and Prinsesse Margrethe Ø (Figure 65). Moreover, all seabird breeding colonies and their immediate surroundings are generally protected from disturbing activities (Figure 37). According to the Mineral Extraction Law, a number of 'areas important to wildlife' are designated and, in these, mineral exploration activities are regulated in order to protect wildlife. There are several of these 'areas important to wildlife' within the assessment area, and in relation to seismic surveys a number of protection areas for whales and walrus have been designated along the coasts (Figure 66) (EAMRA 2015).

The available knowledge (including local knowledge) on ecosystem components of the National Park and adjacent areas was reviewed in 2005 (Aastrup et al. 2005), and later updated (Aastrup & Boertmann 2009). This work identified a number of areas with important biological interests (Figure 67).

4.3 Threatened species

Greenland has red-listed (designated according to risk of extinction) eight species of mammals and thirteen species of birds (Table 8) occurring in the assessment area (Boertmann & Bay 2018). A number of species have been categorised as 'Data Deficient' (DD) or 'Not Applicable' (NA) and they may become red-listed when additional information is available (Table 9).

Greenland has a special responsibility for species for which a significant part (>20%) of the global population occurs within the territory, implying that their global survival depends on a favourable conservation status in Greenland. National responsibility species occurring in the assessment area include

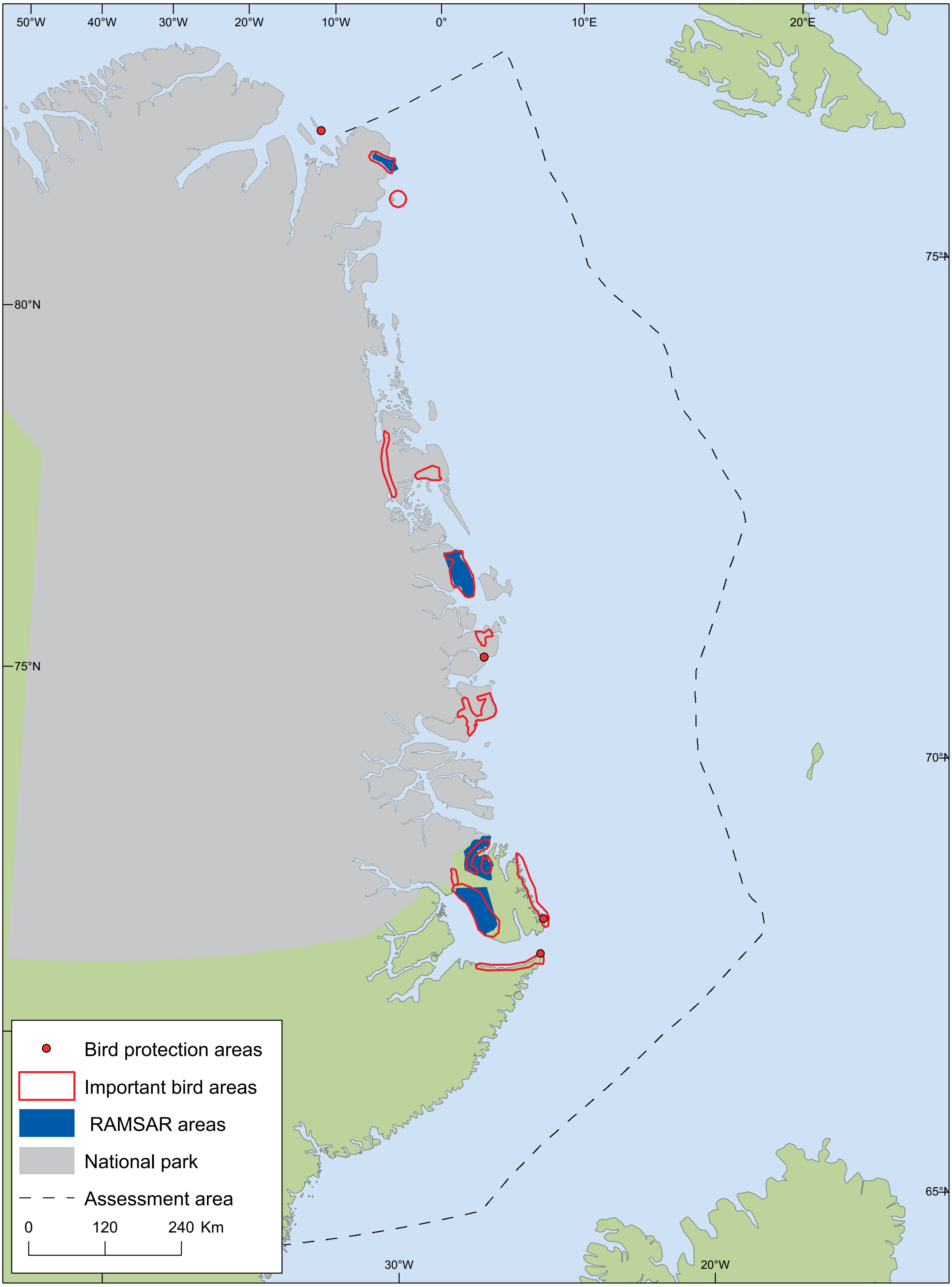


Figure 65. Areas protected according to the Greenland Nature Protection Law (National Park in North and East Greenland and Bird Protection areas), international conventions (Ramsar) and areas designated as Important Bird Areas (IBAs) by BirdLife International.

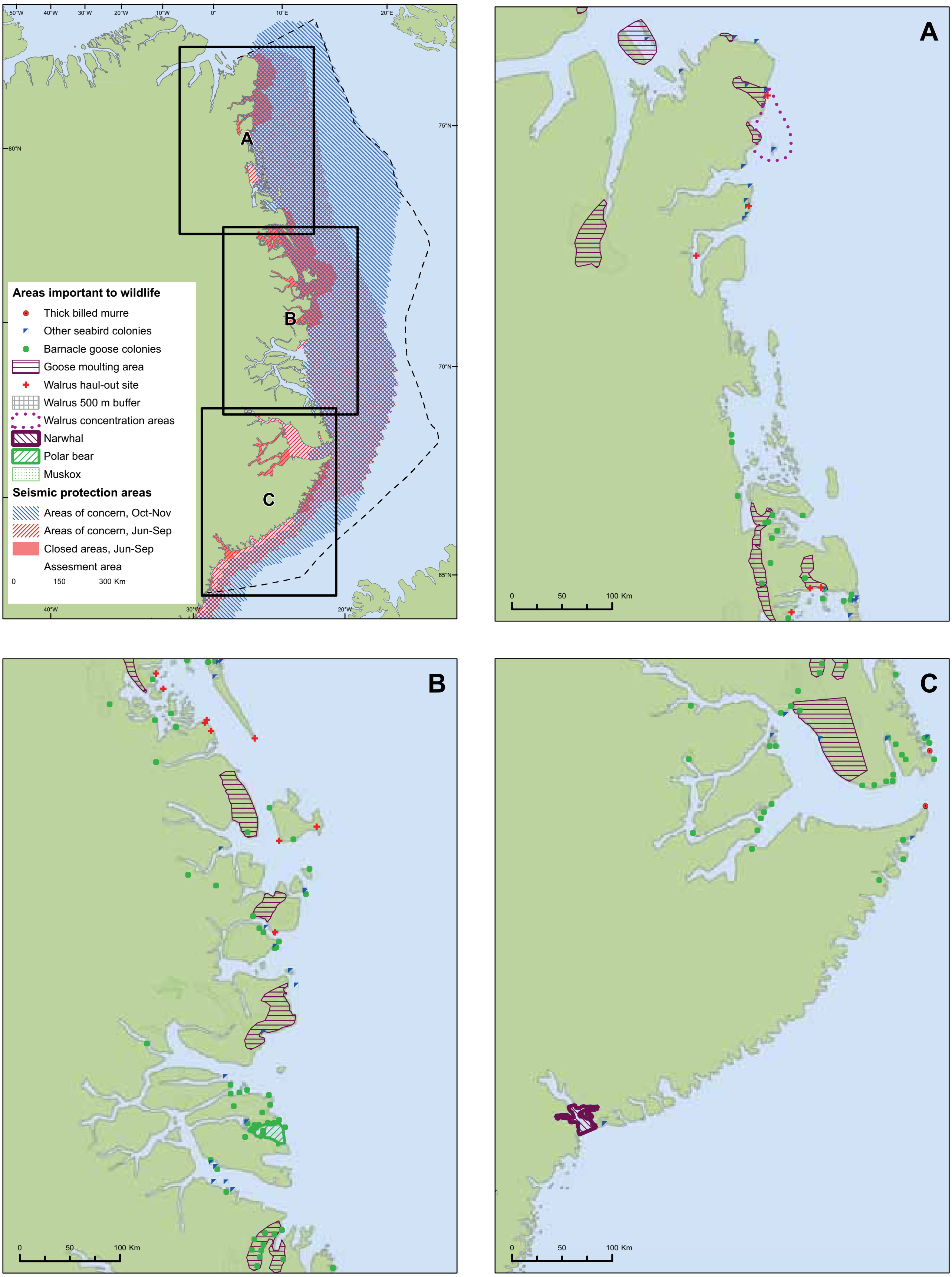


Figure 66. Areas designated as "important to wildlife" by EAMRA as a part of the guidelines for offshore prospecting and exploration activities, and seismic protection areas (EAMRA 2015). In the areas important to wildlife, flying and other traffic is regulated in order minimize disturbance. In the seismic protection zones, seismic surveys are regulated in order not to disturb walrus, narwhal and bowhead whale in certain periods of the year. Closed areas are no-go areas in the specified season, and in areas of concern seismic surveys can be subjected to specific regulation.

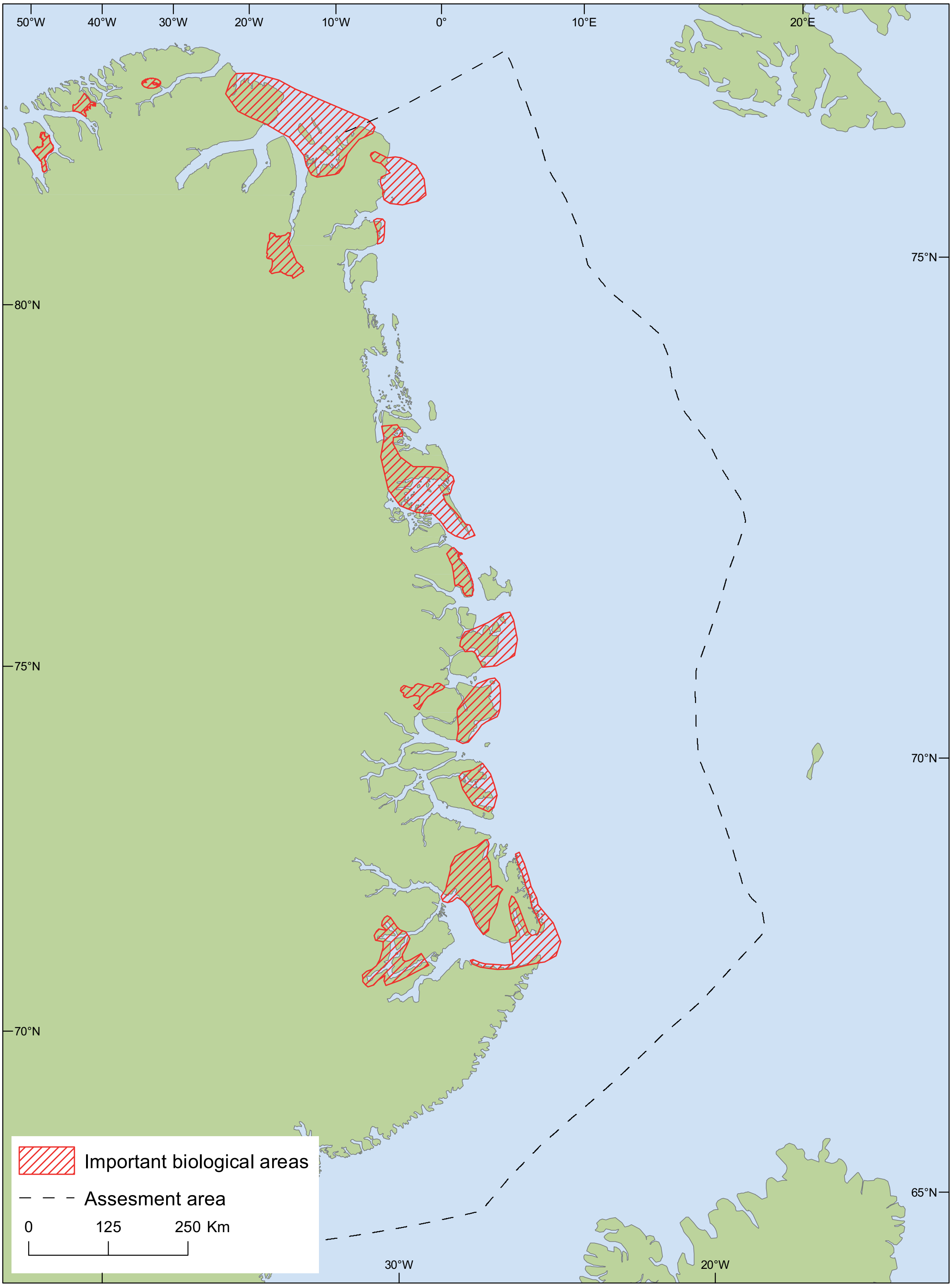


Figure 67. Areas with major biological interests in and adjacent to the National Park of North and Northeast Greenland designated based on a review of available information (Aastrup et al. 2005, Aastrup & Boertmann 2009).

Table 8. Red-listed species occurring in the assessment area.

Species	Greenland Red List status
Wolf**	Vulnerable (VU)
Polar bear	Vulnerable (VU)
Walrus	Near Threatened (NT)
Hooded seal	Vulnerable (VU)
Bowhead whale	Vulnerable (VU)
Blue whale	Vulnerable (VU)
Sei whale	Endangered (EN)
Narwhal	Endangered (EN)
Sperm whale	Vulnerable (VU)
Great northern diver	Near Threatened (NT)
Light-bellied brent goose	Near Threatened (NT)
Gyrfalcon**	Near Threatened (NT)
European golden plover**	Near Threatened (NT)
Whimbrel**	Near Threatened (NT)
Sabine's gull	Near Threatened (NT)
Ross's gull	Vulnerable (VU)
Black-legged kittiwake	Vulnerable (VU)*
Ivory gull	Vulnerable (VU)
Arctic tern	Near Threatened (NT)*
Thick-billed murre	Vulnerable (VU)
Atlantic puffin	Vulnerable (VU)
Snowy owl	Near Threatened (NT)

* applies to the entire Greenland population, and red-listed because the population in West Greenland is decreasing, a trend not apparent in East Greenland.
** are not associated to the marine environment.

Table 9. National responsibility species (more than 20% of global population in Greenland) and species listed as 'Data Deficient' (DD) occurring in the assessment area. Only species which may occur in marine habitats are included.

National responsibility species	Specie listed as 'Data Deficient' (DD)
Polar bear	Killer whale
Hooded seal	Bottlenose whale
Harp seal	
Bowhead whale	
Pink-footed goose	
Light-bellied brent goose	
Barnacle goose	
Knot	
Black guillemot	
Little auk	

four mammals and six birds (Table 9). However, also narwhal may be included here but the total number of narwhals and the proportion in Greenland is unknown. Two marine mammal species occurring in the assessment are deemed Data Deficient.

Within the assessment area there are some hotspots containing threatened species, in particular the mouth of Scoresby Sund, the Sirius Water Polynya, the entrance to Dove Bugt, and the Northeast Water including the islands of Henrik Krøyer Holme.

Threatened species on a global scale and occurring in the assessment area are listed in Table 10.

4.4 NGO designated areas

The international bird protection organisation BirdLife International has designated a number of Important Bird Areas (IBAs) in Greenland (Heath & Evans 2000), and fourteen are within the assessment area (Figure 65). These areas are particularly important for birds and are areas which should be protected by national regulations. They are designated using a large set of criteria, for example that at least 1% of the global population of a bird species should occur in the area on a regular or predictable basis. For further information see the IBA website (Link, including the global criteria). Some of the IBAs are included in or protected by the national regulations, e.g. within the National Park, but many are without protection or activity regulations.

Table 10. Globally threatened species occurring in the assessment area (IUCN 2020).

Species	Red list status
Long-tailed duck	Vulnerable (VU)
Ivory gull	Near Threatened (NT)
Polar bear	Vulnerable (VU)
Walrus	Vulnerable (VU)
Hooded seal	Vulnerable (VU)
Bowhead whale, Spitsbergen population	Endangered (EN)
Fin whale	Endangered (EN)
Sei whale	Endangered (EN)
Blue whale	Endangered (EN)
Sperm whale	Vulnerable (EN)
Narwhal	Near Threatened (NT)

5 Biologically important areas

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

5.1 Identification of biologically important areas

5.1.1 Overlay analysis

For this assessment, a GIS-based overlay analysis of spatial and temporal data on different ecosystem components has been carried out, i.e. thematic maps are layered on top of each other to highlight areas where many and/or important occurrences overlap. The purpose of the analysis was to support the identification of biologically important areas. In total, 59 species and other ecosystem components were included. For species where information data on seasonal changes in spatial distribution exists, a series of seasonal map layers were prepared using species-specific separation dates between the layers; this approach expanded the analyses to include 131 information layers.

The method is explained in appendix 1 of Christensen et al. (2017), and we refer to this report for a detailed account of the technicalities of the overlay analysis. In short, each species is attributed a number of points (a score) based on an assessment of its relative importance, and in the seasonal species layers, these points are distributed across 1x1 km cells covering the assessment area according to best available information on the spatial distribution of the species during the given period of the year (e.g. a spatial model, a survey, or expert judgement based on literature data). Thereby cells in known concentrations areas receive a higher proportion of the species score than cells in low density areas. Then, for each day of the year, the seasonal species layers valid at this date are stacked on top of each other, and for each cell, a sum is calculated across the stack to provide a daily overlay result. Subsequently, the daily overlay results are smoothed in space (10 km radius) and time (±5 day window) as none of the raw data layers have a spatio-temporal precision of 1 km/1 day.

The results are presented in a series of maps from selected dates (mid-day of every second month of the year), colour coded in 5% percentiles (20 colour shades). This means that each colour covers 5% of the assessment area. The deep red colour covers the 5% of the area with the highest overlay cell values at the given date, i.e. the most important areas, and combined with the next (paler) red shade in the legend, they cover the top 10% etc. It is important to bear in mind that the maps show the *relative* importance of areas at a given date, and maps from different dates cannot be compared directly. To provide a summary result for the whole year, Figure 68 shows an average of all smoothed daily overlays, also colour coded according in 5% percentiles.

In essence, the red and orange areas show where the most important areas occur for the most important species/ecosystem components, and the overlap at different times of the year; these areas can be interpreted as the *biologically most important areas* at that point in time/season. However, there are many uncertainties, for example concerning the exact distribution of many of the species, which means the results cannot stand alone and must be supplemented by expert judgement. Furthermore, by these methods, important species/ecosystem components with a confined spatial distribution will tend to show up in the overlay results, even though they do not overlap with any other species. This is intentional as such areas tend to be important, but with incomplete data it can also create some peculiar artefacts in the results. The most prominent example of this is the coral reef found in autumn 2017 (Box. 3.2), which stands out as a small red dot at the shelf-break on all of the maps (Figure 76, 77). There are yet no other records of this particular type of coral reef in the assessment area, but it is probably more widespread along the shelf-break. This means that the apparent uniqueness of the area highlighted by the analysis might be misleading, although cold-water coral reefs are considered very important.

One last thing to bear in mind is that the overlay analysis coveys information on biologically *important* areas, not on the *sensitivity* of areas with respect to different stressors such as oil spills, seismic noise, hunting etc. While the identified areas certainly will tend to be sensitive to a range of different things (as they represent important biodiversity and wildlife concentration areas), a strict analysis of sensitivity requires additional quantification of how the individual species/ecosystem components are affected by the different stressors under consideration (see Christensen et al. 2015).

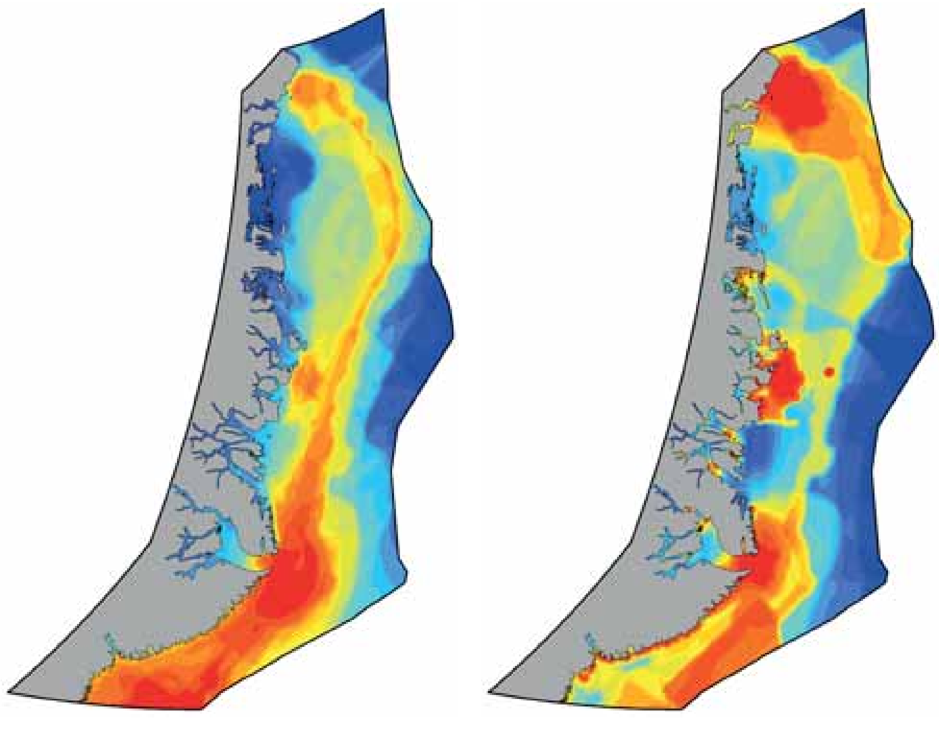


Figure 68. Results of the GIS overlay analysis, averaged across the whole year. In the map to the left, the distributions of individual species/ecosystem components were treated as present/absent, but in the overlay process, a differential weighting of the species was applied. The resulting map can thus be interpreted as a species weighted biodiversity map. The map to the right is more complex as both a differential weighting of species and a differential weighting of the seasonal distribution range of the individual species was applied. Besides biodiversity, this map tends to highlight important species/ecosystem components with a limited spatial distribution. Both maps clearly highlight the polynyas (cf. Figure 12) as biologically important areas. The warmer colours to the south, especially in the map to the left, are caused by a higher biodiversity in these waters. The shelf-break in the northern part of the assessment area (compare with Figure 1) is also highlighted as biologically important in both maps. Note the red dot at the shelf-break a little above the middle in the map to the right: it is the coral garden located during the 2017 oceanographic survey (also visible on all maps in Figure 69). Corals are probably more widespread along the shelf-break, but the 2017 record is the only one documented. Many of the orange areas along the coast in the map to the right are caused by the presence of seabird breeding colonies.

Winter

Figure 69F and A show the winter situation (mid-December and mid-February respectively), when all fjords and coastal areas are covered by land-fast ice, and most of the shelf is covered by dense dynamic drift ice. Open water or thin unstable ice occur in the polynyas and along the marginal ice zone (MIZ) which is usually located over the shelf-break. Marine mammals are concentrated in these open water areas (see Chapter 3.8). Most of the walrus population winters in the Northeast Water but there are also walruses in the other polynyas. Bowhead whales have important wintering areas in the Northeast Water and in the MIZ towards Svalbard. Narwhals have a wintering area over the shelf-break off Blosseville Kyst in the southern part of the assessment area, and probably also over the shelf-break further north. Polar bears occur throughout the area with concentrations of maternity dens along the coasts of the northern part of the assessment area, north of 78° N. Other marine mammals such as ringed seal and bearded seal occur widespread in the assess-

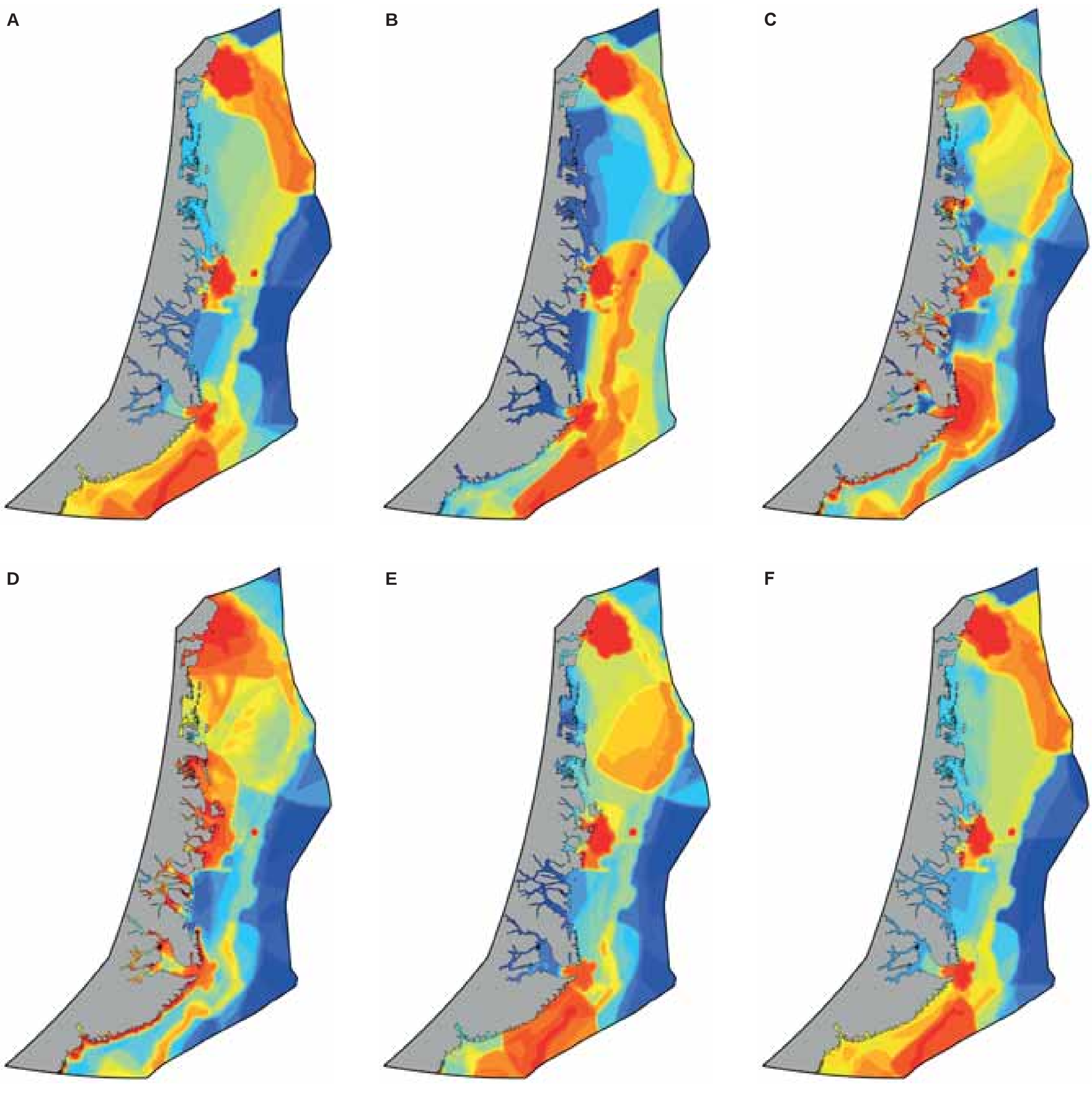


Figure 69. Bi-monthly results of the GIS overlay analysis, involving both a differential weighting of species and a differential weighting of the seasonal distribution range of the different species. A: mid-February, B: mid-April, C: mid-June, D: mid-August, E: mid-October, F: mid-December. The polynyas with their high biodiversity are very apparent on all maps.

ment area, and very few birds are present during this time of the year. Polar cod spawn under the ice in late winter and the eggs accumulate under the ice, where they will be particularly exposed to oil spills, but there is no information on particular concentration areas of spawning polar cod.

According to the overlay analysis, the biologically most important areas in the winter time are the polynyas – appearing clearly (red) on Figure 69F and A due to the concentration of marine mammals, including bowhead whale and walrus – and the MIZ between Greenland and Svalbard and southeast of the Northeast Water, which appears deep orange due to bowhead whales. The shelf-break off Blosseville Kyst is red mainly because of wintering narwhals. All these red and orange areas will be very sensitive to oil spills and disturbing activities – the latter only in a production phase, as exploration will not take place at this time of the year. If spatial information on polar cod spawning areas existed and was included in the overlay analysis, some ice-covered areas would probably be coloured more warmly in the maps.

Spring

Figure 69B (mid-April) and Figure 69C (mid-June) show the situation in spring when the sea ice gradually disintegrates and retreats. Open-water areas expand, starting in polynyas and along fast ice edges. In coastal areas shore leads open and gradually become wider, offering access for waterbirds. As the waters open, the spring bloom commences.

Like in the winter situation described above, the polynyas stand out as red areas on the maps. Here, the marine mammals are supplemented with waterbirds arriving from their winter quarters. Many of the latter just stage here before the move inland to breeding sites at lakes and ponds, or for the seabirds, breeding colonies along the coasts. The shelf-break/MIZ southeast of the Northeast Water is also clearly marked (orange), although not as pronounced as in winter. Here, between 76° and 78° N, bowhead whales, for example, occur in relatively high numbers in June.

The size of the red area of the Scoresby Sund polynya increases during spring, because huge numbers seabirds (little auks and thick-billed murres) move into their breeding colonies along its coasts and utilise the open water areas up to approx. 100 km away from the colonies. The wide shelf in the northern part is yellow in June because bowhead whales move into the area. Many of the coastal areas also become orange and red in June, due to the presence of dispersed breeding seabirds like black guillemots and common eiders.

The most prominent difference compared to the winter maps is the large orange/yellow area on the shelf northwest of Scoresby Sund in April. This area includes the drift ice zone where large numbers of harp and hooded seals aggregate in whelping areas to give birth to their pups (Figure 52), also attracting some polar bears. However, the season is short, and that is why the area does not appear in the map from mid-June.

Like in winter, the polynyas are sensitive to oiling and disturbing activities. This also applies to the seal whelping area. As the coasts become ice-free, many coastal areas also become sensitive to disturbing activities and oil spills due to the presence of seabird breeding colonies.

Summer

Figure 69D shows the situation in mid-August, when the extent of sea ice is near its minimum (occurs in September) and most coastal areas are free of sea ice.

At this time of the year, the terrestrial walrus haul-outs are in use and bowhead whales disperse over the shelf. Narwhals are in fjords and coastal waters. Blue, minke, humpback and fin whales have moved in from the south and the east and stay mainly at the shelf-break. Sperm whales and bottlenose whales occupy the deep waters to the east of the continental slope. Hooded seals and harp seals moult on the ice, but more dispersed than when they whelp.

Most of the seabirds have fledged chicks and many assemble at moulting sites – common eiders and long-tailed ducks in coastal waters, little auks far offshore on the shelf and shelf-break northeast of their breeding sites, where little auks from Svalbard also stage.

Again in summer the polynyas stand out in red on the map (Figure 69D), but coasts and adjacent waters also show high values in the orange and yellow shades due to seabirds breeding colonies, foraging walrus and narwhals in their summer habitat in the inner fjord systems.

The polynyas are again among the most sensitive areas to oil spills and disturbing activities; also many coastal areas and fjords are sensitive to both oil spills (breeding seabirds) and disturbing activities (narwhals).

Autumn

In mid-October (Figure 69E) the ice expands and soon the fjords and coastal areas will be covered by fast ice while the dense drift ice expands southwards. The marine mammals move towards their wintering areas, mainly in the polynyas and on the shelfbreak south of Scoresby Sund (narwhals) and most birds leave the assessment area. The polynyas and the shelf/shelfbreak areas in southern part of the assessment area are among the most warmly coloured zones in the map for this time of the year due to narwhal wintering grounds.

During the autumn the sensitive areas are the polynyas and the shelfbreak, both in the northern and the southern part of the assessment area.

5.2 Areas of importance

By combining the information from the overlay analysis (Figure 68 and 69) with expert judgements and local knowledge from the areas where hunting takes place (Figure 71), areas of particular biodiversity importance can be identified: Figure 70 shows areas sensitive to oil spills and disturbing activities by season as well as a combined sensitivity map.

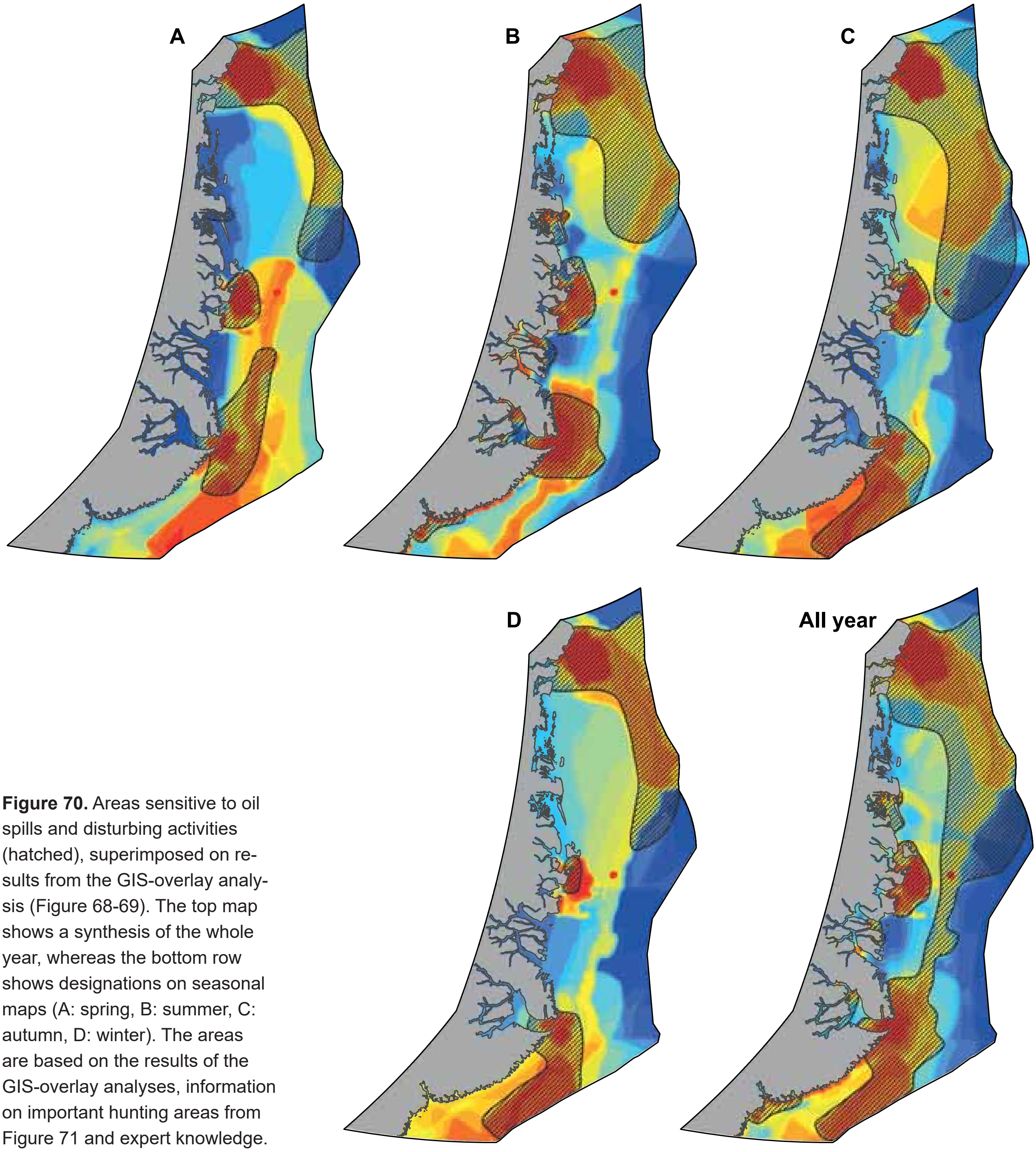


Figure 70. Areas sensitive to oil spills and disturbing activities (hatched), superimposed on results from the GIS-overlay analysis (Figure 68-69). The top map shows a synthesis of the whole year, whereas the bottom row shows designations on seasonal maps (A: spring, B: summer, C: autumn, D: winter). The areas are based on the results of the GIS-overlay analyses, information on important hunting areas from Figure 71 and expert knowledge.

Figure 71. Important hunting areas inside the assessment area for hunters in Ittoqqoormiit and the Tasiilaq area (small map), based on Flora et al. 2019. 1: Rosenvinge Bugt and Hartz Vig. 2: Kangerterajiva (Hurry Inlet), 3: Kangikajik (Kap Brewster), 4: Scorebysund-polynya, 5: Kangertivatsiaakajik (Lillefjord), Nuukajiit Akornganni Kangerterajik (Gabet) and Kolding Fjord, 6: Sulussuutikajik (Steward Ø), 7: Rømer Fjord and Immikkeertikajik (Turner Ø), 8: Kangertertivarmiit (Sydkap), 9: Ankervig/ Hjørnedal, 10: Nertiit Kangersivat (Gåsefjord) and Knækket, 11: Kangikajiip Kangerterajiva (Vikingebugt) and Terrasse Vig, 12: Central Jameson Land and southwestern Liverpool Land, 13: Kangerlussuaq to Nansen Fjord.

6 Environmental status and pressures in the assessment area

Igor Eulaers (AU)

6.1 Background levels of contaminants

6.1.1 Introduction

Knowledge on background levels of contaminants in areas with hydrocarbon exploration and exploitation is important to provide a baseline for future environmental monitoring and assessment of potential contamination impacts resulting from the activities.

This chapter presents an overview of national and international monitoring activities, legislation, and background levels of contaminants in the licence and greater assessment area, and adds temporal or geographic perspectives when possible. In addition to polycyclic aromatic hydrocarbons (PAHs), a number of other compounds are included as well. These comprise both recently legislated and unrestricted persistent and bioaccumulative contaminants that have been documented to reach the assessment area via long-range transport, or may leach unintentionally during the hydrocarbons activities, and are likely to have a health impact on the local fish and wildlife. The following compound classes are considered in this chapter: metals, brominated (BFRs) and chlorinated flame retardants (CFRs), per- and polyfluoroalkyl substances (PFAS), organotins (OTs), polychlorinated naphtalenes (PCNs), short-chained chlorinated paraffins (SCCPs), and PAHs. However, it is important to note that background levels of the legacy persistent organic pollutants (POPs) – including polychlorinated biphenyls (PCBs), chlordanes, dichlorodiphenyltrichloroethanes (DDT and breakdown products), hexachlorobenzene and hexachlorohexanes – are among the highest in the assessment area, compared to other Arctic regions, and are therefore routinely monitored (AMAP 2010a, 2011, 2014, 2016, 2018). A full account of their spatial and temporal trends as well as toxicity is well established and is referred to below. They are, however, not explicitly addressed in this report since these compounds are not likely to enter the environment as a result of hydrocarbons activities.

6.1.2 Monitoring activities

In 1991, the Arctic Council founded the Arctic Monitoring and Assessment Programme (AMAP) in order to identify and assess pollution risks and their impacts on Arctic humans and ecosystems. The Arctic is a region with little industrial or agricultural activities, though associated contaminants are found throughout. This is mainly as a result of long-range transport through ocean and/or atmospheric currents from southern source regions. POPs and mercury (Hg) are considered the major contaminants in the Arctic. AMAP continuously evaluates their spatial and time trends and biological effects in Assessment Reports (ARs; AMAP 1998, 2004, 2005, 2010b, 2011, 2014), recently resulting in dedicated ARs on their time trends (AMAP 2016) and biological effects (AMAP 2018). In Scoresby Sund, within the assessment area, a dedicated AMAP monitoring station has been established and the long-term time trends of Hg and POPs are routinely updated; its associated large sample bank is frequently used in further contaminant screenings. These monitoring activities have contributed to the surveillance of the United Nations Economic Commission for Europe (UNECE) as well as the establishment and expansion of the Minamata and Stockholm Conventions.

PAHs are of concern as well, and these compounds were recently addressed as compounds of 'emerging concern' (AMAP 2017a). AMAP hosts data on the occurrence of contaminants (including the assessment area) using Thematic Data Centers (https://www.amap.no/about/data-compilation).

In 1992, the Convention for the Protection of the Marine Environment of the Northeast Atlantic, also called the OSPAR Convention, was adopted as successor of the Oslo and Paris Conventions. The OSPAR Convention directed attention to hazardous substances as one of the focus areas since 1998. The current OSPAR Joint Assessment & Monitoring Programme (JAMP) holds it contracting parties responsible for assessing and monitoring hazardous substances. JAMP is executed by the Working Group on Monitoring and on Trends and Effects of Substances in the Marine Environment, and requires regular reporting on the impact of certain pressures from the offshore oil and gas industry on the marine environment. This has resulted in Quality Status Reports in 2000 and 2010, and the JAMP plans 2014-2021 (OSPAR 2014) strives to align with the EU Marine Strategy Framework Directive, as reflected in the Intermediate Assessment 2017 (OSPAR 2019b). OSPAR hosts data on the occurrence of contaminants (including the assessment area) using a Data & Information Management System (https://odims.ospar.org/).

6.1.3 Background levels, regulations and spatiotemporal trends

Metals

The United Nations Economic Commission for Europe (UNECE) adopted in June 1998 the Aarhus Protocol on Heavy Metals, more specifically the three particularly harmful metals cadmium, lead and mercury. The Protocol aimed to cut emissions from industrial sources (iron and steel industry, non-ferrous metal industry), combustion processes (power generation, road transport), waste incineration, and leaded petrol (UNECE 2019a). In relation to hydrocarbons activities, metal contaminants may enter the environment mainly via drilling muds and produced water (Chapter 8).

In the assessment area, mining activities at the lead-zinc mine in Mestersvig from 1856 to 1963 caused significant metal pollution due to the disposal of waste rock, tailings and concentrate into the environment. The DCE and the GINR monitor Greenland mine sites and curate a large sample and databank. The contaminant loads around Mestersvig have been monitored since 1979, and a decreasing trend in environmental contamination, mainly with lead and zinc, has been observed since 1991. Larger geographic trends in lead and zinc loads in biota are highly dependent on the species and local geochemistry (AMAP 1998, Søndergaard et al. 2020).

Mercury (Hg) has been used in a wide range of products, e.g. batteries, lamps, dental amalgam, pesticides and paint. The Minamata Convention, entered into force in August 2017, obliges its signatories to, e.g., phase out and phase down mercury use in a number of products and processes, and control emissions to air and releases to land and water. Mercury is of particular Arctic concern as a substantial amount arrives via long-range transport from lower latitude source regions, and has resulted in background concentrations to rise 450% above natural levels with an average yearly increase of 1 to 4%. Moreover, Arctic microbial food webs efficiently transform inorganic Hg to methylmercury, which is highly bioaccumulative and toxic. Consequently, Hg occurs at high levels in a wide range of Arctic biota, spanning the entire food chain, as well as in local human populations, owing to their traditional diet composed of high trophic level fish, seabirds and marine mammals (UN Environment 2019, UNECE 2019a).

Generally, Hg levels follow a west-to-east gradient: being the highest in the Canadian Arctic and West Greenland, followed by the assessment area and, finally, the Russian Arctic. While Hg has been studied in a wide range of species, often from a food web assessment perspective, data of relevance for the assessment area is mainly available from the Svalbard region and, in particular, from studies of marine mammals within the assessment area (AMAP 2011, UN Environment 2019). A dedicated study of Hg background concentrations in the assessment area was therefore initiated (see Box 6.1). Table 11 shows Hg concentrations in a wide range of species spanning all trophic levels within the pelagic and benthic food chains. These results support the body of evidence for the efficient biomagnification of Hg, from concentrations close to the analytical detection limit in zooplankton to considerable concentrations in the seabird species. The Hg concentrations are generally lower than observed in the Canadian Arctic and Svalbard region, but show higher biomagnification.

Flame retardants

Brominated and chlorinated organic compounds have been used as flame retardants (FRs) due to their efficiency in hampering flame propagation. Compounds of environmental concern are the so-called additive FRs, as these continuously leach into the environment during the lifetime of their applications. Of special environmental concern are additive FRs of high production volume, such as PBDEs and hexabromocyclododecane (HBCDD) that were used in polystyrene, electrical devices, furniture, rubber coatings and automotive lubricants. These FRs are now regulated under the UNECE Convention for Long-Range Transboundary Air Pollution (LRTAP; UNECE 2019b) as well as under the Stockholm Convention (SCPOP 2019). In the EU, the use of PBDEs is also regulated by the Directive on the restriction of the use of certain hazardous substances in electrical and electronic equipment (RoHS Directive; EU 2011). The commercial DecaBDE mixture and HBCDD are also considered Substances of Very High Concern (SVHC) by the European Chemicals Agency (ECHA; ECHA 2008a, b, 2012), and are on OSPAR's List of Chemicals for Priority Action (OSPAR 2019a). Nonetheless, the DecaBDE mixture is still manufactured and widely used in China, and a plethora of substitute compounds are of emerging environmental concern (AMAP 2017a). This chapter only considers Dechlorane Plus (DDC-CO) as it recently came under review for ratification under the Stockholm Convention (SCPOP 2019).

Air, seawater and sediment measurements show the PBDE congener BDE 209 to be detectable in air and seawater in the assessment area, though less frequently so than in the Svalbard area. Only few successful detections of BDE 209 in Arctic biota have been made: it accumulates in fish but general biomagnification is disputed as it does not reach higher trophic levels in the marine environment (AMAP 2017a, de Wit et al. 2010). Analyses of sediment or biota in the assessment area remains to be conducted.

PBDEs are characterized as polyphenolic structures, and therefore show quite some similarities in environmental partitioning and biomagnification as PCBs do. PBDEs are nowadays ubiquitous in the Arctic, in both abiota and biota. Temporal trend investigations in ringed seal and polar bear within the assessment area showed exposure to have increased up to the mid-2000s after which it levelled off. Spatial trends in seabirds and marine mammals are similar to those seen previously for PCBs, and show the assessment area to carry the highest environmental loads observed in the entire Arctic, resulting from long-range transport from Europe and North America. Latitudinal trends show lower concentrations at higher latitudes and show that populated areas act as environmental hotspots (de Wit et al. 2010, AMAP 2016, Dietz et al. 2013, Rigét et al. 2019).

Box 6.1.

Off-shore sediment and biota specimen sampling and banking in the assessment area

Igor Eulaers (AU)

As part of the *Strategic Environmental Study Program for Northeast Greenland* an interdisciplinary survey with the R/V Dana was conducted during August/September 2017 (Bouchard 2019, Hansen et al. 2019b, Møller et al. 2019). In parallel with the survey's primary aim to identify offshore hotspots of biological activity, several surface sediment samples (0-2 cm depth) and a wide range of zooplankton, invertebrate, fish and seabird species were collected at several sampling stations, inventoried and primarily banked, i.e. frozen at -20 °C, to allow for future efforts to reconstruct baseline ecological and ecotoxicological processes in the assessment area. However, in order to address some of the knowledge gaps in background levels of contaminants in the assessment area, a subset of the banked biota underwent chemical analysis for contaminants of suspected concern. A wide range of species composing copepods, euphasiids, pteropods (*Clione limacina*), amphipods, fish, and seabirds spanning all trophic levels within the pelagic and benthic food chains were analyzed for Hg (Table 11 in main text). All seabird species as well as the prevailing copepod and amphipod species spanning the lower and higher levels of the local food web were analyzed for PFAS (Table 12 in main text). Finally, the collected sediment samples were analyzed for a wide range of PAHs (Table 13 in main text) and compared to other open-shelf waters, e.g. the Southern Barents Sea, White Sea and Pechora Sea (Table 14 in main text).

Similar to other POPs, HBCDD is ubiquitous across the Arctic and HBCDD has been detected in air at the Villum Research Station (Northeast Greenland) next to the assessment area. Measurements on seawater, sediment and lower trophic species remain to be endeavoured; HBCDD exposure in fish is typically up to 10-fold higher than in marine mammals and, moreover, shows high biomagnification to Arctic seabirds. As is typically observed for POPs, exposure is elevated in the European Arctic and the highest concentrations occur in the assessment area (Scoresby Sund), and HBCDD is the compound with the highest increase rate (AMAP 2016, 2017a, de Wit et al. 2010, Dietz et al. 2013, Rigét et al. 2019).

Air DDC-CO concentrations are relatively elevated in the European Arctic compared to other Arctic regions, and the compound has been detected in Greenland Sea samples of air and seawater as well as in air at the Villum Research Station. Concentrations are lower in open water than at the coast, and increase with latitude, suggesting that melting glaciers and sea ice to be environmental sources. DDC-CO exposure in fish and marine mammals is low, resulting often in sporadic detection, although analyses of several seabird and marine mammal species in the North Atlantic and European Arctic show the assessment area to host the highest DDC-CO levels in the Arctic (AMAP 2017a).

Per- and polyfluoroalkyl substances

Per- and polyfluoroalkyl substances (PFAS) are a large suite of fluorinated aliphatic compounds, composing perfluorocarboxylates (PFCAs), perfluoroalkyl sulfonates (PFSAs), which include the most investigated PFAS perfluorooctane sulfonate (PFOS), and fluorotelomer alcohols (FTOHs). However, extractable organofluorine (EOF) measurements on Arctic seawater and biota show that the above targeted PFAS compounds represent only a small proportion of the total EOF (Miyake et al. 2007, Spaan et al. 2019). PFAS have been widely used in stain repellent polymers, food-contact paper, in fluoropolymer manufacture (e.g. Teflon™), as well as in aqueous film-forming foams, emulsifiers, foaming agents, and dispersants. In 2009, PFOS and its derivatives were included under the Stockholm Convention (SCPOP 2019). Currently, perfluorooctanoic acid (PFOA) is under evaluation as well while the United States Environmental Protection Agency (USEPA) PFOA Stewardship Program eliminated PFOA production in 2015 (USEPA 2020). Nonetheless, production of C_8-related PFAS continues in China, Russia and India.

Table 11. Hg concentrations (µg g^{-1}) in a wide range of species spanning all trophic levels in both the pelagic and benthic food chain in the assessment area.

	Common name	Scientific name	Sample	n	Dry weight			Wet weight		
					mean ± SD	median	min - max	mean ± SD	median	min - max
Invertebrates	Mollusk	*Clione limacine*	whole	1*	0.10	0.10	0.10 - 0.10	0.01	0.01	0.01 - 0.01
	Copepod	*Calanus glacialis*	whole	1*	0.18	0.18	0.18 - 0.18	0.02	0.02	0.02 - 0.02
	Copepod	*Calanus hyperboreus*	whole	19	0.03 ± 0.01	0.03	0.02 - 0.05	0.00 ± 0.00	0.00	0.00 - 0.01
	Krill	*Meganyctiphanes norvegica*	whole	1*	0.04	0.04	0.04 - 0.04	0.01	0.01	0.01 - 0.01
	Krill	*Thysanoessa inermis*	whole	1*	0.02	0.02	0.02 - 0.02	0.00	0.00	0.00 - 0.00
	Krill	*Thysanoessa longicaudata*	whole	1*	0.01	0.01	0.01 - 0.01	0.00	0.00	0.00 - 0.00
	Amphipod	*Themisto libellula*	whole	1*	0.01	0.01	0.01 - 0.01	0.00	0.00	0.00 - 0.00
	Amphipod	*Gammarus wilkitzkii*	whole	1*	0.04	0.04	0.04 - 0.04	0.01	0.01	0.01 - 0.01
	Amphipod	*Anonyx nugax*	whole	1*	0.27	0.27	0.27 - 0.27	0.08	0.08	0.08 - 0.08
	Amphipod	*Paraeuchaeta* spp.	whole	1*	0.06	0.06	0.06 - 0.06	0.01	0.01	0.01 - 0.01
Fish	American plaice	*Hippoglossoides platessoides*	muscle	10	0.28 ± 0.13	0.26	0.15 - 0.58	0.07 ± 0.03	0.07	0.04 - 0.12
	Arctic char	*Salvelinus alpinus*	muscle	10	0.27 ± 0.13	0.25	0.11 - 0.54	0.06 ± 0.03	0.06	0.02 - 0.12
	Arctic cod	*Arctogadus glacialis*	muscle	10	0.14 ± 0.05	0.13	0.08 - 0.24	0.03 ± 0.01	0.03	0.02 - 0.05
	Arctic skate	*Amblyraja hyperborea*	muscle	2	1.80 ± 0.30	1.80	1.59 - 2.01	0.27 ± 0.05	0.27	0.23 - 0.30
	Atlantic poacher	*Leptagonus decagonus*	muscle	6	0.70 ± 0.22	0.66	0.48 - 1.07	0.17 ± 0.04	0.16	0.13 - 0.24
	Atlantic wolffish	*Anarhichas lupus*	muscle	1	0.08	0.08	0.08 - 0.08	0.02	0.02	0.02 - 0.02
	Capelin	*Mallotus villosus*	muscle	5	0.03 ± 0.01	0.03	0.02 - 0.04	0.01 ± 0.00	0.01	0.00 - 0.01
	Deepwater redfish	*Sebastes mentella*	muscle	10	0.12 ± 0.04	0.11	0.07 - 0.18	0.03 ± 0.01	0.03	0.02 - 0.04
	Greenland halibut	*Reinhardtius hippoglossoides*	muscle	10	0.22 ± 0.06	0.20	0.15 - 0.33	0.07 ± 0.02	0.07	0.05 - 0.11
	Leatherfin lumpsucker	*Eumicrotremus derjugini*	muscle	4	0.37 ± 0.16	0.37	0.21 - 0.54	0.09 ± 0.04	0.09	0.05 - 0.13
	Polar cod	*Boreogadus saida*	muscle	10	0.12 ± 0.04	0.12	0.07 - 0.19	0.02 ± 0.01	0.02	0.02 - 0.04
	Spotted wolffish	*Anarhichas minor*	muscle	1	0.39	0.39	0.39 - 0.39	0.07	0.07	0.07 - 0.07
	Variegated snailfish	*Liparis gibbus*	muscle	2	0.47 ± 0.19	0.47	0.34 - 0.60	0.07 ± 0.03	0.07	0.05 - 0.09
Seabirds	Black-legged kittiwake	*Rissa tridactyla*	liver	10	1.07 ± 0.20	1.07	0.74 - 1.35	0.37 ± 0.10	0.36	0.24 - 0.60
			muscle	21	0.23 ± 0.07	0.23	0.02 - 0.36	0.08 ± 0.02	0.08	0.01 - 0.12
	Glaucous gull	*Larus hyperboreus*	liver	1	2.08	2.08	2.08 - 2.08	0.69	0.69	0.69 - 0.69
			muscle	1	0.43	0.43	0.43 - 0.43	0.12	0.12	0.12 - 0.12
	Little auk	*Alle alle*	liver	10	0.37 ± 0.15	0.32	0.20 - 0.66	0.12 ± 0.05	0.10	0.06 - 0.22
			muscle	40	0.12 ± 0.08	0.09	0.05 - 0.43	0.03 ± 0.02	0.03	0.01 - 0.12
	Northern fulmar	*Fulmarus glacialis*	liver	10	7.00 ± 8.09	3.87	0.68 - 28.00	2.29 ± 2.75	1.24	0.22 - 9.46
			muscle	31	0.52 ± 0.34	0.44	0.10 - 1.85	0.15 ± 0.09	0.13	0.03 - 0.50

While no data from air samples from the assessment area are available, seawater in the Greenland Sea seems to contain rather low PFAS levels, in agreement with general observations that open ocean water concentrations are much lower than coastal ones. Then again, sea ice contains up to 10-fold higher PFAS concentrations than surface seawater (AMAP 2016, 2017a, Muir et al. 2019).

Intensive investigations have been undertaken on Scoresby Sund apex species, including ringed seal and polar bear; temporal trend investigations on PFAS levels showed strongly increasing concentrations up to the mid-2000s, followed by a sharp decline. However, levels of the very bioaccumulative long-chained PFASs generally continue to increase; recently only a few of them have started to level off. The PFAS loads in these two well-studied species, as well as other apex wildlife such as killer whale, hooded seal and the threatened ivory gull, show that high trophic level species in the assessment area are carrying the Chinese market product 6:2-Cl-PFAES, and in general have elevated exposure to PFAS compounds (AMAP 2016, 2017a, Muir et al. 2019, Rigét et al. 2013, 2019).

PFAS compounds have been detected across all trophic positions in Arctic food webs although most, if not all, efforts focused on the Canadian and Norwegian Arctic. Therefore, a dedicated study of Hg background concentrations in the assessment area was conducted (Box 6.1). Table 12 presents PFAS concentrations in two zooplankton and four seabird species, spanning the lower and higher levels of the local food web. The results suggest that both the primary and the apex trophic positions in the food web carry higher concentrations than recorded in Canadian Arctic food webs, though with a similar degree of biomagnification. However, further studies of PFAS exposure and dynamics in the food web in the assessment areas remain to be undertaken.

Organotins

Organotins (OTs) are characterized by one or more covalent bonds between tin and carbon, present as an alkyl or aryl group, or an anion, such as chloride, oxide, hydroxide, or acetate. With the exception of a few biogenic methyl-tin species, OTs are anthropogenic compounds used as additives in the manufacturing of plastics and polyurethane foams and silicones. Triorganotins, especially tributyltin (TBT) and triphenyltin (TPT) derivatives, have been extensively used in preventing the fouling of boats and moorings by marine organisms. The International Maritime Organization (IMO) treaty has banned the use of TBT-based ship paints since 2003 with full implementation of the treaty in 2008 (Senda 2009). Moreover, OTs are included under the OSPAR Convention (OSPAR 2019a).

Greenlandic harbours have been documented to present an exposure risk, as blue mussels (*Mytilus edulis*) show similar concentrations at which dogwhelks (*Nucella lapillus*) in Icelandic and Norwegian harbours exhibit imposex (a type of sexual abnormality). Decreasing concentrations and effects away from harbours do indeed identify such hubs as point sources. No data on OT levels in abiotic or lower trophic species is available for the assessment area, nor are there any temporal trend perspectives. Nonetheless, in other areas 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).

Short-chained chlorinated paraffins

Short-chained chlorinated paraffins (SCCPs) are anthropogenic chlorinated hydrocarbons composed of carbon chains with a varying degree of chlorination. SCCPs have been made available on the market in no less than 200 commercial mixtures, and are used in a wide range of applications, ranging from additives in metalworking fluids, plasticizers, and flame retardants to additives in adhesives, paints, coatings, rubber, and sealants. Due to their persistent, bioaccumulative and toxicological properties, SCCPs are considered the 'new PCBs', and are therefore also recognized as POPs under the UNECE LRTAP and Stockholm Conventions (UNECE 2019b, SCPOP 2019). They are included on the list of harmful substances under the OSPAR and HELCOM Commissions (UNEP 2015d), are on the USEPA Toxic Release Inventory, and are considered Priority Toxic Substances under the Canadian Environmental Protection Act (Muir et al. 2000). Furthermore, the EU's Chemical Agency has classified SCCPs as Substances of Very High Concern (ECHA 2008c) and the European Water Framework Directive considers them Priority Hazardous Substances (EU 2013). Nonetheless, China has increased SCCP production.

Table 12. PFAS concentrations (ng g^{-1} wet weight) in two zooplankton and four seabird species, representing the lowest and highest trophic positions, respectively, within the assessment area.

	Common name	Scientific name	Sample	Compounds	n	mean ± SD	median	min - max
Invertebrates	Copepod	*Calanus hyperboreus*	whole	perfluorooctanesulfonic acid	1*	2.50	2.50	2.50 - 2.50
				perfluorononanoic acid	1*	0.05	0.05	0.05 - 0.05
				perfluorododecanoic acid	1*	0.01	0.01	0.01 - 0.01
				∑PFAS	1*	2.56	2.56	2.56 - 2.56
	Amphipod	*Themisto libellula*	whole	perfluorooctanesulfonic acid	1*	0.16	0.16	0.16 - 0.16
				perfluorononanoic acid	1*	0.05	0.05	0.05 - 0.05
				perfluorododecanoic acid	1*	0.02	0.02	0.02 - 0.02
				∑PFAS	1*	0.23	0.23	0.23 - 0.23
Seabirds	Black-legged kittiwake	*Rissa tridactyla*	liver	perfluorooctanesulfonic acid	3	11.65 ± 2.71	11.65	8.94 - 14.35
				perfluorononanoic acid	3	3.24 ± 0.91	3.22	2.33 - 4.15
				perfluorododecanoic acid	3	0.76 ± 0.07	0.73	0.72 - 0.84
				∑PFAS	3	15.65 ± 3.63	15.72	11.99 - 19.24
	Glaucous gull	*Larus hyperboreus*	liver	PFOS	1	21.34	21.34	21.34 - 21.34
				PFNA	1	4.10	4.10	4.10 - 4.10
				PFDoA	1	0.98	0.98	0.98 - 0.98
				∑PFAS	1	26.42	26.42	26.42 - 26.42
	Little auk	*Alle alle*	liver	perfluorooctanesulfonic acid	3	3.00 ± 1.25	2.71	1.92 - 4.37
				perfluorononanoic acid	3	0.68 ± 0.15	0.71	0.52 - 0.82
				perfluorododecanoic acid	3	0.31 ± 0.05	0.32	0.25 - 0.35
				∑PFAS	3	3.99 ± 1.44	3.74	2.69 - 5.54
	Northern fulmar	*Fulmarus glacialis*	liver	perfluorooctanesulfonic acid	3	6.37 ± 3.15	6.45	3.18 - 9.49
				perfluorononanoic acid	3	1.44 ± 1.27	1.21	0.30 - 2.80
				perfluorododecanoic acid	3	0.60 ± 0.32	0.50	0.35 - 0.95
				∑PFAS	3	8.41 ± 4.72	8.17	3.82 - 13.24

* pooled sample

Across the Arctic, atmospheric and biotic SCCP concentrations have been increasing steadily, and have even surpassed legacy POP levels up to 3-fold. While temporal trend perspectives for biota are not readily available, with the exception of Canadian white whale, SCCPs have been detected across the Arctic in a variety of fish, seabird and marine mammal species. Spatial analyses of sediment and fish show SCCP concentrations to decrease with increasing latitude, and with increasing distance to urban sources. SCCP levels in polar bear populations across the Arctic show the assessment area to host the highest concentrations. Aside from a handful of investigations within the assessment area, on black guillemot, glaucous gull, ringed seal and polar bear, SCCP levels in the abiotic environment and the food web remain to be explored (AMAP 2017a).

Polychlorinated naphtalenes

Polychlorinated naphtalenes (PCNs) are composed of a naphthalene ring chlorinated with one to eight chlorines. PCNs had industrial applications similar to those of PCBs, although produced in lower volumes, up to one tenth of the estimated global PCB emissions. PCNs are formed during combustion or coking processes, and diagnostic fractions or ratios can be used to elucidate sources. Since 2015, di- through octachlorinated naphthalenes are included under the Stockholm Convention as well as OSPAR's List of Chemicals for Priority Action (OSPAR 2019a, SCPOP 2019).

PCNs are present across the Arctic, though there is considerable spatial variation in air concentrations, up to a factor 100 in comparison to a factor up to 3 typically observed for POPs. There are no data available for abiota in the assessment area but analyses of marine mammals – ringed seal, hooded seal and polar bear – show exposure up to 10-fold lower than in the Canadian Arctic. However, no perspectives on temporal trends can be given (AMAP 2017a).

Polycyclic aromatic hydrocarbons

Polycyclic aromatic hydrocarbons (PAHs) are hydrophobic organic compounds comprising at least two fused aromatic rings. Among several hundred individual PAHs sixteen compounds were selected in the mid-1970s as priority pollutants by USEPA, based on their toxicity, ability to be analyzed, and environmental occurrence (Keith 2015). PAHs enter the environment as a result of naturally biogenic processes, forest fires and volcanic eruptions, as well as anthropogenic activities, such as coal and petroleum use and exploration. Attribution ratios aid in discriminating petrogenic from pyrogenic sources. Perylene, though, is a typical PAH of biogenic origin. In 1998 the UNECE LRTAP adopted the Aarhus Protocol which obliged it parties to reduce PAH emissions below levels observed in 1990, or an alternative year between 1985 and 1995 (UNECE 2019b). While PCNs are included under the Stockholm Convention (SCPOP 2019) PAHs as a wider group are not, although they are on OSPAR List of Chemicals for Priority Action (OSPAR 2019a).

Most abiotic measurements for PAHs have been performed on marine sediments, and most efforts have been made on the Barents Sea and Svalbard archipelago, which neighbour the assessment area (Balmer et al. 2019). Since no data on marine sediment PAH concentrations in the assessment area were available, a dedicated study of PAH background concentrations was conducted (Box 6.1). Table 13 shows that surface sediment PAH concentrations in the assessment area are of similar magnitude to those observed for other open-shelf waters, e.g. the Southern Barents Sea, White Sea and Pechora Sea. Total PAH concentrations in the assessment area a magnitude lower than those observed for the Northern Barents Sea and Svalbard Archipelago, and seem to reflect background contamination, especially when levels are compared

Table 13. PAH concentrations (ng g^{-1} wet weight) in surface layers of marine sediment (top layer, 0-2 cm) collected at different locations within the assessment area.

Compounds	n	DF	dry weight			wet weight		
			mean ± SD	median	min - max	mean ± SD	median	min - max
naphthalene	11	0.82	9.04 ± 4.95	8.20	2.87 - 17.24	6.65 ± 3.45	6.12	2.32 - 11.38
acenaphthylene	11	0.27	1.81 ± 1.98	0.68	0.65 - 4.10	1.28 ± 1.38	0.51	0.46 - 2.87
acenaphthene	11	1.00	1.74 ± 2.14	1.02	0.52 - 7.97	1.27 ± 1.49	0.74	0.41 - 5.58
fluorene	11	1.00	4.41 ± 2.92	3.39	1.61 - 9.38	3.23 ± 2.04	2.67	1.30 - 6.81
phenanthrene	11	1.00	25.48 ± 16.21	19.20	11.38 - 59.70	18.77 ± 11.57	14.6	8.76 - 44.78
anthracene	11	0.36	6.48 ± 4.34	5.28	2.99 - 12.38	4.60 ± 3.09	3.87	1.98 - 8.66
fluoranthene	11	1.00	13.66 ± 21.91	2.75	1.68 - 71.14	9.79 ± 15.4	2.15	1.34 - 49.80
pyrene	11	0.36	41.65 ± 36.77	35.44	4.44 - 91.28	29.78 ± 25.69	25.90	3.42 - 63.90
benzo[a]anthracene	11	0.91	17.93 ± 31.34	0.68	0.43 - 92.71	12.82 ± 22.19	0.48	0.33 - 64.89
chrysene	11	1.00	17.54 ± 26.54	2.53	1.24 - 77.23	12.56 ± 18.78	1.97	0.90 - 54.06
benzo[bjk]fluoranthene	11	1.00	23.85 ± 32.66	5.75	2.79 - 85.82	17.18 ± 23.14	4.49	2.01 - 60.08
benzo[a]pyrene	11	0.27	34.24 ± 19.84	26.58	19.37 - 56.77	24.29 ± 13.53	18.61	14.53 - 39.74
benzo[ghi]perylene	11	0.91	8.75 ± 13.09	1.00	0.50 - 32.88	6.33 ± 9.48	0.72	0.36 - 24.66
indeno[1,2,3-cd]pyrene	11	1.00	16.69 ± 26.51	2.13	1.11 - 71.85	12.03 ± 19.00	1.49	0.88 - 50.29
dibenzo[ah]anthracene	11	0.27	13.51 ± 4.68	13.44	8.86 - 18.22	9.76 ± 3.74	9.41	6.20 - 13.67
perylene	11	0.27	24.39 ± 19.46	20.29	7.31 - 45.57	18.13 ± 15.37	14.20	5.11 - 35.09
dibenzothiophene	11	0.45	3.14 ± 0.98	3.05	1.88 - 4.48	2.28 ± 0.58	2.14	1.47 - 2.96
2-methylphenanthrene	11	1.00	4.70 ± 4.68	2.17	0.96 - 12.60	3.41 ± 3.28	1.69	0.68 - 9.45
3.6-dimethyldimethyl-phenanthrene	11	1.00	1.45 ± 1.90	0.52	0.31 - 6.09	1.05 ± 1.35	0.40	0.22 - 4.26
benzo[a]fluorene	11	1.00	5.03 ± 8.11	0.99	0.59 - 27.61	3.59 ± 5.69	0.78	0.43 - 19.33
1-methylpyrene	11	0.27	32.16 ± 32.18	28.04	2.23 - 66.20	22.95 ± 22.49	21.03	1.47 - 46.34
benzo[e]pyrene	11	0.82	30.14 ± 47.97	4.35	0.65 - 140.69	21.51 ± 33.84	3.35	0.53 - 98.48
∑16PAHs			166.04 ± 221.54	46.41	29.67 - 681.64	119.81 ± 157.15	36.67	24.03 - 477.15
∑22PAHs			218.53 ± 301.68	57.60	33.46 - 957.67	157.53 ± 213.52	44.93	27.10 - 670.37
anthracene/(anthracene + phenanthrene)	11	1.00	0.05 ± 0.08	0.00	0.00 - 0.22			
phenanthrene/anthracene	11	0.36	6.81 ± 3.51	6.32	3.61 - 11.00			
fluoranthene/pyrene	11	0.36	0.82 ± 0.16	0.77	0.69 - 1.06			
fluoranthene/(fluoranthene + pyrene)	11	1.00	0.80 ± 0.28	1.00	0.41 - 1.00			
fluoranthene/fluorene	11	1.00	2.96 ± 4.46	0.78	0.48 - 14.81			
phenanthrene/fluorene	11	1.00	6.18 ± 1.47	5.79	4.40 - 8.99			
indeno[1,2,3-cd]pyrene/(indeno[1,2,3-cd]pyrene + benzo[ghi]perylene)	11	1.00	0.71 ± 0.11	0.68	0.60 - 1.00			

to those reported for Norwegian fjords affected by industry. Source attribution ratios seem to indicate pyrogenic sources, either from long-range transport reflecting lower latitude wood and coal burning or from local erosion of coal seams and sea bed leakage. These conclusions are in agreement with an effort to detect oil pre-exposure using PAH-associated bacterial community screening in the assessment area (Johnsen et al. 2019). This report also underscores that PAH sources on the shelf are more likely long-range than from local seeps since generally low concentrations of only a few light alkyl-PAHs, typically indicating petrogenic sources, were detected at the sampled shelf stations. This indicates very low or absent oil pre-exposure. Furthermore, low concentrations of perylene, typically of natural origin, confirmed observations of rather low biological activity.

Altogether, the Greenland Sea seems to have a unique PAH fingerprint, strengthening earlier observations that the different basins of the Arctic are compositionally different from one another. Finally, elevated concentrations were found in sediment on the shelf-break and close to Danmarkshavn. These were not joined by source attribution ratios indicating petrogenic sources, but do echo findings in the Barents and Norwegian Sea as well as the PAH associated microbial screening (Boitsov et al. 2009, Dahle et al. 2006, 2009, Jiao et al. 2009, Johnsen et al. 2019, Næs et al. 1995, Zaborska et al. 2011).

Only one study investigated surface seawater in the assessment area at several locations along transects between Northeast Greenland and the Svalbard archipelago (Lohmann et al. 2009). While no clear latitudinal or longitudinal trend can be described, the two highest observations of PAH concentrations were recorded at the two northernmost stations, contradicting other observations of declining seawater concentrations with increasing latitude (Balmer et al. 2019). Overall, concentrations were highest for phenanthrene, fluoranthene, and fluorene, while concentrations of acenapthene, anthracene, and pyrene were at least a degree of magnitude lower. For all PAHs source attribution ratios indicated a pyrogenic origin.

PAH concentrations have been monitored since 1994 at station Zeppelin, Svalbard, just east of the assessment area. The range of detected PAH concentrations is situated between those typically detected at station Alert, Canada and station Pallas, Finland. Nonetheless, all stations agree on PAH levels to decrease with increasing latitude, and to have generally declined between 1994 and 2001, when it reached a plateau (NILU 2014, Yu et al. 2019).

Bioaccumulation of PAHs has been observed across the Arctic for a wide variety of species including plankton, molluscs, crustaceans, echinoderms, annelids and fish. However, classical biomagnification does not apply, most likely because of the capacity of vertebrates to metabolize these compounds. While fish have been studied in many areas, only one investigation, off the Norwegian coast, has analysed PAH concentrations in eggs of seabird species, i.e. common eider, European shag and herring gull, while no data exists for marine mammals. Spatial investigations in the North Atlantic, using blue mussel and Icelandic scallop (*Chlamys islandica*), show that coastal waters and especially populated regions or harbours remain environmental point sources, presenting exposure similar to the one in the Baltic Sea. Moreover, in sharp contrast to generally declining concentrations of POPs in Arctic biota over the last decades, concentrations of PAHs have increased up to 30-fold in mussels and fish in the neighbouring Barents Sea. As our reported PAH concentrations for the assessment area are comparable to those, it is plausible to assume a similar increase in natural background levels has occurred in the Greenland Sea, though this would require a sample bank collection to be verified (AMAP 2010a, 2017a, Balmer et al. 2019).

6.1.4 Biological effects

Effect studies are mainly based on correlative relationships between body tissue contaminant concentrations and health biomarkers. A vast number of studies have shown exposure to POPs and Hg, the two dominant environmental pollutants in the Arctic, capable of disrupting concentrations of hormones and vitamins, depending on species and tissue. POPs and Hg are also well-established immune- and neurotoxic compounds, ultimately even modifying behaviour. Oxidative stress and allergenic reactions also increase with exposure, as does the prevalence of histopathological changes. Especially seabird and marine mammal populations in the North Atlantic, including the assessment area, and southern Greenland show moderate or high risk of POP and Hg-mediated exposure (AMAP 2010b, 2011, 2018, Letcher et al. 2010, Sonne 2010).

Most compounds addressed in this chapter, including PAHs, are still considered to be 'emerging contaminants' for which there is still a large knowledge gap with respect to biological or toxicological effects in Arctic biota. Nonetheless, disconcerting toxicological effects in non-Arctic species have been observed for those compounds, supporting their current listing, or consideration for inclusion, under the Stockholm Convention (SCPOP 2019). SCCPs and PFASs are classified as carcinogenic to humans; the latter also induce developmental toxicity as well as neurological toxicity. PCNs exhibit dioxin-like effects through aryl hydrocarbon receptor-mediated mechanisms. In terms of FRs, DDC-CO seems to interfere with proteins associated with stress response, metabolism, signalling pathways, and apoptosis. OTs, especially TBT and TPT, have been shown to impair immunological, reproductive and metabolic functioning, particularly in gastropods, and to disrupt the endocrine system in marine invertebrates. Finally, PAHs have been shown to pose cytotoxic, immunotoxic, mutagenic and carcinogenic risks in fish, and to cause abnormal proliferation of cardiac and neural structure and functioning (AMAP 2017a).

6.1.5 Concluding remarks

There are very few local sources of contaminants in the assessment area. However, the Arctic region receives a wide range of contaminants via long-range atmospheric or oceanic transport from industrial areas in more southern latitudes. Due to their long lifespan and association to lipids in the environment these contaminants may reach critical concentrations at high trophic levels in Arctic fish and wildlife (Dietz et al. 2019). Contamination of Hg and PAHs is not especially elevated within the assessment area but rather comparable to those in other Arctic regions. However, levels of these two compounds in the Arctic are currently estimated to exceed their natural background 45- and 30-fold, respectively (Balmer et al. 2019, UN Environment 2019). Compared to other Arctic regions, the assessment area has high concentrations of a wide range of contaminants, including POPs, FRs, PFAS and SCCPs (Table 14). While high exposure of POPs and FRs is likely to pose health effects to local biota, the current concentrations seem to either decrease slowly or remain stable over time. In contrast, PFAS and SCCPs may be of emerging concern, not only because of their high concentrations, but especially as some of these compounds continue to increase rapidly (e.g. long-chained PFAS) or are increasingly detected in local biota (e.g. SCCPs).

Table 14. Perspectives on the background levels of contaminants in the assessment area in comparison to other Arctic regions, their temporal trends and potential toxic impact on local species given the current levels.

Compound group	Spatial perspective[1]	Temporal perspective[2]	Toxicological perspective
POPs	high in assessment area	decreasing or stable	likely health effect
Hg	comparable to other regions	increasing	unlikely health effect
FRs	high in assessment area	decreasing or stable	likely health effect
PFAS	high in assessment area	stable or increasing	insufficient data
OTs	insufficient data	insufficient data	insufficient data
SCCPs	high in assessment area	increased detection	insufficient data
PCNs	comparable to other regions	insufficient data	insufficient data
PAHs	comparable to other regions	insufficient data	insufficient data

[1] Relative to levels of the same contaminant in other Arctic regions
[2] Based on temporal trend data for abiota or species within the assessment area

The background studies in this assessment have added considerably to the background information, especially on contaminants relevant for oil activities (e.g. Hg and PAH; see Box 6.1). However, knowledge gaps remain for background levels in the assessment area. For this reason, the specimen bank established (Box 6.1) is invaluable for providing a baseline of background contaminant levels against which the future impact of a rapidly changing climate as well as further oil exploration of the region can be assessed. Both climate change (McKinney et al. 2015) as well as increased tourism, shipping and oil exploration and exploitation may elevate levels of the above-mentioned contaminants, together with long-range atmospheric and hydrologic transport from southernly regions.

6.2 Human activities

David Boertmann (AU), Kasper L.Johansen (AU) & Janne Flora (AU)

6.2.1 Hunting

Hunting takes place only in the southern part of the assessment area by the people living in the settlement of Ittoqqortoormiit, and around Kangerlussuaq where people from Tasiilaq (south of the assessment area) go for hunting narwhals. In the National Park of East and North Greenland covering most of the land areas north of Scoresby Sund, hunting is not allowed. The hunt is the primary occupation in Ittoqqortoormiit, and can be termed as subsistence hunt. In 2017-2018 this hunt was studied as a part of the *Strategic Environmental Study Program for Northeast Greenland* (Flora et al. 2019). Some of the results of this study are summarised in this section.

In Ittoqqortoormiit there are 68 full time and part time hunters, out of a total population of approx. 360. Ten hunters participated in the study, and they reported 601 catch events over a year: The ringed seal dominated (353 catch events), followed by muskox (43), bearded seal (38), harp seal (34), Arctic char (29), common eider (21), black guillemot (18), walrus (10), polar bear (9) and narwhal (8) – and a total of 38 catch events distributed across 12 species. Based on number of individuals bagged, small animals like little auk and Arctic char were most prominent. If the composition of recorded catches is assessed by biomass of the different species, the ringed seal makes up about one third of the hunting bag followed by narwhal (25%), and muskox (15%). Next in order are walrus, bearded seal, harp seal, and polar bear with approx. 10, 10, 5 and 3% of the total weight of the recorded harvest, respectively. All other species contribute less than 1%.

The hunting activities and the land use of the hunters changed significantly through the different seasons (see Figure 71). In November 2017, hunting activities were concentrated in Rosenvinge Bugt and Kangerterajiva (Hurry Inlet) near Ittoqqortoormiit with ringed seal and muskox as the most important quarry. December 2017 was marked by ringed seal hunting in Rosenvinge Bugt, but a few longer hunting trips targeting muskox in Jameson Land and southwestern Liverpool Land were still undertaken. In January - February 2018 the land use of the hunters was at its lowest and almost completely confined to Rosenvinge Bugt. At this time, the ringed seal was the dominant quarry, but in February the year's first catches of polar bear and walrus were recorded, particularly in proximity to Uunarteq (Kap Tobin). In March 2018, polar bear and ringed seal hunting continued in and around Rosenvinge Bugt, but the overall hunting area expanded as a consequence of long hunting trips into Jameson Land for muskoxen, and trips to Immikkeertikajik (Rathbone Ø) targeting polar bear. April, May and June 2018 were characterized by ice edge hunting along the polynya in the outer parts of Kangertittivaq (Scoresby Sund). The fast ice edges in Rosenvinge Bugt, at the mouth of Kangerterajiva (Hurry Inlet), and along Flakkerhuk were used most intensively. The hunters bagged a broad spectrum of different species, including seals, polar bears, walruses, narwhals, seabirds (e.g. thick-billed murre, common eider, little auk, and king eider), geese (barnacle goose and pink-footed goose), and Arctic char. During April, one of the participating hunters moved into the Scoresby Sund fjord complex (to Kangertertivarmiit (Sydkap)) and hunted a variety of species in this area until mid-summer. In June, the outer coast south of Scoresby Sund was visited to catch narwhals. Later in July, when the entire Scoresby Sund fjord became accessible, narwhal hunting and Arctic char fishery took place there. As the quota on most large game species were spent and the seals sink when they are shot during late summer, only a few catch events – involving muskox and Arctic char – were recorded in August. In the course of September, the hunting area was reduced to the inner parts of Kangerterajiva (Hurry Inlet), where the hunters bagged large numbers of ringed seals as well as other seal species and muskoxen. This pattern continued in October 2018, however with addition of hunting of ringed seals, bearded seals and black guillemots in Rosenvinge Bugt and Hartz Vig. The hunting in November-December 2018 was strikingly similar to the pattern described for these months in 2017.

The hunters from Tasiilaq navigated to Kangerlussuaq and Nansen Fjord in July and August to catch narwhals (Figure 71: area 13).

Figure 72 shows the temporal variation in the species composition of the bagged quarry.

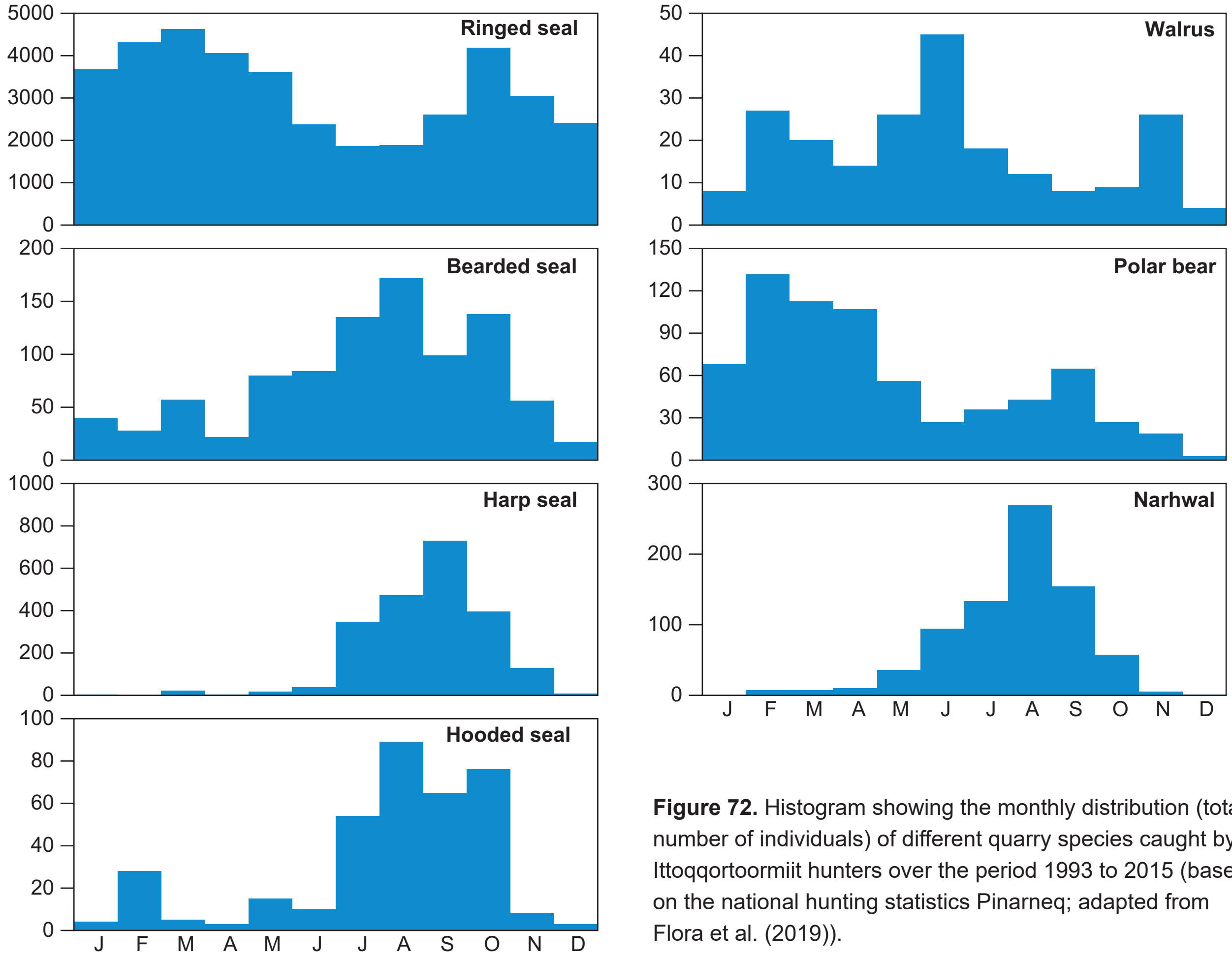


Figure 72. Histogram showing the monthly distribution (total number of individuals) of different quarry species caught by Ittoqqortoormiit hunters over the period 1993 to 2015 (based on the national hunting statistics Pinarneq; adapted from Flora et al. (2019)).

6.2.2 Fishing

No commercial fishery takes place out of Ittoqqortoormiit, and fishery activity for domestic use is rather limited. The most important species in this subsistence fishery is Arctic char which is mainly caught along the coast of Hurry Inlet, at Sydkap inside the Scoresby Sund fjord, and in some of the fjords of the Blosseville Kyst (Figure 35). Other species caught include spotted wolffish, Greenland shark (used for dog food), Greenland halibut, sculpin and polar cod (Sandell & Sandell 1991, Petersen 1993).

The only species fished on commercial basis inside the assessment area is Greenland halibut, and the landed catch is very small (annual catch 2014-2018 approx. 530 tonnes) compared to the total for Greenland as a whole (approx. 30,000 tonnes). The fishery takes place in the southernmost part of the assessment area (Figure 73).

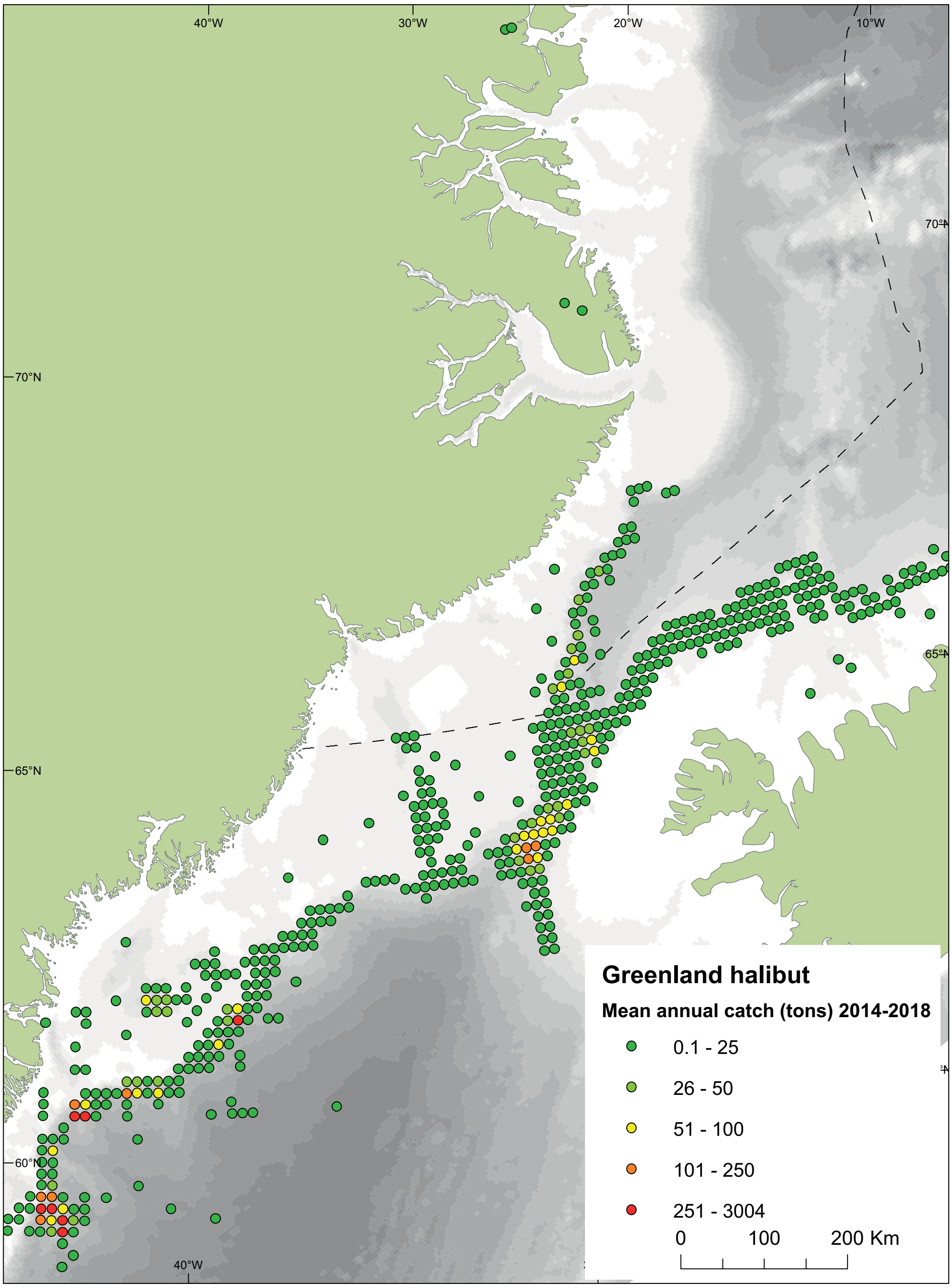


Figure 73. Distribution and amount of Greenland halibut catches within and close to the assessment area in the period 2014 to 2018 (data from GINR). Only a small fraction of the fishery takes place inside the assessment area (see text).

6.2.3 Tourism

The tourist industry is one of three major sectors within the Greenland economy and it is, and will be, facilitated by climate change, particularly with the reduction in sea ice cover (Dawson et al. 2017, Christensen et al. 2017). It was increasing significantly in importance in Greenland until 2010, but decreased again until 2015 when a new increase was apparent (Statistics of Greenland 2019). The same tendency is apparent also in the Greenland Sea assessment area (Table 15). The National Strategy of Tourism 2008-2010 planned a 10% increase per year in the number of cruise ship tourists alone (Department of Industry 2007), but this was not achieved (Grønlands Selvstyre without year).

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

Two kinds of tourists visit the assessment area: tourists spending the night on land (hotels, camping, and other kinds of accommodation) and tourists based on cruise ships. Tourists spending the night on land include those on scientific expeditions or those engaging in outdoor recreational activities, e.g. mountaineering and kayaking. The land-based tourists all arrive through the airport at Nerlerit Inaat/Constable Pynt, and usually operate from there or from Ittoqortormiit/Scoresbysund town, explaining why this type of tourism is concentrated in the southern part of the assessment area – mainly the Scoresby Sund Fjord and the southern part of the National Park.

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

Both types of tourists have increased in numbers in the area in recent years (Table 15).

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

Much of the tourist activities within the assessment area take place in the coastal zone, which potentially could be exposed to oil spills. As the most important asset for the tourism sector in the area is the unspoilt nature, an extensive oil spill would have the potential to seriously impact the local tourist activity and industry.

Table 15. Some statistics on tourism in East Greenland; Tasiilaq is south of the assessment area (source Greenland Statistics).

Category	2015	2016	2017	2018
Overnight stays at hotels Tas. and Itt.	11.546	11.864	17.775	21.239
Cruise ship passengers, Itt.	1273	1916	1649	1754
Cruise ship passengers, Tas.	1963	3971	5302	4074
International passengers, airport Nerlerit Inaat	434	357	851	869
International passengers, airport Tasiilaq	6196	5764	5219	5114

Expeditions

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

Cruise ships

Cruise ships spend the majority of time in the coastal zone where sightings of marine mammals and birds are major highlights alongside the scenic views, historical sites and visits to the settlements. Table 15 shows the number of cruise ships passengers visiting Ittoqqortoormiit and Tasiilaq (south of the assessment area).

Cruise ship activity will most likely intensify in the assessment area, in terms of both number of ships and passengers, but also in terms of visiting more remotely situated sites.

Destination Ittoqqortoormiit/Scoresbysund

As the only town in the area, most tourists pass through Ittoqqortoormiit and its airport Nerlerit Inaat /Constable Pynt. There is a locally based tour operator, Nanu Travel; in addition a couple of operators based in Iceland also organise activities. Activities for tourists include:

- Dog sled trips take place mainly in Liverpool Land in April/May when it is still cold, but the sun has returned from the dark winter period. The local operator, Nanu Travel, arranges about 600 sled passenger-days, normally one day per tourist.
- Kayaking takes place in the open-water season (July-September), and each year a number of tourists go kayaking in Scoresby Sund and the fjords of the southern part of the National Park.
- Boat trips are arranged mainly as transport to landing sites for hiking or kayaking in the summertime.
- Hiking takes place in summer in the Scoresby Sund fjord complex or in the southern part of the National Park.
- Trophy hunting (muskox) takes place Scoresby Sund fjord complex.

The National Park

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

Tourism impacts

The environmental impacts of tourism occur on many levels, from hiking persons to cruise ships and aircrafts. Disturbance of wildlife, erosion of vegetation is well known from sites with intensive tourist activity, while cruise ships and aircrafts have the potential to disturb wildlife in both the water and on land to much greater extent. Cruise ships add to the discharge loads to the sea and atmosphere and by the risk of accidental oil spills (see below).

6.2.4 Shipping

Shipping in the Arctic is expected to increase considerably, due to the reductions in the sea ice, both in space and time (Christensen et al. 2017), including cruise ships (see above). Smith & Stephenson (2013) projected the optimal shipping routes across the pole in September (period with lowest ice cover), and the optimal routes from North America to the Pacific for ships with medium ice strengthening of the hull (Polar Class 6) currently pass through the assessment area, while routes for ships with no ice strengthening only pass through the southern and eastern part. However, this will probably change considerable when the Northwest Passage opens since the most optimal routes for both ship types will pass that way. As almost no ships pass across the pole today, the future trans-pole shipping through the assessment area will most likely be very limited.

Environmental impacts from shipping include noise in the underwater environment, disturbances of marine mammals and seabirds, introduction of invasive species from ballast water and hull, discharges of waste and wastewater, emissions to the atmosphere from combustion of fuel (especially heavy fuel) and the risk of accidental oil spills. A large oil spill is regarded as the most serious threat from shipping to the Arctic marine environment (Christensen et al. 2017). All these impacts from shipping, including from cruise ships, should be included when analysing the cumulative impacts of oil exploration and exploitation activities in the assessment area.

6.2.5 Mining

Exploration of minerals will also be facilitated by the reduced sea ice cover because access and the transport of ore and other products will be much easier. There are currently no active mines in the land adjacent to the assessment area. However, an exploitation licence has been granted to a company planning to exploit zinc from a site in Citronen Fjord north of the assessment area, and there are exploration activities going on here and there. The marine environment will primarily be impacted by the shipping when ore is to be transported to smelters in Europe or North America. For environmental impacts of shipping, see above.

6.3 Plastic in the assessment area

Jannie Fries Linnebjerg (AU)

Plastic litter in the marine environment is of increasing concern due to its effect on marine life and possibly human health, and has therefore been recognised as one of the largest global environmental problems currently faced (UNEP 2011, 2014). Marine plastic pollution is commonly observed across all oceans and has been documented in all compartments of the ocean from coastal shallow waters to the deep seafloor, as well as in sea ice (Barnes et al. 2009, Schlining et al. 2013, Obbard et al. 2014, Woodall et al. 2014, van Sebille 2015, Halsband & Herzke 2019). It is assessed that on a global scale, that most of the plastic litter in the marine environment comes from land-based sources in regions with inadequate waste management systems (Jambeck et al. 2015). Once in the sea, the plastic is redistributed by the wind and sea currents. The impact of plastic pollution is multiple and complex and can affect biota, habitats and ecosystems. Marine plastic litter affects marine species in many different ways depending on the size and type of plastic. The shape, size and type of marine species also determines the potential effects (Werner et al. 2016). The main impacts are through ingestion and entanglement. Mortality by entanglement is the most visible, with species being caught in fishing gear, rope and plastic bags (Laist 1986, 1997, Provencher et al. 2017). If not causing acute death, it is to be expected that entanglement by, and ingestion of, plastic litter will affect the performance of individuals by hampering their ability to capture and digest food, reproduce, as well as reducing their body condition leading to constrained locomotion, including migration and escape from predators (CBD 2012). Due to their small size (<5 mm), microplastics can be ingested by a much broader range of marine organisms than macroplastics, ranging in size from zooplankton and bivalves to fish, seabird and marine mammals. Ingestion of microplastics can result in physical damage such as obstruction or internal abrasions (Wright et al. 2013). Larger fish, seabirds and marine mammals can in some case also ingest larger plastic particles, i.e. mesoplastic (5-25 mm) and marcoplastic (>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 2017). To date, over 690 marine species have been reported to have been affected by marine litter including cetaceans, pinnipeds, 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. Fisheries-related activities have been identified as a major source of the plastic litter (PAME 2019). Recent studies have reported concentrations of macroplastics on beaches (PAME 2019), of floating plastics in the Greenland Sea, Fram Strait and Barents Sea (Bergmann 2016, Cózar et al. 2017), and in seabirds, especially Fulmars (see review by PAME 2019). Microplastics have been found in 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 found in blue mussels (Sundet et al. 2016), snow crabs (Sundet et al. 2014), in fish (Morgana et al. 2018) and in seabirds (Amélineau et al. 2016).

There are very few local sources of plastic and other sources of litter within the assessment area. Actually, the only major source is the dump of the settlement Ittoqqortoormiit, where garbage is deposited without any treatment other than some of it is burned. Macroplastic from this dump, mixed with plastic from outside Greenland, can be retrieved along the coasts of the fjord systems and the outer coasts Generally there are only very few litter items registered at more remotely located coastlines in East Greenland indicating that not much litter is transported to this area with the south-going current from the Arctic Sea. However, elevated amounts of litter dominated by litter from fishery and other sea-based sources have been registered at, e.g., Henry Land in the assessment area, indicating that deposition also sometimes can occur from the Northern Atlantic – at least at this specific location (Strand et al. 2018).

In the assessment area microplastics have been found in sub-surface waters, in two species of mid-trophic level fish: bigeye sculpin and polar cod as well as in the zooplanktivorous seabird the little auk (Amélineau et al. 2016, Morgana et al. 2018).

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.

6.4 Climate change in Northeast Greenland

Anders Mosbech (AU) & Eva Friis Møller (AU)

The Arctic climate 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 render precise predictions 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 in the Arctic have been made by IPCC (Meredith et al. 2019), NOAA report cards (Link), AMAP (2017b, 2019) and CAFF (2017). The AMAP Arctic Climate Change Update 2019 supports the fundamental conclusions of the larger scientific reports and it has been used extensively as reference for the following introduction (AMAP 2019).

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 since 1900.

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 more significant declines (Figure 75). Sea ice thickness in the central Arctic Ocean has declined by 65% over the period 1975–2012. 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. Older ice that has survived multiple summers (multi-year ice) is rapidly disappearing; most sea ice in the Arctic is now 'first year' ice

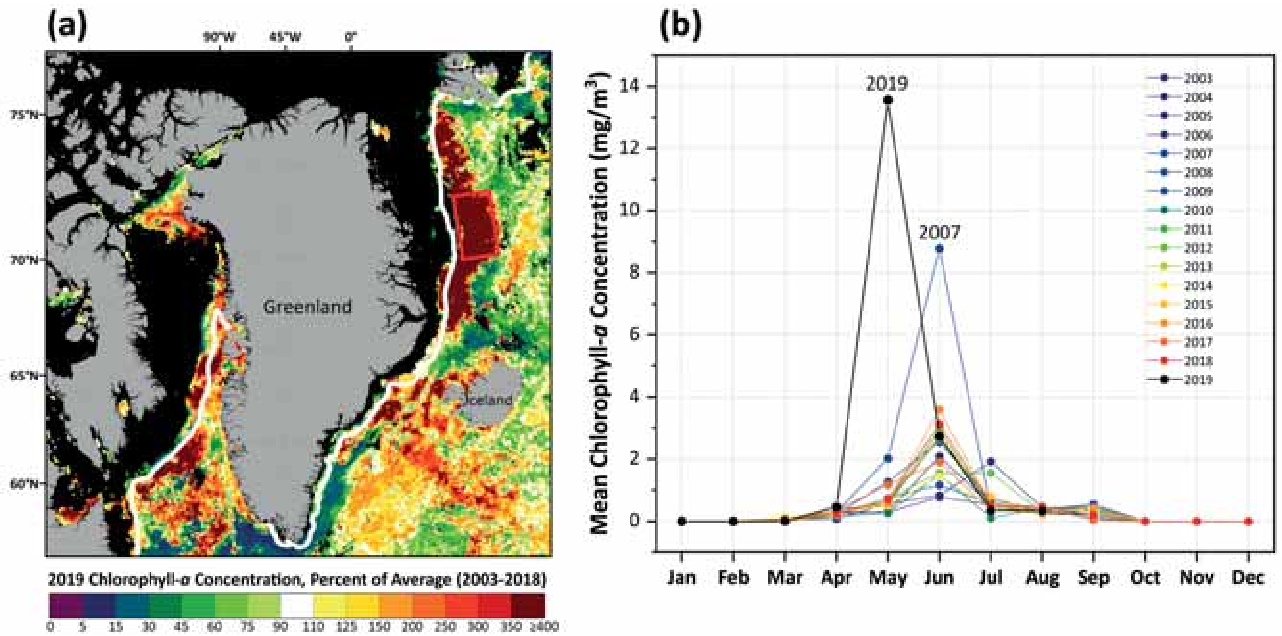


Figure 74. Left figure: Mean chlorophyll-a anomalies surrounding Greenland in May 2019, shown as percent of the 2013-18 average. The white line denotes the mean sea ice extent (i.e., sea ice concentration at 15%) for May 2019. The red box denotes the area along the sea ice edge in the Greenland Sea for which data are shown in the right figure; this area is just east of the assessment area. Right figure: Mean chlorophyll-a concentrations for the region in the Greenland Sea high-lighted in the figure to the left from 2003-2018, where May 2019 showed an average ~18 times higher concentrations than previously recorded. Phytoplankton blooms are distinctly seasonal in high-latitude seas, with peak production occurring once light levels and stratification are sufficient (with melting snow and break-up of sea ice) and then dissipate once nutrients in the water column are depleted (from Frey et al. 2019).

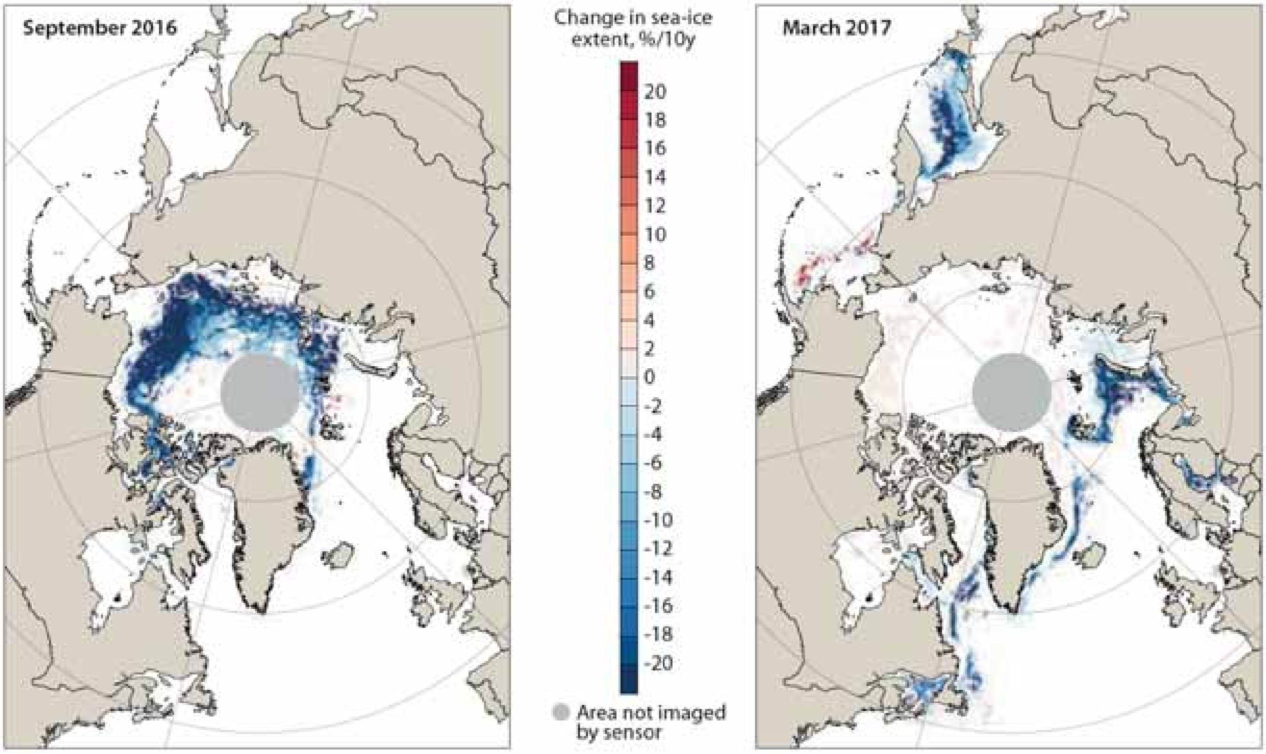


Figure 75. Linear trends in sea-ice extent (relative to the 1981-2010 average) for September 2016 and March 2017. Data source: NASA Team algorithm and the NSIDC Sea Ice Index (Fetterer et al., 2016).

that grows in the autumn and winter but melts during the spring and summer (Figure 76).

Arctic winter sea ice maximums in 2015, 2016, 2017 and 2018 were at record low levels, and the 12 lowest minimum extents in the satellite record have all occurred in the last 12 years (Figure 10). The volume of Arctic sea ice present in the month of September has declined by 75% since 1979 (Figure 77). Sea ice has gone through a transition from mostly thick multi-year sea ice to younger and thinner seasonal sea ice (Figure 76). The reductions in sea ice are caused by a combination of atmospheric warming and the influx of warmer waters from the south. The coverage, extent, and thickness of multi-year sea ice reflect climate conditions over years to decades, making its loss an indicator of Arctic and global climate change. The later freeze-up of sea ice contributes to the rise in cold-season Arctic air 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. Sea ice loss also has direct impacts on species such as polar cod, 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.

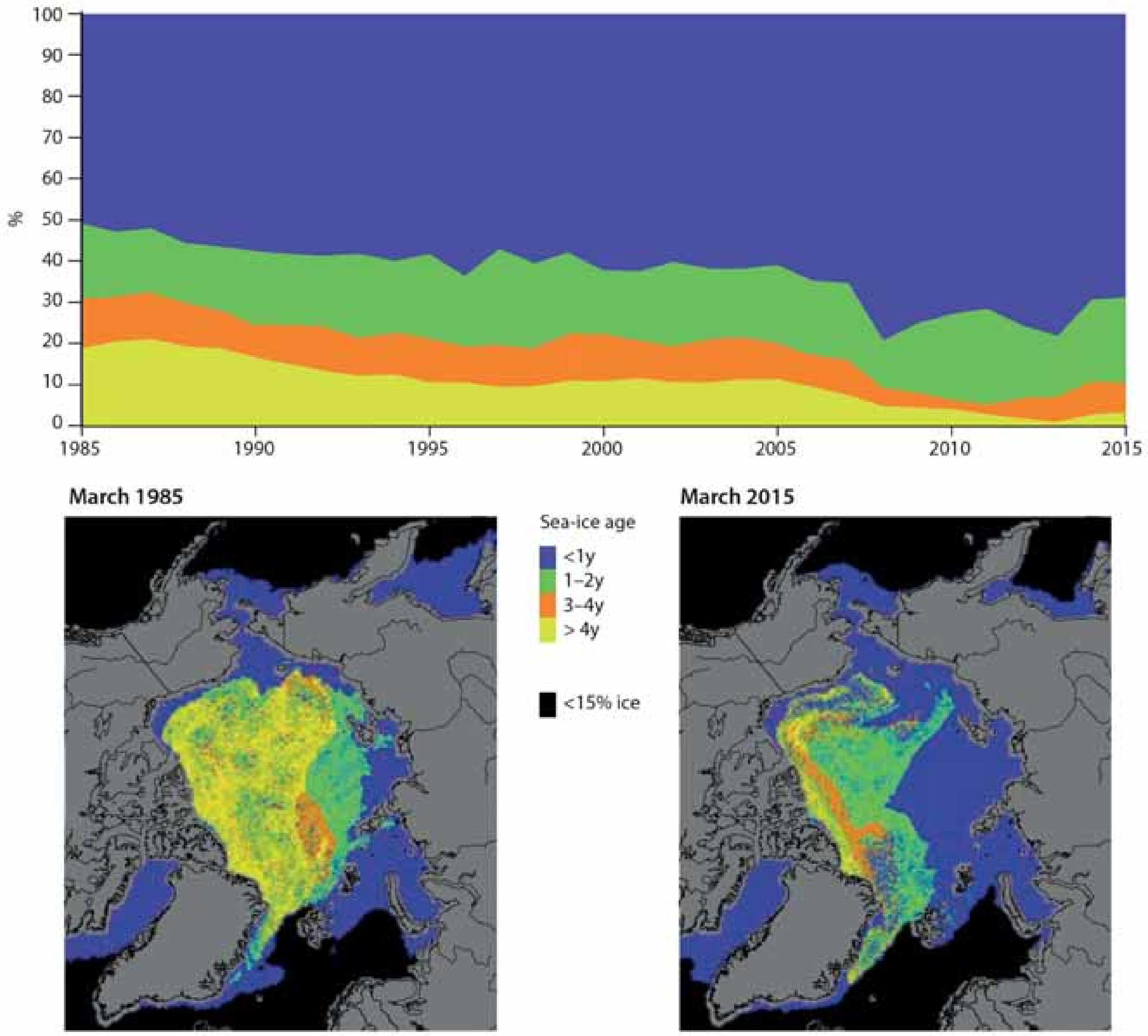
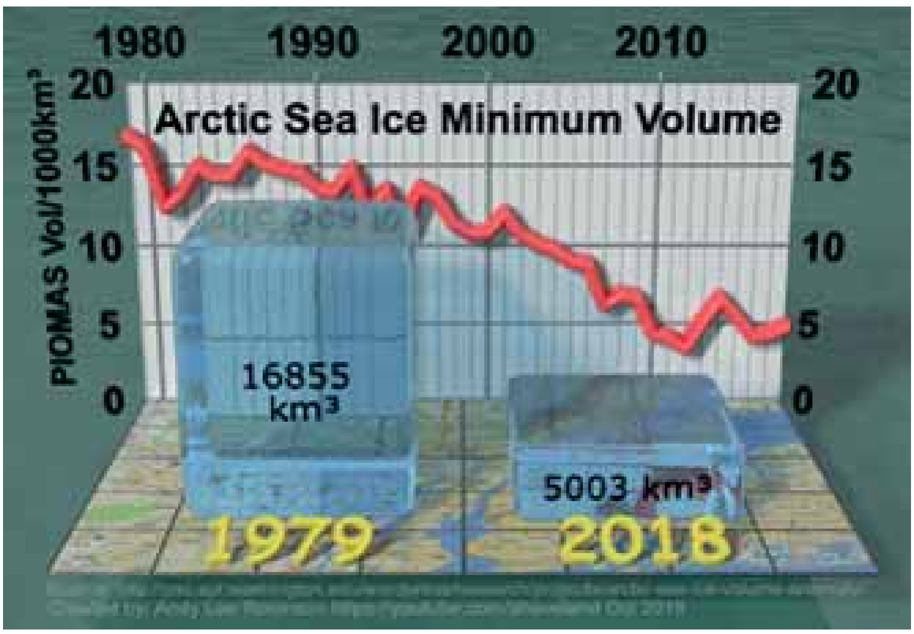


Figure 76. A time series of sea-ice age in March from 1985 to the present and maps of sea ice age in March 1985 and March 2015 (Perovich et al., 2015, here from Barber et al. in AMAP 2017).

Figure 77. 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.



6.4.1 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 significant changes during this century even if greenhouse gas emissions are stabilized globally at a level lower than today's. If emissions continue to increase, future changes in the Arctic would be even more substantial and long-lasting. Climate models, using scenarios that depict plausible changes in future greenhouse gas emissions and concentrations over time, offer the following updated projections for the Arctic in AMAP (2017b and 2019):

Temperature

Autumn and winter temperatures will increase by a regional average of 4 °C over the next 30 years—twice the warming projected for the Northern Hemisphere as a whole—with new record temperatures observed in some regions and years (Figure 78). The strongest warming is projected to occur during the cold season. Even several years of cold weather due to natural variations are unlikely to affect the long-term trend, and efforts to reduce greenhouse gas emissions will not affect projected temperatures until the latter half of this century. The warming climate will change the seasonal distribution and increase the amount of freshwater in the Arctic, with important implications for people, industries, ecosystems, and infrastructure.

Sea ice

The Arctic is expected to be largely free of sea ice in late summer within the next few decades, possibly as early as the 2030s, although natural variability and other factors make it impossible to make precise predictions. Some models suggest that if global warming is stabilized at 1.5 °C, the probability of an ice-free summer occurring in any given year would be roughly 2 percent; at 2 °C, the probability would rise to 19–34 percent. The ice that appears in winter will be thinner, more salty, less rigid, and more mobile than today's sea ice. More open water is expected in winter, affecting temperature and the exchange of moisture and heat between the atmosphere and ocean, leading to more extreme weather locally and at lower latitudes. Sea ice is currently thinning and shrinking more rapidly than projected by most models. However, the assessment area is the main gateway for export of sea ice from the Polar Basin with the East Greenland Current, and this export is projected to continue although it will decline.

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). Acidification is projected to be high in East Greenland. Water with partial CO_2 pressure (pCO_2) substantially higher than the atmospheric values is currently 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 (Nilsson et al. 2018).

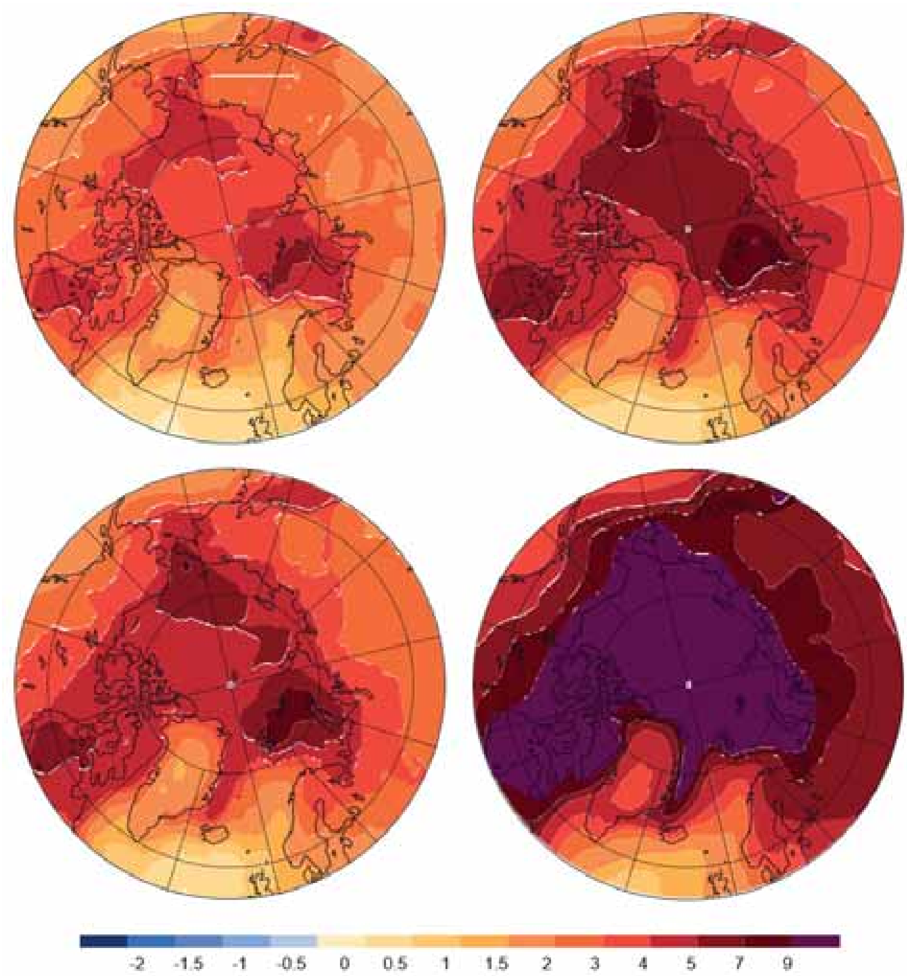


Figure 78. Projected changes in near-surface temperature (50th percentile), relative to 1986–2005, for December–February under the IPCC 'intermediate' RCP4.5 scenario (left panels) and the 'worst case' RCP8.5 scenario (right panels). Upper panels are for the decade of the 2050s, lower panels are for the 2080s (graphic courtesy of G. Flato, Environment and Climate Change Canada).

Populations and ecosystems

The rate and magnitude of changes projected for the Arctic will push some species out of their ranges, while other species may colonize new areas and the food web will change. See Table 16 for a summary of responses of Arctic marine organisms to climate change (and see CAFF 2017).

Phytoplankton production may become less predictable and may increase due to the warmer waters and reductions in sea ice. As an example of the variability, a very high primary production was recorded in the assessment area in 2019 (Figure 74). See Box 6.2 for a discussion of Climate Change effects on phyto- and zooplankton in the assessment area.

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 more nutritious Arctic relatives *C. glacialis* and *C. hyperboreus* (Møller & Nielsen 2019). While this could be a threat to a high Arctic specialist like the little auk depending on catching the large nutritious copepods one by one (Frandsen et al. 2014), the overall ecosystem may be more resilient (Renaud et al. 2018).

Some Arctic species are shifting their ranges northwards to seek more favourable conditions as the Arctic warms. These movements pose unknown consequences for these species and their interactions, such as predation and competition. The northward movement is easier for mobile open water species such as polar cod, while species linked to shelf regions, such as benthic invertebrates and some fish, may encounter problems finding suitable habitat if

Table 16. Summary of responses of Arctic marine organisms to climate change (Wassmann et al. 2011).

Responses	Nature of changes
Range shift	Northward displacement of sub-Arctic and temperate species, cross-Arctic transport of organisms from the Pacific to the Atlantic sectors
Abundance	Increased abundance and reproductive output of sub-Arctic 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 sub-Arctic 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

Box 6.2

Climate change effects on phyto- and zooplankton

Eva Friis Møller (AU)

As described in Chapter 5.2 the expected effects of climate change in the Arctic include reduced sea ice extent, longer growing season, and to some degree an increase in sea water temperature. Remote sensing has shown that reduced sea ice extent and longer growing season have led to an earlier phytoplankton spring bloom in some areas of the Arctic Ocean (Kahru et al. 2011), and that the annual net primary production (NPP) in the Arctic Ocean has increased 30% between 1998 and 2012 (Arrigo & van Dijken 2015). The prolonged open water season has also, in some regions, led to development of a second bloom in the fall, which coincides with delayed freeze-up and increased exposure of the sea surface to wind stress (Ardyna et al. 2014). However, the phytoplankton productivity not only depends on the light availability, but also on the degree of stratification and the supply of nutrients, and locally the patterns may not follow the general patterns just described. For example two sectors of the Arctic Ocean at each side of Greenland dominated by outflow shelves exhibited either no significant change in annual NPP over time from 1998 to 2012 (Baffin Bay) or saw a significant decline (Greenland Sea) (Arrigo & van Dijken 2015). Proximity to land may also lead to decreases in phytoplankton biomass or production because increased run off leads to increased turbidity (Pozdnyakov et al. 2007). The run off may increase production further away from the glacier by a combination of increased upwelling of nutrients driven by glacier terminations at sea, and establishment of a stratified water column (Lydersen et al. 2014, Juul-Pedersen et al. 2015, Meire et al. 2017). In contrast, the run off from glaciers terminating at land will not create similar upwelling (Meire et al. 2017). Consequently, pronounced changes in primary production and higher trophic levels can be expected if sea terminating glaciers become land-based (Lydersen et al. 2014).

Increased stratification, and therefore reduced delivery of nutrients to the surface layers, have been suggested to lead to an increase in the smallest algae and bacteria along with a concomitant decrease in somewhat larger algae (Li et al. 2009). Hence, in a changing climate zooplankton may be influenced by both changes in the availability and size of their prey. At the same time zooplankton will also be affected by their predators. A study of zooplankton from the Barents Sea from a time series study from 1959-93 suggested zooplankton dynamics to be under shifting top-down and climatic control, the relative importance of the two processes varying spatially, seasonally, and inter-annually (Stige et al. 2009). The data series existing for zooplankton all show high inter-annual variation (Arendt et al. 2013, Dalpadado et al. 2012, Ershova et al. 2015, Aarflot et al. 2018, Møller & Nielsen 2019).

This and the limited data available or short time series may be the reason that no changes in the total abundance/biomass of zooplankton have been observed in connection to the changes in phytoplankton. At species level, increase or decrease in abundance/biomass has been found, or shifts in geographical distribution in response to temperature changes. This probably often reflects the presence of different water masses carrying along different species rather than a response by the organisms themselves (Dalpadado et al. 2012, Kraft et al. 2013, Bauerfeind et al. 2014). In Disko Bugt, western Greenland the dominating zooplankton genera *Calanus*, is now dominated by the North Atlantic species *Calanus finmarchicus* over the two Arctic species *C. glacialis* and *C. hyperboreus*. This change happened along with a decrease in the sea ice cover and increased Atlantic water influence (Møller & Nielsen 2019). On the other hand, in Young Sund, Northeast Greenland both the copepod abundance and the community composition at the genus level seem to have been relatively constant during the last decade, despite the open-water period varying between 72 and 140 days in the same period and an increase in the freshwater content (Sejr et al. 2017, Middelbo et al. 2018).

they move northward. The Greenland halibut is an example of a species that have the potential to expand into the Arctic Basin with climate change, but only given the availability of suitable prey. Changes in climate may be too fast to allow for the long-lived sessile organism like cold-water corals to establish communities in suitable habitats further north (see Box 6.3 for a discussion of climate change effects on benthos on the Northeast Greenland shelf).

Food resources could be lost for many species in the Arctic marine environments. Many species therefore have to move further around and expend more energy to feed, leading to concerns about individual health and potential effects at the population level. An example is the ivory gull where population declines coincide with reduction in their sea ice feeding areas (Strøm et al. 2019). As the ice cover is reduced and moves away from the coastlines, polar bears may become landlocked and predate on alternative food resources and, for example, impact colonial seabird populations (Prop et al. 2015).

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. See the Chapter 3.8.1 on future scenarios for polar bears, and Box 6.4 for a discussion of seals and polar bears in Northeast Greenland in relation to climate.

Invasive, alien species have not been recorded in the assessment area. However, rising water temperatures will facilitate the establishment of such species for example introduced by release of ballast water from ships.

There is a marine climate research facility within the assessment area, at Daneborg in Young Sund. Climate and the ecological climate response is monitored in the Fjord as part of the Greenland Ecosystem Monitoring System (see https://g-e-m.dk/). A recent focus has been on the impact of increased freshwater input and how upwelling from marine terminating glaciers increase the primary production (Meire et al. 2017). However, the GEM monitoring does not cover the offshore ecosystem.

Box 6.3

Climate change effects on benthos on the Northeast Greenland Shelf

Jørgen L.S. Hansen (AU)

Predicted climate change effects in the Northeast Greenland shelf area include less sea ice cover and increasing water temperature. Furthermore, this will probably result in a cascade of other small- and large-scale effects on the hydrographic conditions, ranging from changes in the North Atlantic Gyre system to local changes in bottom-near currents as well as displacement of hydrodynamic hotspots. However, the effects cannot be predicted in detail.

As described in Hansen et al. (2019) the Northeast Greenland shelf is a so-called outflow shelf characterized by low primary productivity, leading to low biomasses of the shelf benthos as compared with the West-Greenland shelf. Less ice cover in the future will probably lead to increased productivity in the water column; presently there are extended periods where light is limiting for primary production due the presence of sea ice. This could lead to somewhat higher biomasses of the shelf benthos with a possible footprint on higher trophic levels.

During the *Strategic Environmental Study Program for Northeast Greenland* in 2017, cold-water corals were discovered at the continental shelf slopes (Box 3.2) and these communities are of special concern with regard to anticipated climate change. Investigations of the holocene geological deep-sea depositions have documented that the coral responds to warm and cold periods possibly due to large-scale changes of the North Atlantic Gyre systems. Other studies have documented that hydrodynamic hotspots seems a prerequisite for their cold-water growth. Given that the 2017 findings of cold-water corals coincide with such hydrodynamic hotspots, it is likely that any changes in hydrography will cause the present populations to die out. Thus, even though specific indirect effects of climate change on the hydrography are unpredictably, the change in itself could lead to a *de facto* disappearance the present biogenic habitats of cold-water corals. This is because it takes up to centuries for new recruits to grow to meter-long stands of corals as discovered during the 2017 cruise. Therefore, even though general large-scale environmental conditions favouring cold-water corals are retained, the critical environmental conditions for the corals are local stability and continuity which, on the other hand, is the most unlikely outcome of climate change – on the Northeast Greenland shelf as anywhere else.

6.4.2 Implications for industries

Climate change may facilitate access to oil, minerals, and other resources, although market forces may play a larger role than climate change in those industries' activities in the Arctic (e.g. Wegeberg et al. 2018b). Extraction of oil and gas will lead to more greenhouse gas emissions, exacerbating the impacts described here. Commercial fisheries may also be affected by climate change, in both positive and negative ways, due to changes in phytoplankton growth, changes in ocean temperature, northward shifts in the ranges of some fish species (e.g., the recent migration of mackerel into waters around Svalbard and Greenland), and acidification of the ocean by carbon dioxide.

6.4.3 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, including changes in numbers and distribution of key species like the copepod *Calanus hyperboreus* and the polar cod, as well as also iconic Arctic species of high conservation value like ivory gull, polar bear, narwhal and bowhead whale. Some of the areas we have 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 important 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 in any detail, and the management must consider all the pressures of oil development, shipping, 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.

6.5 Cumulative effects

David Boertmann (AU) & Anders Mosbech (AU)

Cumulative effects derive from the combined impacts from past, present and future human activities. Effects of a single activity can be insignificant but the cumulative effects – either from repeated activities or a combination of several activities – can be additive, synergistic or antagonistic (Ray 1994). They can originate from human activities (pressures) such as hunting and fishing, industry, shipping, tourism etc. and can be direct (such as the mortality from hunting) or indirect such as disturbance. Climate change is also often considered as a factor in this context (National Research Council 2003).

In the assessment area cumulative effects could, for instance, be the result of several seismic surveys carried out at the same time within a limited area. During a single survey many alternative habitats would still be available, but extensive activities in several licence blocks may, for example, exclude baleen whales from normally available habitats. This could reduce their food uptake and, consequently, their general fitness due to decreased storage of the lipids needed for the winter migration and breeding activities.

Another example is produced water: The oil concentration in the discharged produced water is usually low. However, the total amount of produced water from a single platform is considerable, and if several platforms are operating in the area the discharge would add up to substantial amounts.

Box 6.4

Seals and polar bears in Northeast Greenland in relation to climate

Aqqalu Rosing-Asvid (GINR)

A Canadian study have documented that polar bears and ringed seals are found in a ratio of approximately 1:200 in areas where ringed seals are the main prey for polar bears (Stirling & Øritsland 1995). The 200 ringed seals can produce the approximately 40 ringed seals annually needed for a polar bear and nearly all ringed seal mortality is linked to polar bear predation in those areas. A drop in the ringed seal population will therefore also lead to a drop in the polar bear population and the two species will fluctuate around this equilibrium of about 1:200.

The conditions in Northeast Greenland differ from this setup because the bears have access to alternative food sources: in addition to ringed seals there are bearded seals along the coast and large breeding and moulting concentrations of harp and hooded seals in the offshore drift ice zone (Figure 52). The harp seals that whelp in the Greenland Sea give birth in early April, about a month later than in the whelping areas off Newfoundland and in the White Sea, so that their whelping happens simultaneously with the whelping of ringed seals. The ringed seals mainly give birth on the land-fast ice and most polar bears are therefore hunting ringed seal pups when the harp and hooded seals give birth further off the coast. Preliminary results (Chapter 3.8.1) from recent satellite tracking studies of polar bears in the assessment area confirm that in spring (April-June) some bears venture into areas identified as 'potential whelping areas' for harp and hooded seal (Figure 44-47, see also Figure 52, Øigård et al. 2008). Laidre et al. (2015) also reported that bears in East Greenland were using poorer habitats (reduced ice concentrations and areas closer to open water) in the 2000s compared to the 1990s.

Warming during the ringed seal nursing period can have great impact on the pup survival, because the roof of the subnivean lairs may collapse, exposing the cubs, which can lead to significantly increased predation by polar bears and foxes (Stirling & Smith 2004). That is not necessarily an advantage for the polar bear, because a newly weaned ringed seal pup (approximately 6-7 weeks old) contain up to 50% fat (Stirling & McEwan 1975) and have a caloric value that is 7-8 times higher than that of a newborn pup. So, increased hunting success of newborn pups might actually lower the amount of blubber the polar bears get from ringed seals (Rosing-Asvid 2006).

In areas with tight ringed seal polar bear dynamics (with the 1:200 ratio mentioned above) this would lead to a decline in both the ringed seal and the polar bear population. As noted above, the polar bears that live along the East Greenland coast do have access to other prey species (especially harp and hooded seals) and there are reason to believe that periods with less sea ice increase the acessability of these prey species.

Only relative few polar bears find the harp and hooded seal breeding concentrations (see Figure 48), but the harp and hooded seals will gather again on the drift ice to moult in May and in June-July, respectively. At that time a year (especially June-July) the edge of the drift ice is closer to the coast in the southernmost parts of the assessment area, and south of the assessment area hooded seals in some years moult on ice right along the coast and even in the fjords.

This is confirmed by a study on the fatty-acid compositions of a time-series of polar bear blubber (polar bears from Ittoqqortoormiit; McKinney et al. 2013). Harp and hooded seals mainly forage in the sub-Arctic East Atlantic and from a completely different food-chain than the ringed and bearded seals that are associated with the polar current along the Greenland east coast; these differences leave 'fatty acids markers' in prey and their predators. The study of polar bear fatty acids showed that periods with warmer temperatures and less sea ice (years with low North Atlantic Oscillation (NAO) index) were associated with more harp and hooded seal and less ringed seal in the polar bear diet (McKinney et al. 2013). It also showed that the East Greenland bears mainly consumed Arctic ringed seals (47.5%), harp (30.6%) and hooded (16.7%) seals and rarely, if ever, consumed bearded seals. During a 28 year period, ringed seal consumption declined by 14%/decade (90.1 in 1984 to 33.9 % in 2011) while hooded/harp seal (hard to differentiate between those species by the fatty acids method) consumption increased by 9.5%/decade (0% in 1984 to 25.9 in 2011). Those long-term changes may have implications for the contaminant exposure of the bears since the sub-Arctic seals have higher contaminant burdens than the true Arctic ringed seals (McKinney et al. 2013).

The human hunt on ringed seals is targeting seals that have left the breeding lairs (survived the main polar bear predation) and the catch statistics indicate that access to ringed seal by the east Greenland hunters have decreased during warm periods and increased during cold periods (Rosing-Asvid 2006).

The harp and hooded seal populations that whelp and moult in the Greenland Sea have been strongly influenced by commercial sealing. The hooded seals are belived to have been reduced from more than a million around World War II to around 80,000 when the commercial sealing stopped in 2007. The surveys since then indicate that the population has been stable or slightly decreasing, not increasing as would have been expected (ICES 2019). The harp seal population has been stable or increasing since the 1970s, but the pup-production has declined significantly during the last three surweys from 110,000 (2007) to 90,000 (2012) and 54,000 (2018). The reason for this decline (i.e. if this reflect a decline in the population or a drop in the reproduction rate), is somewhat unclear at the moment (ICES 2019).

If the ongoing reductions in sea ice extent, duration, thickness and composition continue, the interlinked population dynamics of the seal species and the polar bear in the assessment areas will continue to develop. A decrease in sea ice in the southern range of the polar bears will imply that areas with optimal polar bear sea ice habitat (ringed seal habitat) in Northeast and North Greenland will become more important (see Chapter 3.8.1).

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 living on the seafloor and in the water column and could, subsequently, be transferred to the higher levels of the food web, i.e. seabirds and marine mammals feeding on benthic organisms, plankton or fish (Lee et al. 2005).

Seabird hunting takes place in the populated part of the assessment area, and the breeding populations of thick-billed murre have been declining, mainly due to unsustainable harvest (GINR, unpublished). Tightened hunting regulations were introduced in 2001, but without effect on the negative population trend. The thick-billed murre relies on a high adult survival rate, giving the adult birds many seasons to reproduce, and the two colonies in the assessment area are still decreasing (Boertmann et al. 2020). 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).

The human pressures in the Arctic are still relatively few (Andersen 2017a), and include in the assessment area: commercial fishery in the southernmost part, shipping (mainly research ships and freighters to the manned stations on the coast), tourism (especially with cruise ships), exploration of mineral resources on land, subsistence hunting and fishing in the populated area, 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. These developments will add to the cumulative effects. Climate change is expected to be the largest pressure in the coming decades.

7 Review of oil and gas activities and their environmental impacts

David Boertmann (AU) & David Blockley (GINR)

7.1 Phases of oil and gas activities

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. Environmental safe production requires maintenance of equipment and facilities, waste management, environmental monitoring. Finally, during decommissioning, wells are plugged, all structures and facilities are dismantled and removed, and the surrounding environment may be restored. These phases occur over several decades and may happen simultaneously in a particular hydrocarbons 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.

7.1.1 Exploration

In order for hydrocarbons deposits to be commercially viable, there needs to be 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 Greenland Sea 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 assessment area.

Environmental impacts of exploration activities relate to:

- Noise from seismic surveys and drilling.
- Cuttings and drilling mud.
- Disposal of various substances.
- Emissions to air.
- Placement of structures.

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 latter phases of the life cycle of an oil and gas field.

7.1.2 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, and well logging and testing 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 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.

7.1.3 Development and production

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

In contrast to the temporary activities of the exploration phase, the activities during development and production are usually longer lasting, depending on the amount of producible petroleum products and the production rate. Environmental concerns from routine activities during the development will mainly be related to:

- Construction and placement of structures including production facilities, structures 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 two major areas of concern during exploitation are from discharge of produced water and emissions to the atmosphere.

7.1.4 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 concerns typically relate to the large amounts of waste material which has to be disposed of or regenerated. In case of land-based activities, built facilities should be removed and the surrounding environment should be restored to its approximate natural state. During decommissioning, impacts can potentially arise from noise at the sites and traffic from ships, aircraft and other vehicles needed to transport personnel, equipment and waste material. There is also the potential for the release of contaminants from the structures themselves as well as the immediate vicinity of the development that 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 around contaminants on the seabed contained in drill cuttings (e.g. mercury) and on the structures as well as the removal of hard substratum that can form habitat for a variety of marine life.

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 toxic to marine life. This should however be mitigated by an approval procedure, like in Greenland.

The other emerging issue with regards to decommissioning is the physical removal of the structures 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 structures 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.

7.2 Environmental impacts from exploration and exploitation activities

7.2.1 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, and underwater noise is increasingly recognized as a source of negative impacts on marine ecosystems (Kyhn et al. 2019).

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 marine animals (see Kyhn et al. 2012). Regional seismic surveys (2D seismic) for locating reservoirs are characterised by widely spaced (over many kilometres) survey lines, while the more localised surveys (3D seismic) for identifying drill sites usually cover small areas with densely spaced (for example 500 m) lines. Rig site investigations, vertical seismic profiling and shallow geophysical investigations use comparatively much smaller sound sources than 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 effects on marine mammals and fish caused by sound 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 zoo- and ichthyoplankton

Zooplankton (for example copepods such as *Calanus* and larvae of benthic crustaceans) and fish larvae and eggs (= ichthyoplankton) are unable to avoid the pressure wave from the airguns and the general impression was that they could be killed within a distance of up to 2 m, and sublethal 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 2017), but this remains to be verified. A more recent study of impacts on *Calanus* from Norway could not confirm the large mortality zone (Fields et al. 2019) and Pascoe & Innes 2018 also question the significance of the results.

The volume of water affected by a seismic survey is small compared to the non-affected volume and therefore population effects are considered to be limited, according to Norwegian and Canadian assessments (National Research Council 2003). However, some species have discrete spawning areas in certain periods of the year, where mortality could be more pronounced due to very high densities in the water column. In Norway, such areas (e.g. Lofoten) are closed to seismic surveys in the spawning period, mainly to prevent scaring away the spawning cod (see below).

Impact 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). Negative 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-to-peak) down to 5-15 m distance sustained extensive ear damage, with no evidence of repair nearly 2 months after exposure (McCauley et al. 2003). It was estimated that a comparable exposure could be expected at ranges < 500 m from a large seismic array (44 l = 2685 in^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-to-peak) (Wardle et al. 2001). The reef fish showed involuntary startle reactions (C-starts), but did not swim away unless the explosion source was visible to the fish at a distance of only about 6 m. Despite a startle reaction displayed by each fish every time the gun was fired, continuous observation of fish in the vicinity of the reef using time-lapse video and tagged individuals did not reveal any sign of disorientation, and fish continued to behave normally in similarly quite large numbers before, during and after the gun firing sessions (Wardle et al. 2001). Another study performed during a full-scale seismic survey (2.5 days) also showed that seismic shooting had a moderate effect on the behaviour of the lesser sandeel (Hassel et al. 2004). However, no immediate lethal effect was observed on sandeels, neither in cage experiments nor in grab samples taken at night when sandeels were buried in the sediment (Hassel et al. 2004).

The studies described above indicate that behavioural and physiological reactions to seismic sounds among fish may vary between species, i.e. depending on whether they are territorial or pelagic and on the seismic equipment being applied. Generalisations should therefore be made with caution.

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 (Engås et al. 1996) have shown that 3D seismic surveys (i.e. a shot fired every 10 seconds and 125 m between 36 lines 10 nm long) reduced catches (trawl and longline) of Atlantic cod and haddock at 250-280 m water depth. This occurred not only in the shooting area, but as far as 18 nautical miles away. The catches did not return to normal levels within 5 days after shooting (when the experiment was terminated), but it was assumed that the effect was short-term and catches would return to normal after the studies. The effect was more pronounced for large fish compared to smaller fish.

Impacts of 3D seismic survey on gillnet and longline fisheries were studied in Norway, and they showed contradicting results (Løkkeborg et al. 2010): Gillnet catches of Greenland halibut and redfish increased during seismic shooting and remained higher in the period after shooting. Longline catches of Greenland halibut, on the other hand, decreased. Saithe catches in gillnet showed a tendency to decrease (but not statistically significant) during the shooting, and acoustic surveys of fish densities also indicated that saithe left the shooting area.

An analysis of the official catch statistics from an area with seismic surveys in Norway in 2008 showed very different results (Vold et al. 2009): Catch rates of Atlantic cod, ling, tusk and Atlantic halibut had not changed significantly. Catch rates of redfish and anglerfish seemed to increase, while catch rates of saithe and haddock caught in gillnet decreased and catches with other gear were not affected. The majority of the seismic surveys included in the analysis were 2D and scattered in time and space, for which reason major impacts on the fisheries were not expected. This substantial variation in catch rates (among species and fishing methods) was also found by an Australian review (Pascoe & Innes 2018).

Greenland halibut is very different from Atlantic cod and haddock with respect to anatomy, taxonomy and ecology. It has no swim bladder, which means its hearing abilities are reduced compared to fish with a swim bladder, in particular at higher frequencies. Thus, Greenland halibut is likely to be sensitive only to the particle motion part of the sound field, but not the pressure field. Moreover, the fishery takes place in much deeper waters than in the Norwegian experiments with haddock and Atlantic cod.

The only Norwegian studies including Greenland halibut was focused on gillnet fishery and not trawling (Engås et al. 1996), thus the results cannot be applied to Greenland offshore fisheries.

In that study an increased catch of Greenland halibut were found in the gillnets. There are also other examples of this trend (Hirst & Rodhouse 2000, Bruce et al. 2018), which is most likely the result of changed behaviour (more moving around) of the fish.

In the review by Dalen et al. (2008) it was concluded that the results described by Engås et al. (1996) (mentioned above) cannot be applied to other fish species or to fisheries taking place at other water depths, such as the Greenland halibut fishery.

In summary, there is a risk of reduced catches of Greenland halibut in areas with intensive seismic activity, although no effects have been observed in West Greenland where seismic surveys have overlapped with trawling grounds for Greenland halibut.

Impact of seismic noise on birds

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 breeding and moulting congregations 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 has found that the great cormorant is better at hearing underwater than expected, and the hearing thresholds are comparable to seals and toothed whales in the frequency band 1–4 kHz (Hansen et al. 2017). However, no attempts have been made to assess possible impacts of exposure to airgun sounds when seabirds are in the water column.

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 anthropogenic noise include changes in type or timing of vocalisations. In addition, there may be indirect effects of noise as prey availability may change (scared away by the noise) (Gordon et al. 2003).

There is strong evidence of behavioural effects on marine mammals from seismic surveys (Compton et al. 2008). Mortality has not been documented but there is a potential for physical damage, primarily auditory damages. Under experimental conditions, temporary elevations in hearing threshold (TTS, temporary hearing loss) have been observed (Southall et al. 2007). Such temporarily reduced hearing ability is considered unimportant by Canadian researchers unless it develops into permanent threshold shift (PTS, permanent hearing loss) or occurs in combination with other threats normally avoided by acoustic means (DFO 2004). However, entanglement in fishing gear has been linked to hearing damage in a Canadian study (Todd 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. 2005). This exposure criterion is poorly defined from a measuring standpoint and with little experimental support. Thus, Southall et al. (2007) proposed a reorganisation of exposure criteria, allowing more room for differences in sensitivity between different taxa and different sound types. They also implemented a dual criteria approach; 1 / maximum instantaneous sound pressure and 2 / total acoustic energy accumulated over the complete duration of exposure. 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. 1986a, Ljungblad et al. 1988, Brewer et al. 1993, Hall et al. 1994, NMFS 2002, Gordon et al. 2003), although a Canadian study showed somewhat shorter distances (Miller et al. 2005). White whales, generally believed to be sensitive to noise from seismic surveys and drilling (Lawson 2005), avoided seismic operations in Arctic Canada by 10-20 km (Miller et al. 2005). In UK waters, Stone & Tasker (2006) described a significant reduction in marine mammal sightings 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 (for example Reeves et al. 1984, Richardson et al. 1986a, 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 & Clarck (2010) documented that blue whales increase their calling rate during seismic surveys, probably as compensatory behaviour to the elevated ambient noise. A large group of fin whales stopped calling during a seismic survey (Clark & Gagnon 2006 quoted from OSPAR 2009), and fin whales have also been recorded to change the acoustic characteristics of their sounds (Castellote et al. 2010). On the other hand, Dunn & Hernandez (2009) tracked blue whales that were 42-90 km from operating airguns, and they were unable to detect changes in the behaviour of the whales at these distances.

In contrast, minke whales have been observed as close as 100 m from operating airgun arrays (DCE unpublished) – potentially close enough to sustain physical damage.

During a controlled exposure experiment in the Gulf of Mexico, sperm whale horizontal movements were not noticeably affected by a seismic survey, but foraging effort seemed to diminish when airguns were operating (Miller et al. 2009).

A tagged northern bottlenose whale was exposed to strong noise from naval sonar, and it showed strong behavioural reaction. The sound source was not directly comparable to a seismic airgun array except for the source level, but the study showed that this whale species is highly sensitive to acoustic disturbance (Miller et al. 2015).

Harbour porpoises exposed to seismic noise from a commercial 2D survey (7.7 l = 470 in^3 airgun, sound pressure level 165-172 dB re 1µPa and SEL of 145-151 dB re 1 µPa^2 s^{-1}) were short-term displaced at 5-10 km distance, but returned after a few hours and also showed habituation (Thompson et al. 2013).

The ecological significance of eventual displacement is generally unknown. If alternative areas are available, the impact will probably be low. The temporary character of seismic surveys also allows displaced animals to return after the surveys.

In West Greenland waters, satellite tracked humpback whales utilised extensive areas and moved between widely spaced feeding grounds, presumably searching for their preferred prey (krill, sandeel and capelin) as prey availability shifted through the season (Heide-Jørgensen & Laidre 2007). The ability of humpback whales to find prey in different locations may suggest that they would have access to alternative foraging areas if they were displaced from one area by a seismic activity. However, even though many areas can be used, a few key zones seem to be especially important. The satellite tracked humpback whales favoured a zone on the shelf with high concentrations of 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 has a negative impact on the energy uptake 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 (Federal Register 2013). A few studies have observed lack of measurable behavioural changes in cetaceans exposed to the sound of seismic surveys taking place several kilometres away. For instance, Madsen et al. (2006) found no reaction of sperm whales to a distant seismic survey operating tens of kilometres away. Later, Dunn & Hernandez (2009) did not detect changes in the behaviour of blue whales that were 15-90 km from operating airguns. The authors estimated that the whales experienced sounds of less than 145 dB (re 1µPA) and concluded that while their study supports the current US-NMFS guidelines, further studies with more detailed observations are needed (Dunn & Hernandez 2009).

A behavioural effect widely discussed in relation to seismic surveys and whales is the masking effect of communication and echolocation sounds. There are, however, very few studies that document such effects (see Castellote et al. 2010, Di Iorio & Clark 2010, Clark et al. 2009), mainly because the experimental setups are extremely challenging. Masking requires overlap in frequencies, overlap in time and sufficiently high sound pressures. The whales and seals in the assessment area use a wide range of frequencies (from < 10 Hz to > 100 kHz, 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. 2005), and they 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.

Two of the studies of the *Strategic Environmental Study Program for Northeast Greenland* addressed underwater noise and marine mammals. In Scoresby Sund, the effects of seismic noise on narwhals were studied (Box 3.13) – initial analysis showed a cessation of foraging activity when seismic activity was within 15 km from the whales – and the PAM-study (Box 3.12) recorded seismic noise from sources far from Greenland, underlining the long ranges such noise can be detected on.

In a recent paper (Bröker 2019) reviewing hydrocarbon exploration and exploitation impacts on marine mammals, more study results are described and discussed.

7.2.2 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 structures 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 Greenland Sea 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.

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. 1989b), and their migrating routes were displaced away from the coast during oil production on an artificial island, although this reaction was mainly attributed to the noise from support vessels (Greene et al. 2004). Schick & Urban (2000) describe how bowhead whales, also in Alaska, avoided close proximity (up to 50 km) to oil rigs, which resulted in significant loss of summer habitats.

7.2.3 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 (low toxic) and the cuttings are usually released to the seabed 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 floor 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 metres 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 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 if disturbed can be a source of secondary contamination. 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.

Until 1993, the practice in Norway was to dispose all the waste to the seafloor. However, due to environmental concerns, release of OBM was stopped then. Today, only WBM can be released to the seabed and only if the content of chemicals is approved, i.e. they only contain environmentally 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 (for example Davies et al. 1984, Neff 1987, Gray et al. 1990, Ray & Engelhardt 1992, Olsgaard & Gray 1995, Breuer et al. 2004, Breuer et al. 2008). Benthic fauna is still impacted around old deposition sites, although regeneration has been relatively fast, and today impacts can rarely be traced to more than 500 m from the installations (Research Council of Norway 2012).

Synthetic muds (SBM) also lead to impacts on benthic fauna around a platform, though less pronounced than from OBMs (Jensen et al. 1999a). Ester-based cuttings have been shown to cause rather severe, but short-term, effects due to their rapid degradation which may result in oxygen depletion in the sediments. Olefin-based cuttings are also degraded fairly rapidly, but without causing oxygen deficiency and, hence, have more short-term and moderate effects on the fauna.

Studies in Norway conclude that the ban of release of OBM has considerably improved the environmental conditions on the seabed around the offshore installations (Renaud et al. 2007, Schaanning et al. 2008 and references therein) but there is still concern for long-term impacts due to the large amounts released, and due to the chemicals in the mud (Research Council of Norway 2012).

Even though the conditions on the seabed are improved by the use of WBM, there is a risk of moving the adverse effects from the seafloor to the water column where, for instance, suspension of particles gives some reason for concern (Research Council of Norway 2012). Biological effects from the particles in the water based mud have been observed on fish and bivalves, at least under laboratory conditions (Bechmann et al. 2006) and effects on plankton have also been described (Utvik & Johnsen 1999, Jensen et al. 2006a).

Cold-water corals, such as the reef-forming hard corals *Lophelia*, and sponges are sensitive to suspended material in the water column (Freiwald et al. 2004, SFT 2008). However, research in Norway has shown that the *Lophelia* corals are not especially sensitive to sedimentation of cuttings (same sensitivity as to natural sedimentation), and they could remove a layer of up to 6 mm sediment. But where they were unable to remove the sediment layer, the underlying tissues would die (Larsson & Purser 2011).

A modelling study on the shallow Store Hellefiskebanke off West Greenland (Wegeberg et al. 2016a) 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.

The Northwest Atlantic Fisheries Organisation (NAFO) considers cold-water corals and sponge fields, similar to seamounts and hydrothermal vents, as vulnerable marine ecosystems (VMEs). Such corals of the genus *Keratoisis* were found in the assessment area, covering areas of the seabed in 1100 m depths during the background research programme in 2017 (Box 3.2).

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 bioavailable 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.

7.2.4 Produced water discharge

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

Produced water is usually discharged to the sea after a cleaning process that reduces the amount 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 og 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 life 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 2012). Several uncertainties have been expressed concerning, for example, the hormone-disrupting alkylphenols and radioactive components with respect to toxic concentrations, nutrients, bioaccumulation, 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 other marine fauna, 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 PAH effects, 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 uptake of PAHs 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 PAHs on the fish could be measured. This result suggests 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 just below the ice, where degradation and evaporation etc. are slow and the sensitive under-ice ecosystem, including eggs and larvae of polar cod, could be exposed (AMAP 2010a).

7.2.5 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. Similarly, sewage and sanitary waste water will be released to the sea. The handling and extent of such releases are regulated by the OSPAR convention, and these standards must be applied to minimise impacts in case of production in the assessment area.

Ballast water from ships poses a special biological problem, i.e. the risk of introduction of non-native and invasive species (also termed as Aquatic Nuisance Species – ANS) to the local ecosystem (Anonymous 2003a). This is generally considered as a severe threat to marine biodiversity. Blooms of toxic algae in Norway, for instance, have been attributed to the release of ballast water from ships. There are also many examples of introduced species that have impacted fisheries in a negative way (for example the comb jelly *Mnemiopsis* in the Black Sea or other ecosystems (Kideys 2002)).

At present, the Arctic Ocean is the least affected area by non-native invasive species as shown by Molnar et al. (2008) 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).

7.2.6 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. 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.

The large amounts of greenhouse gases released from an oil field will increase the total Greenland emissions significantly. The CO_2 emission from Statfjord field in Norway, for example, was in 2003 almost three times the total current Greenland CO_2 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.

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 (Anonymous 2003b). This lack of knowledge also applies to the terrestrial environment bordering the assessment area.

Finally is emission of black carbon (BC) from combustion a matter of particular concern in the Arctic, because the black particles reduce the albedo on snow and ice surfaces and, thus, increase the melting.

7.2.7 Infrastructure construction

The development of a hydrocarbons field requires a large amount of physical infrastructure to support it. Construction activities cause a number disturbances to the environment including transport of materials by land, sea and air, waste and pollution generation, damage or removal of natural habitats, and the introduction of new and novel habitats. Although there may be some support facilities built on land during exploration and appraisal phases, it is only likely to happen if there are no existing service facilities that can support the project. Construction of subsea, surface and land-based infrastructure will likely be at its peak during early development, with some continuing intermittently through the life of the project (e.g. for maintenance or building further subsea pumps and pipes). Most of the disturbances related to the construction of facilities will, therefore, be at the beginning of the development of a field, although the most persistent disturbance will be the presence of the structures 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. Wellheads, pipelines and other subsea structures 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); coral gardens was recently located on the Northeast Greenland shelf (Box 3.2).

The presence of structures 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 structures 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 structures (Boertmann et al. 2006, Merkel & Johansen 2011).

A related problem is known from the North Sea, where millions of passerine birds migrate at night during autumn and spring. Under certain weather conditions large numbers of passerine birds are attracted to light from illumination and flaring, and many die from exhaustion or collision (Bourne 1979, Jones 1980). It has been shown that the attraction of birds can be mitigated by changing the illumination to colours not attracting birds, for example green (Poot et al. 2008).

Placement of structures 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 structures and pipelines, while small ships often choose to avoid the crossing of such structures (Anonymous 2003).

Another effect of the exclusion zones is that they act as sanctuaries, and in combination with the artificial reefs created by the subsea structures attract fish and, in the North Sea, even seals.

7.2.8 Transportation

One of the more significant sources of noise during the life cycle of a hydrocarbons field are ships and helicopters used for intensive transport operations (Overrein 2002).

Depending on the set-up, supply vessels might sail between offshore exploration or production facilities and coastal harbours. Whilst for the exploration phase activities are expected to peak in summer, it could be year-round at the production stage. During production, shuttle tankers could sail between crude oil terminals and the trans-shipment facilities on a regular basis, even in winter and then assisted by icebreakers. The loudest noise levels from shipping activity result from large icebreakers, particularly when operating in ramming mode. Peak noise levels may then exceed the ambient noise level up to 300 km from the sailing route (Davis et al. 1990).

Helicopters produce strong noise that can scare and displace marine mammals as well as birds (Patenaude et al. 2002, Frederiksen et al. 2017). Particularly walruses hauled out on ice 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 long periods of time, and when scared off from their breeding ledges they may push eggs or small chicks off the ledge on steep cliffs, resulting in a failed breeding attempt (Overrein 2002). There are two breeding colonies of thick-billed murre in the assessment area. Also, concentrations of feeding birds can be sensitive, as they may lose feeding time due to the disturbance.

7.3 Environmental impacts from oil spills

7.3.1 Probability 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 (Anonymous 2003). The likelihood of a large oil spill from a tanker ship accident is generally estimated to be higher than for an oil spill due to a blowout (Anonymous 2003). Another study estimated that the probability of a deep water blowout in the Greenland part of the Labrador Sea would be one blowout for every 8488 exploration wells drilled, although the data base was meager (Acona 2012).

Drilling in deep waters[2] and ultra-deep waters[3] 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). Contributing to raise the probability of oil spills in the assessment area, is also that there is no tested/proven technology for drilling in heavy multiyear drift ice (combined with icebergs).

7.3.2 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 and currents).

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2 > 600 m according to Norwegian (NORSOK) standards – which are adopted by Greenland authorities – and between 1000 and 5000 feet ≈ 305-1524 m according to US authorities (cf. Graham et al. 2011).

3 > 5000 feet ≈ 1524 m according to US authorities (cf. Graham et al. 2011).

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 & Karlson (2002). Behaviour of potential offshore oil spills in West Greenland with special regard to the potential for clean-up was evaluated by Ross (1992).

7.3.3 Surface spills

Oil released to open water spreads rapidly, resulting in a thin slick (often about 0.1 mm thick in the first day) that covers a large area. Wind-driven surface currents move the oil at approx. 3% of the wind speed (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, including light oil adsorbed onto sediment particles in the water column (Hjermann et al. 2007). Sediment particles are found in many Greenland waters where the turbid melt water from glaciers can disperse widely into the open sea.

7.3.4 Subsurface spills

Blowouts from a platform initially typically cause a surface spill, but may start or continue as a subsurface spill if the riser from the wellhead collapses. The risk of such a collapse is increased in deeper water. The oil in a subsurface blowout may float to the surface or remain in the water column for a longer period of time where it typically will be dispersed into small droplets. Oil type, oil/gas ratio, temperature and water depth are factors influencing the fate of oil from a subsea blowout, i.e. whether it remains in the water column as a dispersed plume or float to the surface. As the potential oil type and oil/gas ratio is unknown for the assessment area, it is too early to predict the behaviour of possible spilt oil. The oil in the DMI models of subsurface spills in West Greenland, for instance, quickly floated to the surface (Nielsen et al. 2006), while a SINTEF model estimated that oil would not reach the surface at all, but rather form a subsea plume at a depth of 300-500 m (Johansen et al. 2003).

The *Deepwater Horizon* oil spill in the Mexican Gulf in 2010 was unusual in size, location and duration, but in many ways similar to the *Ixtoc* blowout in 1979, also in the Mexican Gulf. It revealed new and not yet described ways spilled oil could be distributed in the environment, although this probably also happened during the *Ixtoc* spill (Jernelöv 2010). The unusual dispersion of the oil was mainly caused by the spill site on the seabed at more than 1500 m water depth.

From studies of deep-water blowout events, Johansen et al. (2001b) predicted that a substantial fraction of the released oil and gas will be suspended in pelagic plumes, even in the absence of added dispersal agents. The fate of oil in deep water is likely to differ strongly from that of surface oil because processes such as evaporative loss and photo-oxidation do not take place (Joye & Macdonald 2010). Microbial oxidation and perhaps sedimentation on the seabed is the primary fate expected of oil suspended in the deep sea (Joye & Macdonald 2010). In the Gulf of Mexico, natural oil seeps contribute to the marine environment with an estimated 140,000 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 was reported in accordance with this hypothesis (Hazen et al. 2010) and later studies also support that indigenous communities of 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 by 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 was discharged. Unexpectedly, approx. 50% of the oil and all of the natural gas was sequestered in deep waters (Joye 2015). The fate of the oil was estimated by McNutt et al. (2012): Burned 5%, skimmed 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 (Diercks et al. 2010a, Thibodeaux et al. 2011, 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. 2018). 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 (Passow & Ziervogel 2016). Chanton et al. (2015) 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 Greenland Sea.

7.3.5 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 to the roughness of the subsurface of the ice, at least as long as the ice does not move. If an oil slick below ice is 1 cm thick on average, a spill of 15,000 m^3 covers only approx. 1.5 km^2 below the ice, and less if thicker. This also means that very high oil concentrations may occur and persist for prolonged periods 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. 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 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).

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).

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.

7.3.6 Dissolution of oil and toxicity

The amount of oil in the water column from a surface oil spill depends on different natural physical and chemical processes, such as dispersion, evaporation, oxidation, dissolution, biodegradation and emulsification. These processes are facilitated or hampered by climatic factors such as wind, temperature, presence of ice etc.

Different physical processes, for example wind and waves, produce oil/water emulsions, where oil is dispersed via oil droplets both horizontally and vertically. The horizontal drift depends on wind, water currents, waves and turbulent diffusion processes. The vertical transport of oil in the water column is driven by water currents, oil buoyancy and turbulence from waves. The process of dissolution of oil in the seawater is of particular interest, as it increases the bio-availability of the oil components. Fractions of the total oil present in the aqueous phase following a period of mixing are a water-soluble fraction (WSF) and a water-accommodated fraction (WAF). The difference between these two fractions of dissolved oil is that WAF can contain micro-emulsions of fine droplets, and WSF is a true solution (Kang et al. 2014, Singer et al. 2000).

The water soluble fraction (WSF) is a multi-compound fraction that is bioavailable and toxic to aquatic organisms (Melbye et al. 2009, Salaberria et al. 2014). The typical oil compounds in WSF from fresh oils include phenols, naphthalenes, 2-3 ring PAHs and so-called NSO compounds (highly polar compounds with nitrogen, sulphur, and oxygen atoms in their structures) (Word 2013). Melbye et al. (2009) showed that the main contributor to toxicity of the WSF was one of the most polar fractions, (besides the naphthalenes, PAHs, and alkylated phenols), which contained a large number of cyclic and aromatic sulfoxide compounds and low amounts of benzothiophenes.

The water soluble fraction (WSF) 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. 2008a). Leakage of water-soluble components to the ice is of special interest, because of a high bio-availability to marine organisms, relevant both in connection with accidental oil spills and release of produced water.

7.3.7 PAHs in the environment

Among the many components found in oil, the polycyclic aromatic hydrocarbons (PAHs) are regarded as the contaminants that have the most serious long-term environmental effects (Martínez-Gómez et al. 2010). Due to their toxicity, selected PAHs are listed as priority pollutants by the US Environmental Protection Agency (US EPA) and as high priority substances in the European Water Framework Directive (Directive 2000/60/EC) (European Commission 2001).

PAHs are acutely toxic down to 0.9 mg oil/l (0.9 ppm or 900 ppb), and Johansen et al. (2003) applied a safety factor of 10 to reach a PNEC (Predicted No Effect Concentration) of 90 ppb oil for 96-hour exposure. This was based on fresh oil which leaks a dissolvable fraction, mostly toxic for fish eggs and larvae, while weathered oil is less toxic.

PAHs are taken up by marine organisms directly from the water (via the body surface or gills) or through the diet, and as they are non-polar and lipophilic compounds they tend to accumulate in the fatty tissues. Many studies have indicated that PAHs are more or less easily metabolised by invertebrates and generally efficiently metabolised by vertebrates such as fish (review by Hylland et al. 2006). Therefore, and in contrast to other organic pollutants, PAHs are not bio-magnified in the marine food web. Dietary exposure to PAHs may, however, be high in species that preferentially feed on organisms with low ability to metabolise PAHs, such as bivalves (Peterson et al. 2003), and filter feeding zooplankton can be exposed to high levels through filtering out oil droplets containing PAHs from the surrounding water (Hylland et al. 2006).

Marine sediments function as an ultimate sink for PAHs, and these are therefore useful for environmental monitoring (Beyer et al. 2010, HELCOM 2010). PAHs tend also to accumulate in bivalves due to low biotransformation capabilities, and bivalves can also be useful for assessments in the environment. Fish, as other aquatic vertebrates, have well developed enzymatic systems that efficiently metabolise PAHs 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). PAHs were measured in sediments collected by the *Strategic Environmental Study Program for Northeast Greenland* in 2017 (see Chapter 6.1 and Box 6.1).

Since some PAHs are known to be potent carcinogens, this contaminant class is generally regarded as a high priority for environmental pollution regulation and in ecological risk assessment of industrial effluent discharges (Hylland et al. 2006, Neff 2002).

Toxicity data is a key factor in risk assessment, and since there is limited information on effects of toxic substances in Arctic organisms, further data on local species is essential for risk assessment in Arctic ecosystems (Chapman & Riddle 2003, 2005, Mosbech 2002, Olsen et al. 2011). There is a particular need for toxicity data on early life stages, as they are most vulnerable (Frantzen et al. 2012, Khan & Payne 2005, Short et al. 2003). This data gap has been addressed in recent years: Nahrgang et al. 2016 (polar cod), Beirão et al. (2018, 2019) (capelin), Toxværd et al. (2018a, 2018b) (*Calanus*), Agersted et al. (2018) (*Calanus*), Skottene et al. (2019) (*Calanus*), Tairova et al. (2019) (capelin).

Experience from the Deepwater Horizon blowout

Boehm et al. (2011) reported the results of analyses for total petroleum hydrocarbons (TPH) and total polycyclic aromatic hydrocarbons (TPAH) in water column samples collected in the vicinity of the spill from the *Deepwater Horizon* incident in the Gulf of Mexico during the 3-month release period (May through mid-July) and in a 3 month period after the well was capped. Overall, during the release, concentrations of TPAHs in water samples ranged from not detected 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 PAHs ranged from 0.01 to 0.070 µg/g (ppm) which, according to international sedimentary quality guidelines (ERL-ERM), indicated a low probability of harmful effects to benthic organisms (Botello et al. 2015). Chemical analysis of sediments sampled during repeated surveys between June 2010 and June 2012 to test for selected PAHs as indicators of contamination due to the spill showed that PAHs in samples from the continental slope in May 2011 were highest near the well site, and were reduced in samples taken one year later. PAHs from continental shelf sediments during the spill (June 2010) ranged from 10 to 165 ng/g (ppb) (Snyder et al. 2014).

Boehm et al. (2011) also reported other substances from water column samples near the *Deepwater Horizon* blowout. Total Petroleum Hydrocarbons (TPH) ranged from 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).

7.3.8 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 bird plumage and fish eggs) and the toxic effects due to skin contact, ingestion or inhalation. Physical contact may cause acute effects, while toxic effects can cause both acute and chronic effects.

Exposure to oil also involve indirect effects, as oil in the environment may interfere with other environmental stressors, both natural and anthropogenic, or it may impact food resources for species not directly affected by the oil. Such effects are also important to consider and assess when effects of oil pollution are evaluated (Whitehead 2013).

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.

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 responded negatively on increasing concentrations of WAF, and that the effect was increased by exposure to sunlight (phototoxic effect).

Subsurface oil spills at least, may therefore have the potential to impact primary production at a large scale and localised primary production hotspots may be particularly vulnerable.

Effects on copepods

Copepods are very important in the food web, as they represent one of the most important groups in terms of energy transfer to upper trophic levels (See Chapter 3.2). Among the large copepods, the *Calanus* species *C. hyperboreus* and *C. glacialis* are dominant throughout the Arctic region (Word 2013). They are perennial and hibernate near the sea floor on great depth for ascending to surface waters in spring. Copepods can be affected by the toxic oil components from the WAF and the WSF in the water below a surface oil spill. Recent exposure experiments with *Calanus* spp. showed that PAHs can accumulate in these animals and cause effects such as lowered reproductive output, reduced grazing and increased mortality rate (Grenvald et al. 2012, Hansen et al. 2013, Toxværd et al. 2018a, Nørregaard et al. 2015). A recent study showed strong delayed effects on fecal production, egg production and high sensitivity to oil contamination (Toxværd et al. 2018a), effects which may be the result of a subsurface spill affecting hibernating *Calanus* in deep waters.

Other studies also showed negative effects of pyrene (PAH) on reproduction and food uptake among *Calanus* species (Jensen et al. 2008) and on survival of females, feeding status, and nucleic acid content in *Microsetella* spp. from Western Greenland (Hjorth & Dahllöf 2008). The pyrene concentrations applied were, however, difficult to compare to actual spill situations. Negative effects of combined temperature changes and PAH exposure on pellet production, egg production and hatching of *C. finmarchicus* and *C. glacia-*

lis have also been demonstrated (Hjorth & Nielsen 2011). Effects from both naturally dispersed and chemically dispersed oil, such as increased mortality and decreased filtration rates in filter feeding copepods *C. finmarchicus* have also been demonstrated, with only slight differences between the treatments (Hansen et al. 2012).

Comparison of acute toxicity, expressed as mortality of herbivorous copepods (*Acartia tonsa*) and growth inhibition of a primary producer (*Skeletonema costatum*) of WAFs from non-weathered and naturally weathered oil, shows a general decrease in effect as a function of weathering degree (Faksness et al. 2015) 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 accumulate and "store" (bioaccumulation) oil compounds from oil-polluted waters, and thereby perhaps 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. 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: Petroleum hydrocarbons 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 petrogenic PAHs (from sediment) and (1) increased content of bile metabolites, (2) induced hepatic cytochrome P-4501A, (3) elevated concentrations of DNA adducts in liver, and (4) increased prevalence of neoplasia (cancer) in liver. Studies of biological responses in fish from different coastal sites in the Gulf of Mexico following the *Deepwater Horizon* spill, linked oil exposure to 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. This could be explained by factors obscuring negative populations effects and factors dampening population-level costs, such as behavioural (spatial/dietary) avoidance, oil concentrations below toxic levels for fish in nature, sub-lethal effects that do not impact fitness, impacts occurring prior to density-dependent bottlenecks or other compensatory processes, and also the representativeness of model species in laboratory assays (Fodrie et al. 2014).

Adult northern shrimp live at and near the 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 have been shown through exposure to petroleum hydrocarbons. These included cytological and histological damage to the hepatopancreas, the main detoxifying organ in shrimp (Sreeram & Menon 2005).

Fish and shrimp larvae: Fish/shrimp eggs, embryos or larvae are vulnerable to direct contact with oil, and more so than later life stages (Pasparakis et al. 2019). The adverse effects are due to, e.g., ingestion and dermal absorption of toxicants, 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 PAHs caused direct effects on cardiac conduction, which had secondary consequences for late stages of heart and kidney development, neural tube structure and formation of the craniofacial skeleton. Additionally, pyrene, a four-ring PAH, induced anaemia, peripheral vascular defects and neuronal cell death (Incardona et al. 2014). 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 petroleum hydrocarbons 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 (Carls et al. 1999, Kocan et al. 1996, Incardona et al. 2015).

Another study on an Arctic key species – the capelin – exposed fertilized eggs to different kinds of oil in concentrations similar to concentrations found at spill sites (Tairova et al. 2019). This experiment also found elevated mortality among the eggs, and developmental effects on the hatched larvae. Two studies also on capelin (Beirão et al. 2018, 2019) showed that embryos and sperm cells were harmed by exposure to chemically dispersed oil and by the dispersant alone. Capelin that spawn in Greenland use the subtidal part of the coasts, where eggs can be continuously exposed to oil sequestered in the sediments (slow release stressor) (Culbertson et al. 2008). Another key species – the polar cod – has also been shown to be susceptible to oil in the water in the early life stages (Nahrgang et al. 2016).

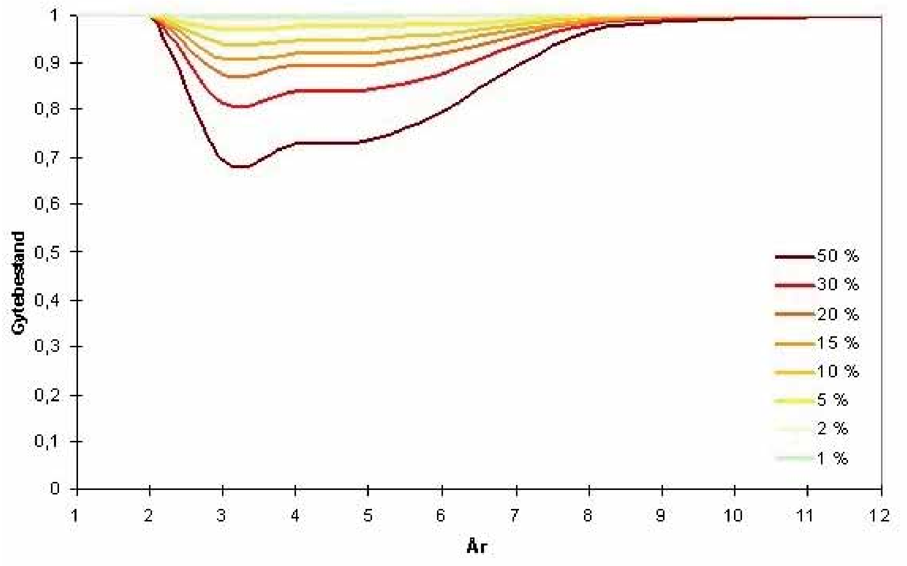
Juvenile penaeid shrimps showed reduced growth rates after exposure to non-lethal concentrations of petroleum hydrocarbons following the *Deepwater Horizon* spill (Rozas et al. 2014).

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 toxic impacts from very low oil concentrations in the water of the spawning grounds (Incardona et al. 2015).

Moreover, species with distinct spawning concentrations and with eggs and larvae in distinct geographic concentrations in the upper water layer may be particularly vulnerable. The Barents Sea stock of Atlantic cod is such a species where eggs and larvae may be concentrated in the upper 10 m in a restricted area (Johansen et al. 2003). As oil is also buoyant, the highest exposure of eggs is under calm conditions while high energy wind and wave conditions mix eggs and oil deeper into the water column, where both are diluted and the exposure reduced. As larvae grow older their ability to move around becomes increasingly important for their depth distribution and their ability to avoid oil in the water (Johansen et al. 2003).

Based on oil spill simulations for different scenarios and different toxicities of the dissolved oil, the individual oil exposure and population mortality on cod egg and larvae has been modelled (Johansen et al. 2003). The population impact is, to a large degree, dependent on whether there is a match or a mismatch between high oil concentrations in the water column (which will only occur for a short period when the oil is fresh) and the highest egg and larvae concentrations (which will also only be present for weeks or a few months,

Figure 79. Estimated reduction and recovery in Barents Sea cod spawning biomass following large losses of egg and larvae due to large ’worst case’ oil spills. The lines shows results for different degrees of losses. Gydebestand = spawning stock, År = year. Sources: Anonymous (2003b), Johansen et al. (2003).



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 10x safety factor, there could be losses in the region of 5% and, in some cases, up to 15% for a blowout lasting less than 2 weeks, while very long-lasting blowouts could give losses of eggs and larvae in excess of 25%. A 20% loss in recruitment to the cod population is estimated to cause a 15% loss in the cod spawning biomass and to take approx. eight years to recover fully (Figure 79).

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, Gustavson et al. 2020, Wegeberg et al. 2020a). 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. 2020).

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 (unpublished 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 (West Greenland) using microcosms. Benthic microalgae were especially sensitive to pyrene, and increased toxicity was found at high levels of UV light already at low pyrene concentrations (Petersen & Dahllöf 2007, Petersen et al. 2008). The pronounced pyrene effects caused algal death and 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 petroleum hydrocarbons 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.

Oil spill impacts on benthic fauna

Bottom-living organisms (benthos) are generally very sensitive to oil spills and high hydrocarbon concentrations in the water. They are often sessile – and thus cannot escape the oil. Also, many species have a slow growth and a long lifespan making population recovery very slow.

The sensitivity of many benthic species has been studied in the laboratory, and a range of sub-lethal effects have been demonstrated from exposures not necessarily comparable to actual oil spill situations (Camus et al. 2002a, b 2003, Olsen et al. 2007, Bach et al. 2009, 2010, Hannam et al. 2009, 2010). Effects occur especially in shallow water (< 50 m), where toxic concentrations can reach the seafloor. In such areas, intensive mortality has been recorded following an oil spill, for example among crustaceans and molluscs (McCay et al. 2003a, 2003b, 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 or as 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 THC and TPAH contents and distance to the wellhead. Moreover, the authors of this study estimated that recovery rates would be slow, in the order of decades or longer. For example were detrimental effects on deepwater corals documented below the subsea plume of dispersed oil (Fisher et al. 2012, White et al. 2012). These corals was impacted by oil contaminated marine snow (MOS) (Girard et al. 2017). 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 WSF have been demonstrated on sea ice fauna (Camus & Olsen 2008, Olsen et al. 2008a).

As described above, polar cod is sensitive to oil spills in ice due to the spawning behaviour. In experiments, both in the laboratory and in the field, polar cod have been exposed to PAHs and crude oil, and several sub-lethal effects were demonstrated. Moreover, polar cod seems to be a suitable indicator species to monitor pollution effects caused by oil (Nahrgang et al. 2009, 2010a, b, c, d, Christiansen et al. 2010, Jonsson et al. 2010).

The question is how sensitive the ice-associated ecosystem is to oil spills. The available knowledge is very limited (Camus & Dahle 2007, AMAP 2010a), 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 2010a).

Oil spill impacts in coastal habitats

One of the lessons learned from the *Exxon Valdez* oil spill was that the nearshore areas were the most impacted habitats (NOAA 2010). Oil was trapped in shallow bays and inlets, where oil concentrations could build up in the water column to levels that were lethal to adult fish and invertebrates (for example McCay 2003). A status report from NOOA'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 animal populations living in this habitat in Prince William Sound have since recovered (birds, fish), for example the sea otter population was declared as recovered in 2013 (Ballachey et al. 2014). But certain populations of other affected species were still under recovery and as late as in 2014, the pigeon guillemot (a close relative to the black guillemot in Greenland) and pacific herring were assessed as ‘not recovered’ (EVOS 2014a Link, EVOS 2014b Link, 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 bioavailability of this oil is disputed (Page et al. 2013).

Almost 30 years after the spill, Nixon & 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 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 oil floating on the sea. 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). 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 sublethal and more long-term effects. However, the main cause of seabird losses following an oil spill is direct oiling of the plumage.

Many seabird species aggregate in small and limited areas for certain periods of their life cycles. Even small oil spills in such areas may cause very high mortalities among the birds present, and small chronic spills may also impact seabirds (Wiese et al. 2004). The high concentrations of seabirds found at coasts, for example breeding colonies, in moulting areas or in offshore waters at important feeding areas (see Chapter 3.7) are particularly vulnerable.

After the *Deepwater Horizon* spill, bird mortality was estimated 600,000 to 800,000. Most affected were gulls, terns, pelicans and gannets; especially the local breeding population of laughing gulls was reduced (Haney et al. 2014a, b). The toll after *Exxon Valdez* was estimated to 650,000 birds (Piatt & Ford 1996), while a much lesser oil spill (350-500 m^3) in Danish waters with very high concentrations of birds resulted in 35,000 collected and euthanized birds (Clausager 1979), which probably represented only a fraction of the killed birds.

Oiled birds that have drifted ashore are often the focus of the media when oil spills occur. This, as a minimum, documents the individual suffering, but the question in an ecological context is how the populations are affected. This can only be demonstrated by extensive studies of the natural dynamics of the affected populations and the surrounding ecosystem (Figure 80).

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.

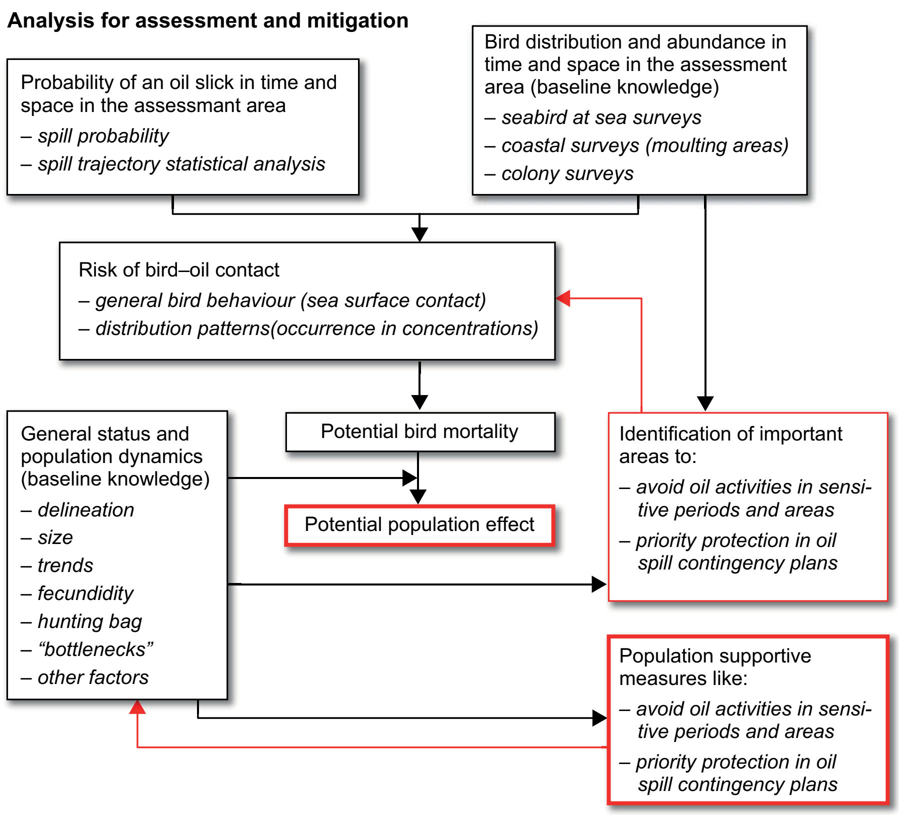


Figure 80. Basic principles of assessing the vulnerability of seabird populations to oil spills. Black lines indicate main effects on bird populations, red lines indicate effect of potential mitigative measures. Indirect effects not included for simplicity (based on Mosbech 1997).

Oil spill impacts on marine mammals

Marine mammals are relatively robust and can generally survive short periods of fouling and contact with oil, except for polar bears and seal pups, for which even short-term exposure can be lethal (Geraci & St. Aubin 1990).

It is moreover difficult to assess mortality of marine mammals after an oil spill because carcasses are rarely found in a condition suitable for necropsies. Nevertheless, increased mortality of killer whales, sea otters and harbour seals exposed to the *Exxon Valdez* event in Prince William Sound has been well documented (for example Spraker et al. 1994, Matkin et al. 2008, 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. In addition, oil can poison seals through ingestion or inhalation and oil spills can have a disruptive effect by interfering with normal behaviour patterns.

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 have a strong negative effect on the insulating properties of this fur. The mother seals recognize their pups by smell and a changed odour caused by oil might therefore affect the mother’s ability to 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.

The bearded seals which feed on benthic organisms and may also be exposed to oil contaminated food.

Walruses are gregarious year round and often in close physical contact with each other (Fay 1982, 1985). This means that oil exposure will concern groups in contrast to the more dispersed species as ringed seal and bearded seal (Born 1995, Wiig et al. 1996).

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. They also pointed out that if walrus feeding areas was impacted, ingestion of toxic bivalves or reduction of available food supply could impact the populations. This latter effect could be critical for walruses wintering in limited open-water areas. Walruses are also sensitive to oil spills in ice-covered waters, where they may be forced to surface in oil spills and thereby inhale oil vapours (see above).

Whales

There are several reports of whales that have repeatedly moved directly into oil slicks (for example Harvey & Dalheim 1994, Smultea & Würsig 1995, Anonymous 2003a, Matkin et al. 2008). Whales are therefore probably not able to detect oil and probably do not avoid oil-contaminated waters (Goodale 1981, Harvey & Dalheim 1994, Anonymous 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, if ingested, toxic effects and injuries in the gastrointestinal tract have been described (Albert 1981, Braithwaite et al. 1983, St. Aubin 1990, Werth 2001). Not much is known about the toxic effects of oil on whale skin, but the oil is likely to adhere and possibly stay for a long time on the skin, and may be toxic.

Baleen whales feed by filtration through the baleen plates. Spilled oil fouling the baleen plates may affect filtration, but this issue has not been studied so far. Any oil related effect on the baleen likely depends on factors such as the 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, Venn-Watson et al. 2015a, 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.

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). In the assessment area this problem will only apply to the Greenland halibut fisheries in and near the southernmost part.

Strict regulation and control of the fisheries in contaminated areas will be necessary to ensure the quality of the fish from these areas.

Suspension of fisheries would usually last for some weeks in offshore areas, and longer in coastal waters. The coastal fishery was banned for four months after the *Braer* incident off the Shetland Islands in 1993 and for nine months after the *Exxon Valdez* incident in Alaska in 1989 (Rice et al. 1996). However, some mussel and lobster fishing grounds were closed for more than 18 and 20 months, respectively, after the *Braer* incident (Law & Moffat 2011). During the *Deepwater Horizon* spill starting in April 2010, 230,000 km^2 were closed for both commercial and recreational fishing; in September 2010 approx. 83,000 km^2 were still closed (Graham et al. 2011), and in April 2011 – after a year – the last of the closed areas was reopened for fishery (NOAA 2011). In the Prince William Sound both commercial fishery and subsistence harvest and fishery were still considered as 'recovering' in 2010, 21 years after the oil spill in 1989 (NOAA 2010).

A recent paper by Pascoe & Innes (2018) reviews the potential oil spill economic impacts on fisheries.

Oil spill impacts on tourism

The tourism industry will be vulnerable 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).

Long-term effects

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 (Rice & Peterson 2018, Aderhold et al. 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 bioavialable 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).

8 Assessment

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This chapter gives an overview of potential environmental impacts from oil and gas activities and their effects on the ecological elements in the Greenland Sea assessment area.

The assessments presented here are based on our present knowledge on the distribution of Artic species and their sensitivity and threshold levels toward human activities, noise and pollution in relation to oil exploration. However, the Arctic is increasingly affected by climate change – a process that accelerate – so the conclusions and assessments presented here may not apply to future conditions. Furthermore, an increase in knowledge from further investigations may also contribute to future adjustments of assessments and conclusions.

At present, we do not know much about the adaptive capacity of important species in the assessment area and how their sensitivity to human impacts might change under changing environmental conditions. Changes in habitat availability and quality forced by climate change, e.g. reduced sea ice coverage, are to be expected, with consequences for the local fauna. Along with increased temperatures, this will affect the distribution patterns and living conditions for relevant species, with implications for the food web. Northward range expansion of fish targeted by commercial fisheries could, for example, result in increased fishing activities in the assessment area.

8.1 Potential environmental impacts from oil and gas activities in the assessment area

See Chapter 7 for a review of the specific activities which may impact the ecosystem in the assessment area.

8.1.1 Impacts from seismic noise

The most noise-sensitive species in the assessment area are narwhal, bowhead whale and walrus. Potential areas for seismic surveys will most likely overlap with the range of these species, and there will be a risk of displacement from critical habitats.

Narwhals occur widely along the fast-ice edge in spring and early summer, and when the fast ice disappears most of them move into coastal areas and fjords with calving glaciers. At these habitats concentrations of whales may occur, for example in the Northeast Water Polynya, in Dove Bugt and in Scoresby Sund. Narwhals show a high degree of site fidelity and predictable habits and these sites are critical for the survival of the local stocks (Heide-Jørgensen et al. 2015). The impact of a single seismic survey in or near a critical narwhal habitat is most likely temporary, but repeated over years the effects are probably more serious. Effects on narwhals of seismic surveys in a fjord habitat was one of the studies in the *Strategic Environmental Study Program for Northeast Greenland* (Box 3.13).

Bowhead whales are also sensitive to seismic surveys, and effects include potential displacement from critical habitats. Important areas for this species include the Northeast Water both winter and summer, the ice edge and shelf-break south to Germania Land especially in spring, the MIZ further south to

Scoresby Sund in summer, and probably also the former Southern Whaling Ground (see Chapter 3.8.4).

Walrus occur gregariously at terrestrial haul-outs and feed at the sea floor at shallow feeding grounds which are critical to the population. Seismic activity nearby has the potential to displace walrus from these sites. The population in the assessment area is small and could be limited by available feeding grounds in shallow coastal waters and banks (Born et al. in prep.), making it particularly sensitive to displacement.

Other whale species, such as blue, fin, humpback and minke whale, may also be displaced from important areas. These whales occur mainly at the shelf-break and in the Atlantic water east of the shelfbreak, and at least humpback whales have been observed in high numbers at specific sites. But the predictability of these areas is not known, and the whales probably have alternative feeding grounds, making them less sensitive to displacement.

It is unknown to which degree seismic noise may affect seabirds. But diving species may be at risk. The most vulnerable population will then be the little auk. Feeding, moulting and autumn concentrations of this species could overlap with potential seismic surveys.

Fish eggs and larvae can be impacted by seismic surveys at close distance. But concentrations in Greenland waters are generally low in the upper 10 m and most fish species spawn in a dispersed manner in winter or spring. This is particularly the case in the assessment area, where the densities of fish generally is very low. This means that the temporal overlap of the spawning season with seismic activities is unlikely. When the seismic surveys takes place, the eggs and larvae of fish (icthyoplankton) is 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.

The only commercial fishery which can be impacted by disturbance of the fish from seismic surveys is the minor Greenland halibut fishery in the southernmost part of the assessment area. This area may be included in the central East Greenland area planned to be opened for exploration in 2022. Reduced catches due to displacement of the fish may be expected during, and for a short period after, a seismic survey. However, this effect has not been observed in West Greenland, where overlap between seismic surveys and trawling grounds for Greenland halibut has occurred.

There is also a risk of displacing especially narwhals from important hunting grounds, affecting their availability (to hunters). This problem could occur in the southern part of the assessment area, near the town of Ittoqqortoormiit and southwards along the coast towards Tasiilaq.

The risk for long-term impacts on marine mammals from a single seismic survey is low. However, long-term impacts must be considered if several surveys are carried out simultaneously or if surveys are carried out in the same areas in consecutive years (cumulative effects).

Table 17 provides an overview of potential impacts from a single seismic survey in the assessment area, and Chapter 7.2.1 includes a summary of available evidence on how far from seismic surveys different whale species may be affected.

Table 17. Overview of potential impacts from a single seismic survey (both 2D and 3D) on important ecological elements in the Greenland Sea and associated important occupations (hunting and fishing). Displacement indicates spatial movement of animals away from an impact, and is classified as none, short term, long term or permanent. Sublethal effects include all notable fitness-related impacts, except those that cause immediate mortality of adult individuals. Sublethal effects and direct mortality are classified as none, insignificant, minor, moderate or major. A dash (-) indicates that it is not relevant to discuss the described effect. Several surveys, either simultaneously or consecutive, have the potential to give more pronounced cumulative impacts. (L) = local extent, (R) = regional extent. The assessment of potential impacts assumes the application of current mitigation guidelines (EAMRA 2015).

Important ecological elements	Typical vulnerable organisms	Overlap	Risk of impact on critical habitats	Potential impacts worst case with current regulation			
				Displacement 2D	Displacement 3D	Sublethal effects	Direct mortality
Pelagic hotspots	copepods, amphipods, fish eggs, fish larvae	small	no	no	no	insignificant (L)	insignificant (L)
Tidal/subtidal zone	bivalves	no	no	–	–	–	–
Demersal fish and seabed fauna	Greenland halibut	pot. large	no	short term (L)	short term (L)	none	no
Ice fauna	polar cod	small	no	short term (L)	short term (L)	none	no
Seabirds		small	no	–	–	–	–
Walrus	–	small	yes	short term (L)	short term (L)	insignificant	no
Seals	ringed seal, harp seal, hooded seal	small	no	short term (L)	short term (L)	insignificant	no
Whales	narwhal, bowhead, blue whale	pot. large	yes	short term (L)	short term (L)	potential	no
Polar bear		small	no	short term (L)	short term (L)	insignificant	no
Comm. fisheries	–	pot. large	yes	short term (L)	short term (L)	–	–
Hunting	–	small	no	short term (L)	short term (L)	–	–

8.1.2 Impacts of noise from exploration drilling rigs

High levels of underwater noise are generated during drilling, mainly from the propellers securing the position of floating rigs (Chapter 7.2). The most vulnerable species (in respect to continuous noise) in the assessment area are narwhal, bowhead whale and walrus. If drilling rigs are placed in areas where these species occur, displacement of these species from critical habitats is a risk.

Exploration activities are temporary and, consequently, displacement of marine mammals caused by noise from drilling rigs is also temporary. However, exploration may take several years, and in an area with many licence blocks, combined exploration may last for decades resulting in extensive cumulative impacts, and population effects cannot be excluded.

Table 18 gives an overview of potential impacts of noise and discharge from a single exploration drilling in the assessment area.

8.1.3 Impacts of drilling muds and cuttings

Drilling activities continue during exploration, development and production phases. The release of drilling mud and cuttings to the seabed can be a major impact on the environment. Effects on the seabed communities will occur depending on the amounts and the type of drilling mud (see below). It is therefore important to conduct baseline studies and monitoring at the drill sites in

Table 18. Overview of potential noise and discharge impacts from a single exploration drilling on important ecological elements in the Greenland Sea, and associated important occupations (hunting and fishing). Several drillings, either simultaneously or consecutive, have the potential to give increased cumulative impacts. The assessment of potential impacts assumes the application of the current mitigation guidelines, see text and Table 17 for details and explanation.

Important ecological elements	Typical vulnerable organisms	Overlap	Risk of impact on critical habitats	Potential impacts worst case with current regulation		
				Displacement	Sublethal effects	Direct mortality
Pelagic hotspots	copepods, amphipods, fish eggs, fish larvae	small	no	–	–	–
Tidal/subtidal zone		no	no	–	–	–
Demersal fish and seabed fauna	Greenland halibut, corals, sponges	small	yes	short term (L)	minor	yes*
Arctic char		no	no	–	–	–
Ice fauna	polar cod	small	no	short term (L)	minor	no
Seabirds	thick-billed murre, little auk, ivory gull etc.	small	no	short term (L)	no	no
Walrus		small	yes	short term (L)	no	no
Seals	ringed seal, harp seal, hooded seal	small	no	short term (L)	no	no
Whales	narwhal, bowhead, blue	small	yes	short term (L)	minor	no
Polar bear		small	no	short term (L)	no	no
Com. fisheries		small	no	–	–	–
Hunting		small	no	–	–	–

* benthos such as coral reefs

order to document effects and assess if there are unique communities or species that could be impacted.

Drilling muds and cuttings are usually discharged to the sea in case of water based drilling muds (WBM). Physical impacts of the sediment load are expected on the benthic communities near the release sites (Table 18). 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 for 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. If muds are transported to land or reinjected it can contribute to reduce environmental impacts.

8.1.4 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 7.2.4). Effects of produced water in the assessment area are difficult to evaluate but, for example, polar cod, and especially their egg concentrations below ice, could be exposed and impacted. Plankton production seems to have hotspots along the shelfbreak and release of production water in such sites could also be of concern.

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. Thus, ballast water management and antifouling systems on hulls following international standards should be demanded before any activities are initiated.

Sewage and sanitary wastewater will be released from rigs and ships. Such releases will be regulated according to the OSPAR convention, so environmental impacts of these discharges in the assessment area will by 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. 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 is black carbon (BC) and SO_x (sulphur) that will be emitted from all platforms and vessels supporting the operation.

8.1.5 Impacts from construction and presence of infrastructure

Placement of structures have both biological and aesthetic impacts. The biological impacts for marine mammals mainly include disturbance and permanent displacement from critical habitats – walrus being the most sensitive in the assessment area. But habitat loss is also an important issue to consider in this context, both on land and on the seabed.

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 birds may be a problem in relation to little auks in the autumn (Fraser et al. 2006). The 2017 background studies (*Strategic Environmental Study Program for Northeast Greenland*) with aerial surveys (Box. 3.3) and the tracking studies (Box 3.8) revealed that little auks occurred widespread on the shelf off Northeast Greenland in autumn, and in high densities especially along the shelfbreak. Attraction of night-migrating passerines as observed in the North Sea will, however be insignificant, as such migration is of very low intensity in the assessment area.

Placement of structures may affect fisheries due to exclusion (safety) zones around installations. This issue is only relevant in the southernmost part of the assessment area, where the halibut fishing grounds may be included in the area planned to be opened for exploration in 2022.

Placement of structures 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.

8.1.6 Impacts from transportation

Ships and helicopters are widely used in the Greenland environment today. But the level of these activities will increase significantly, both in relation to exploration activities and to development of one or more oil fields. This is particularly the case in the assessment area, where current transport activities are very limited.

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 scaring birds and marine mammals over a range of many kilometres. In the assessment area walrus, narwhal and bird concentrations such as breeding thick-billed murres and moulting geese will be particularly vulnerable to this activity.

An increase in shipping in the assessment area will result in greater disturbance of wildlife from noise pollution as well as potential ship strikes of large whales which increase the risk of oil spills. The shipping also contributes to air emissions and discharges to the ocean (see above).

8.2 Potential impacts from accidental oil spills

8.2.1 Oil spills

Large oil spills are the most harmful incidents to the marine environment in relation to oil and gas exploration and exploitation (AMAP 2010a). The probability of such an incident is low, and the global trend in spilled amounts of oil is decreasing (Schmidt-Etkin 2011). Nevertheless, the risk is evident and the environmental impacts from a large spill can be severe and long-lasting, particularly in an Arctic environment such as in the Greenland Sea region, where the risk is increased mainly because of the presence of icebergs, multiyear ice and ice ridges.

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 as well as exposure to toxic compounds. Harsh weather conditions and occurrence of sea ice year-round may influence the distribution and fate of oil and also hinder an effective oil spill response or even make it impossible.

According to the AMAP oil and gas assessment, tankers are the primary potential source for spills (AMAP 2010a). Tanker accidents can cause large spills while minor spills can occur in connection with offshore bunkering. Another potential source in the assessment area will be a blowout during drilling which, in contrast to a tanker spill, is continuous and may last for days, weeks or even months. The blowout from the *Deepwater Horizon* disaster, for instance, lasted 87 days before it was stopped by the drilling of a relief-well.

8.2.2 Environmental impacts of oil spills in the assessment area

The drift ice in the assessment area is very dynamic and moves with the surface currents, and will probably contribute to spread spilled oil to larger areas compared to areas with solid shore fast ice. Moreover spilled oil in an almost unweathered condition may be released from the melting sea ice to open waters far from the spill site.

A large oil spill in the assessment area has the potential to severely impact the ecology of the region. Effects will be long-lasting, and possibly longer than in Prince William Sound due to the Arctic conditions. Local populations of seabirds, marine mammals and seabed communities will most likely suffer, and if oil is hitting the coasts near the town of Ittoqqortoormiit, hunting and fishing there will be impacted.

Plankton and primary production

Important areas for plankton including fish larvae occur often where ice edges, upwelling and frontiers in the sea occur. Special attention should therefore be given to the implication of oil spills in connection with such sites in the assessment area, particularly during the spring bloom. Fronts between different water masses, upwelling areas and the marginal ice zone are examples of such hydrodynamic discontinuities, 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 to fish larvae is concentrated in the surface layers. But also the autumn/winter time can be sensitive in case of a subsurface spill like the spill from *Deepwater Horizon* (see 7.3.1), because hibernating *Calanus* (zooplankton, ecological key species) in deep waters may be exposed.

Compared to the Lofoten-Barents Sea-area, there is much less knowledge available on concentrations of fish eggs and larvae from Northeast Greenland, and particularly in the assessment area. However, the highly localised spawning areas with high concentrations of eggs and larvae for a whole stock near the surface as seen in the Lofoten-Barents Sea have not been reported from the assessment area. The overall picture here is that fish larvae are widespread and found in low 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. The eggs have a long development time and hatch when the ice starts to disintegrate and melt (Bouchard & Fortier 2011). As oil spilled under ice tends to accumulate in the same space, there is a potential risk for overlap and impacts on the recruitment to the polar cod population in the assessment area. Presently, there is no knowledge on aggregations of spawning polar cod and subsequent accumulation of eggs and larvae in the assessment area. But if such aggregations occur, an oil spill may have the potential to impact recruitment and stock size. This could have effects up through the trophic web, as polar cod is a key species in the ecosystem.

Benthic communities

In the assessment area, the shallow water (down to 50 m) communities generally have high species richness (bivalves, macro algae etc.) and the fauna is available to species on the higher trophic levels such as eiders and walruses. Another characteristic of the benthic communities in the assessment area is that individuals of several species are very long lived with an estimated maximum age of more than 25 years. Moreover, they often constitute the majority of the biomass. Finally, many species are only represented with a single specimen in a sample, showing that they are widely dispersed in very low densities. All these traits contribute to a slow recovery of oil spill impacted benthic communities.

The background studies in 2017 (*Strategic Environmental Study Program for Northeast Greenland*) found rich benthic communities in much deeper waters on the shelfbreak off Northeast Greenland. Here for example, the cold-water corals (Box 3.2) are sensitive both to disturbance and to deposition of oil on the seabed from a subsea blowout (as was the case during the *Deepwater Horizon* spill), and their recovery will be extremely slow. In conclusion, the rich seabed communities in the assessment area are very sensitive oil spills.

The fauna in the rocky tidal and subtidal zones of the assessment area are less sensitive to oiling compared to similar zones at lower latitudes. This is caused by the winter ice, which generally prevents fauna and flora from settling on the rocky surfaces. The self-cleaning potential is also high at exposed rocky coasts. There are also many low sedimentary coast in the assessment area, and here oil may potentially be buried like it happened in Prince William Sound during the *Exxon Valdez* spill.

The 2017 studies of benthic flora identified rich kelp forests and seaweed meadows along the coasts down to 45 m depth and at least as far north as 77° N. The impacts of oil (dispersants and oil spill response activities) on such habitats vary from complete removal 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

The sea ice community is expected to be highly exposed to oil spills as the ice may catch and accumulate oil in the interface between ice and water, and the oil may penetrate the ice through brine channels, all of which are the spaces occupied by sea ice communities.

Sea ice is present in the assessment area year-round, covering the entire area in winter and the northern part in summer. An oil spill at any time of the year will therefore threaten ice habitats and ice-associated flora and fauna, in winter particularly the spawning polar cod (see above).

Fish in the coastal zone

Fish in the nearshore environment are particularly in risk of being exposed to spilled oil. There is, however, only limited knowledge available on fish in this environment of the assessment area. At least Arctic char occur here when they aggregate before moving up into their native rivers to spawn and winter, and capelin probably also occur and spawn in the southernmost parts. There are indications that this species is expanding the spawning range towards north in the assessment area, perhaps becoming an important species in the nearshore environment in the future. Both capelin and Arctic char will be very sensitive to oil spills in the coastal zone.

Seabirds

Species most exposed to direct impact of oil spill are those that tend to congregate and spend much time at the sea surface as described for each species in sections above. Most critical species in the assessment area are thick-billed murre, little auk and common eider gathering on the surface at pre-breeding, foraging or moulting areas.

Many different seabird species breed in the assessment area (cf. Chapter 3.7) and a majority are associated with habitats (sea-facing cliffs or on low islets) along the coastline where they are highly exposed to drifting oil and where oil spill response can be very difficult. A particularly sensitive period occurs when the adults, by swimming, accompany their chicks away from the breeding site, a situation seen among murres and seaducks. Eiders usually stay in sheltered inshore waters, while murres move offshore and disperse over extensive areas (Box 3.7).

Only two breeding colonies of thick-billed murre are known from the assessment area, both situated at the entrance to Scoresby Sund. Here the birds assemble on the water below the colony and also at feeding areas far from the colony (Box 3.7) 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. Finally, this population is particularly sensitive because neighbouring colonies are very far away, making immigration from these sites unlikely. The nearest thick-billed murre colonies are found in Iceland and at Svalbard.

In Prince William Sound, Alaska, the breeding population of common murres (a close relative of the thick-billed murre) was assessed as recovered after 8 years following the impacts of the *Exxon Valdez* oil spill in 1989 (NOAA 2010). This happened in an area with several neighbouring colonies and no hunting; recovery from a similar situation in the assessment area, where there also is a considerable hunting pressure on the murre population, will take longer time.

Other important bird colonies where the population could be severely impacted by an oil spill in the assessment area include kittiwake colonies at several sites, the large common eider colony at Daneborg, and the very large little auk colonies at the entrance to Scoresby Sund. Common to all these colonies is that they are situated at polynyas where open water is accessible in spring and where many birds congregate.

An important seabird breeding colony is found on the islands of Henrik Krøyer Holme at the southern edge of the Northeast Water Polynya. Here, Arctic terns, Sabine's gulls and common eiders breed in relatively high numbers. Until 2008 there was also a large colony of ivory gulls but the gulls have since then moved to other nearby sites. The birds from this site are highly sensitive to oil spills, and the site is completely inaccessible as far as oil spill response is concerned, due to its remoteness and because it usually is surrounded by sea ice even in summer which, on the other hand, may prevent oil from reaching the islands.

There are numerous other seabird colonies which will be at risk to spilled oil in the assessment area (Figure 37).

Concentrations of moulting seabirds are also vulnerable to oil spills and high mortality can be expected if such moulting areas are hit by an oil spill. The aerial survey in July 2008 showed that common eiders moult in flocks distributed along the coastline, however relatively dispersed and without very large concentrations. Long-tailed ducks were more concentrated and assembled at specific bays and coasts, but usually in relatively low numbers. Satellite tracking of common eiders and long-tailed ducks in 2007 and 2008 indicate, consistent with the aerial survey, that the post-breeding moult generally takes place close to the breeding areas (Box 3.4 and 3.9). In contrast, king eiders were only found moulting at one site, a fjord on the Blosseville Kyst. The tracking study in 2009 revealed that king eiders from the assessment area also migrate to Svalbard to moult (Box 3.10), indicating that at least a part of the population are outside the reach of oil spills in the assessment area in the moulting period.

Common eiders and king eiders assemble on spring migration in the coastal areas of the polynyas by the thousands, before they disperse to the breeding grounds. High fractions of the breeding population in Northeast Greenland could be exposed to an oil spill in these waters and effects on the populations are likely.

The most numerous seabirds in the assessment area during autumn migration are little auk, northern fulmar and kittiwake. The little auks occur in concentrations along the shelfbreak and more scattered all over the shelf, and substantial numbers could by fouled by a spill in the assessment area. Kittiwakes and fulmars are found almost all over the shelf in low numbers and smaller proportions of the populations would be at risk of exposure. Ivory gulls from Svalbard, Russia and Northeast Greenland breeding sites also move across the shelf in autumn, and they encompass probably most of the entire breeding population, so a high proportion of the global population would be at risk.

In the 2012 version of this assessment, concern was expressed for the thick-billed murres migrating from Svalbard to winter quarters in Southwest Greenland and Labrador because they were expected to move across the Northeast Greenland shelf. However, the background studies 2017 (*Strategic Environmental Study Program for Northeast Greenland*) and the data provided by Norwegian Seatrack-database show that these birds stay east of the shelfbreak, where they are much less exposed to spills from the potential drill sites on the shelf.

In winter there are very few seabirds in the assessment area. However, the Norwegian Seatrack-data indicate that some species may occur in the southern part, where there is less sea ice. These include thick-billed murres, little auks and kittiwakes from breeding colonies in Iceland, Norway and Russia, and oil spills in this area would potentially cause mortality among these populations.

In conclusion, there are many seabird concentrations that are vulnerable to oil spills in the assessment area, and heavy losses to the populations must be expected in case such bird concentrations are hit by an oil spill. The most important concentrations in the breeding season are the thick-billed murres and the little auks. The thick-billed murres are particularly vulnerable, because the local breeding population is decreasing. In autumn, it is the little auk offshore concentrations and ivory gulls migrating over the shelf that will be particularly vulnerable. In spring it will be the concentrations of common and king eiders in the polynyas.

Marine mammals

The whelping harp and hooded seals are the most vulnerable seals in the assessment area. Large fractions of the populations concentrate in early spring in specific areas, and both adults and pups can be exposed. The hooded seal population is moreover decreasing (Kovacs 2016a, ICES 2019), making it particularly sensitive to increased mortality. The exact positions of these areas have to be verified in a given oil spill situation, as the locations of the whelping areas vary between years depending on the dynamic drift ice distribution.

The two other seal species, ringed seal and bearded seal, occur and whelp dispersed throughout the assessment area, and their populations are therefore less vulnerable to oil spills.

The walrus population in the assessment area is small and concentrated at specific sites which implies that many individuals – and a large part of the population – could be exposed to an oil spill, and increased mortality may impact the small population significantly. If their feeding grounds in shallow water habitats are exposed to spilled oil, their feeding opportunities may be reduced which could be significant, if the population size is food limited.

The whale populations most vulnerable to oil spills in the assessment area are the narwhal and the bowhead whale. With the effects on the killer whales in Prince William Sound in mind (two local pods never recovered from the impact), there will be concern for the local populations of narwhals if their habitats are hit by an oil spill, especially in ice-covered waters where the whales can be forced to surface in oil-covered leads.

Polar bears are very sensitive to oiling as they depend on the insulation from their fur and because they may ingest toxic oil as part of their natural grooming behaviour (Øritsland et al. 1981, Geraci & St. Aubin 1990). Therefore, polar bears that have contact with oil are likely to succumb (Isaksen et al. 1998). As the bears move over considerable distances, many could be at risk of being fouled by a single oil spill. But it is not possible to estimate the fraction (i.e., number of bears) in the entire population that may be exposed to an oil spill due to lack of information on population size. However, planned aerial surveys in the licence area and partial assessment area will shed light on this question.

Fisheries
The fishery for Greenland halibut in the assessment area is very small (annual catch 2014-2018 approx. 530 tonnes) compared to the total for Greenland as a whole (approx. 30,000 tonnes). A closure of the fishery for a season following an oil spill will only have minor economic consequences and none on the local community in the assessment area, as there is no commercial fishery taking place from here.

Long-term effects
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 indicates that long-term impacts can be expected in the assessment area if spilled oil hits such coasts. Moreover, these coasts proved to be some of the most difficult to clean after the *Exxon Valdez* incident (Shigenaka 2014). The Arctic conditions in the assessment area may even prolong the impact period compared to Prince William Sound. However, ice may also prevent oil from reaching the coast and give some 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 that were specific to the Prince William Sound case after the spill, and these cannot be compared to the Northeast Greenland conditions.

A factor which tends to intensify effects in the assessment area compared to those from the *Exxon Valdez* incident is the much more difficult conditions for an oil spill response. Only 14% of the oil was actively recovered/burned during *Exxon Valdez*, and 25% during and after the *Deepwater Horizon* spill. In the assessment area sea ice is one major obstacle, lack of infrastructure is another, and the winter darkness is a third major factor contributing to reduce the efficiency of an oil spill response in the Greenland Sea. In fact, no effective proven response methods are available for a sea covered with dynamic drift ice like the assessment area in the western Greenland Sea.

In certain areas recovery lasted more than 25 years in Prince Williams Sound (Esler et al. 2017). Depending on the spill it may take much longer time in the Greenland Sea assessment area due to the Arctic conditions and due to much more difficult circumstances and limited methods to clean up spilled oil.

Table 19 provides an overview of potential impacts from a large oil spill.

Table 19. Overview of potential impacts from a large surface oil spill on important ecological elements in Greenland, and associated important occupations. The assessment of potential impacts assumes the application of current mitigation guidelines, see text and Table 17 for details and explanation.

Important ecological elements	Typical vulnerable organisms	Potential overlap	Risk of impact on critical habitats	Potential impacts		
				Displacement	Sublethal effects	Direct mortality
Pelagic hotspots	copepods, amphipods, fish eggs, fish larvae	large	yes	–	moderate (L)	moderate (L)
Tidal/subtidal zone	fauna and flora	large	yes	long term (L)	major (L)	major (L)
Demersal fish and seabed fauna	Greenland halibut, seabed fauna	large	yes	short term (L)	moderate (L)	moderate (L)
Ice fauna	Polar cod	large	yes	short term (L)	major (L)	major (L)
Arctic char		large	yes	long term (L)	major (L)	moderate (L)
Seabirds	thick-billed murre, little auk, common eider etc.	large	yes	short term (L)	major (R)	major (R)
Walrus		large	yes	long term (L)	major (R)	moderate (R)
Seals	ringed seal, harp seal, hooded seal, bearded seal	large	yes	short term (L)	moderate (R)	moderate (R)
Whales	narwhal, bowhead, blue whale	large	yes	short term (L)	moderate (R)	moderate (R)
Polar bear		large	no	short term (L)	major (R)	major (R)
Commercial fisheries		large	yes	long term (R)	–	–
Hunting		large	yes	long term (R)	–	–
Tourism		large	yes	long term (R)	–	–

8.3 Mitigation of impacts

David Boertmann (AU)

8.3.1 Mitigation of impacts from normal operations

Mitigation of impacts from seismic noise

Mitigation measures related to seismic surveys generally include a soft start or ramp up of the airgun array each time a new line is initiated (review by Compton et al. 2008). Although not verified by experiments or observations, this approach is commonly considered 'best practice'. A soft start should allow marine mammals to detect and avoid the sound source before it reaches levels dangerous to the animals. A study in Australia (Dunlop et al. 2017) could not find different response among humpback whales exposed to both soft start and constant source, but at least the whales avoided the sound source vessel at distances greater than the mitigation zones generally applied around the vessel.

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, (the latter if seabird surveying is included in their tasks). 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 source are not mitigated by this measure.

A third mitigating measure is to close areas during sensitive periods. Such zones are established in the assessment area for walrus, narwhal and bowhead whale (Figure 66).

The Greenland guidelines to seismic surveying also recommended to inform local authorities and hunters' organisations before seismic activities take place in their vicinity. This may help hunters to take into account that animals may be disturbed and displaced from certain areas at times when seismic activities are taking place.

In Arctic Canada, a number of mitigation measures were applied to minimise impacts from seismic surveys on marine mammals and the subsistence hunting of them (Miller et al. 2005). Some measures are identical to those mentioned above, while the most important measure was a delay of the start of seismic operations until the end of the white whale hunt, and during periods when the whales were utilising important habitats. Some particularly important white whale areas were completely closed for surveys.

Similar measures are included in the set of guidelines issued by EAMRA (Link), defining temporal area restrictions for seismic activities in Northeast Greenland to protect bowhead whale, and narwhal and walrus. 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.

Bröker (2019) reviews and discuss the different mitigating methods described above.

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 should 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 6.1 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.

The best way of mitigating impacts from drilling mud and cuttings on the marine environment is to re-inject the material into the wellbores or to transport it to land for treatment at specialised facilities. The latter option is usually the way to treat oil based drilling mud (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 with the tests of the chemicals, because 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 (‘red’ and ‘black’ chemicals) cf. the Norwegian Environment Agency’s colour category (Link) have been reduced by 99% in the years 1997-2007 by applying international standards, BAT and BEP (SFT 2008). In Greenland the use of ‘black’ chemicals is not allowed and the use of ‘red’ chemicals requires specific permission.

Impacts from oil-contaminated drill cuttings should be mitigated by keeping them on board for deposition or cleaning on land at specialised treatment facilities.

In Greenland, the new 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 register PROBAS.
- More rigorous requirements for the documentation of chemicals critical in an environmental context, including all Norwegian requirements to offshore chemicals.
- More rigorous requirements for the documentation of chemicals planned to be discharged in high Arctic marine environments, including documentation for tests of biodegradability, toxicity and bioaccumulation in Arctic temperature regimes and with Arctic organisms.
- Oil based drilling mud systems can be applied, provided no drilling mud/cuttings are discharged to the marine environment and that internal safety procedures and controls are intensified.

As a consequence of previous experience, e.g. from the North Sea, the Arctic Council guidelines (PAME 2009) recommend preventing discharges as much as possible. When water-based muds are used, additives containing oil, heavy metals, or other bio-accumulating substances should be substituted, or criteria for the maximum concentrations should be established (PAME 2009). Only chemicals registered by HOCNF and the Danish product register, PROBAS, or the like are allowed, and only those classified as 'green' (PLONOR) or 'yellow' according to the Norwegian system based on OSPARs classification. Moreover, wherever possible 'zero discharge of drilling waste and produced water' should be applied. This can be obtained by application of new technologies, such as re-injection of produced water and drilling mud and cuttings (CRI). In the Arctic offshore Oil and Gas Guidelines, it is requested that 'discharge (of drilling waste) to the marine environment should be allowed only where zero discharge technology or reinjection are not feasible' (PAME 2009).

If zero-discharge is not possible, releases to the marine environment must, at a minimum, follow the standards described by OSPAR, applying a sound environmental management based on the Precautionary Principle, Best Available Techniques (BAT) and Best Environmental Practice (BEP).

Based on knowledge concerning site-specific biological, oceanographic and sea ice conditions, discharges of drilling mud and cuttings should occur at or near the seafloor or at a suitable depth in the water column to prevent large sediment plumes. Such plumes have the potential to affect benthic organisms, plankton and productivity and may also impact higher trophic levels such as fish and mammals. The discharges should be evaluated on a case-by-case basis.

Mitigation of impacts of produced water

The best way to mitigate effects of produced water in the marine environment is to prohibit discharge. This can be achieved by re-injecting the water into wellbores or into specific injection wells, for example drilled for increasing recovery of oil. In 2017 approx. 41 million m^3 produced water was reinjected in Norway (Norsk olje og gass 2018). When discharging produced water, 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 og gass 2018).

Mitigation of impacts from other discharges

Best Available Technology (BAT), Best Environmental Practice (BEP), application of international standards (OSPAR and MARPOL) and use of chemicals that cause low or no harm to the environment, and reduction of their releases are the best ways to minimise impacts and effects on the marine environment. In Norwegian offshore areas, the release of hazardous substances to the marine environment has been reduced by 99% over the past 25 years by applying these measures (SFT 2008).

There are methods to minimise the risks from releasing ballast water; the IMO ballast water management convention was adopted in 2017, and guidelines has been produced (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 (Annex 1) treaty from August 2011 and that IMO recommend to avoid using and transporting HFO in Arctic Waters and work on a total ban 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 combining heavy fuel oil with an exhaust gas cleaning system (scrubber). In the scrubber SOx is converted to sulphuric acid and a number of other pollutants (e.g. metals, PAH) occurring in the exhaust gas are trapped in the scrubber wash water. Discharges from the scrubber to the sea should 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 the kingdom of Denmark (incl. Greenland) ratified it in 1982.

Mitigation of impacts from infrastructure

There are few mitigation measures for the presence of infrastructures themselves as they are vital for the operations, but many impacts can be prevented by a combination of accurate background knowledge, careful planning in the design phase, and strict regulation. This may secure that noisy activities are avoided in sensitive areas and in sensitive periods and that infrastructure is not placed in sensitive habitats and landscapes. Because many of such structures will exist in the marine environment for decades there will also be 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 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, particularly bowhead whale, narwhal and walrus. Seabird concentrations may also be displaced by regular traffic. 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 mineral exploration is also regulated by special field rules issued by EAMRA. These rules encompass areas with staging and moulting geese, areas with moulting seaducks, seabird colonies etc. (Figure 66).

8.3.2 Mitigating impacts from oil spills

The primary mitigation task is preventing oil spills from happening. This is done by application of high health, safety and environment (HSE) standards, BAT, BEP and by strict regulation by the authorities. When a spill happens, impacts must be minimised by an effective oil spill response, based on the Environment & Oil Spill Response tool (EOS), 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 entire assessment area in the winter, and in the summer to the northern part. Winter darkness, remoteness and harsh weather conditions contribute additional challenges to an oil spill response.

When exploration drillings were approved in West Greenland in 2011, the company needed to develop a relief well plan which should include allocation of sufficient time to drill a relief well before the winter ice conditions prohibited drilling.

In the assessment area, there are, at least in the northern part (including the licencing round area from 2012) sea ice throughout the year, why drilling following the practice from West Greenland is difficult, if not impossible.

Another important mitigating measure is the dual-rig policy (two rigs operating in the same general area, and in case of a blowout there will be one readily available for drilling a relief well) adopted in Greenland.

A tool for oil spill response planning (See Chapter 9.2) and implementation of contingency plans is oil spill sensitivity mapping, which focuses on the coastal zone and its resources, but also includes offshore areas. Such a tool is presently under development for the assessment area.

A supplementary way to mitigate the potential impact on animal populations that are sensitive to oil spills, for example seabirds and marine mammals, is by regulation of other human stressors (such as hunting) in order to increase the ability of the populations to compensate for extra mortality due to an oil spill (Figure 80).

8.3.3 Monitoring

Monitoring of the surrounding environment is an essential part of mitigation of impacts, both during and after the life cycle of an oil field. In this respect, a proper baseline is needed. The environmental studies plan which is part of the EIA process (see EAMRA guidelines to explorations drillings 2011 Link) shall secure such a baseline.

The purpose of the monitoring is to identify and record unexpected impacts in the environment and to document failures to comply with the environmental requirements specified when the activities gets approval.

The results of the monitoring also provide an important tool for assessing whether the regulations are appropriate, or should be adjusted for subsequent activities.

Monitoring must be carried out at several levels:
- At the point of discharge 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 ecosystem components) with careful planning of structure placement, transport corridors and operations, i.e. planning based on the knowledge from the background studies. Application of BEP, BAT and international standards, for example OSPAR (HOCNF), and guidelines (for example 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.

8.4 Recommendations to offshore normal operations in Greenland

The regulation of offshore exploration and exploitation activities in Greenland include the mitigation of environmental impacts described above and is outlined in the different EAMRA-guidelines to the development of Environmental Impact Assessment (EIA) of the specific activities (Link, Link, 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 shall be approved by the Government of Greenland.

The following is a summary of the recommendations described in the previous sections of Chapter 8.

Drilling mud and cuttings

- Wherever possible zero discharge shall be applied.
- All offshore chemicals planned to be used shall be classified according to the OSPAR guidelines, to Norwegian and Danish guidelines, and they shall be included in the Danish register PROBAS.
- Regulation of offshore chemicals shall be based on data on toxicity and bioaccumulation of the chemical in aquatic organisms (including Arctic organisms) as well as on data for biodegradability in the Arctic environment.
- Oil based drilling mud systems can be applied, provided no drilling mud/cuttings are discharged to the marine environment.
- Drilling activities should always be combined with monitoring of pollution and effects on the sites – Before-after-Control-Impact studies.

Ballast water

- All vessels and drilling units involved in hydrocarbon activities in Greenland shall follow the IMO guidelines (Link) or the relevant Canadian regulations (Link).

Produced water

- Wherever possible zero discharge shall be applied.
- If necessary, discharged produced water shall follow the OSPAR standard, i.e. the oil content may not exceed 30 mg/l.
- Other substances
- Other releases to the sea shall be regulated according to the OSPAR convention.

Emissions to air

- Best environmental practice (BEP) and Best available technology (BAT) should be used to reduce emissions into the atmosphere.

Seismic surveys

- Offshore seismic surveys are regulated by a set of guidelines issued by EAMRA (Link).

9 Oil spill countermeasures

9.1 Biodegradation of oil

Anders R. Johnsen (GEUS)

Microbial degradation is a significant factor in the removal of spilled oil from the water column. For example, a large part of the spilled oil from the *Deepwater Horizon* spill was probably removed in that way, facilitated by an intrinsic potential for biodegradation in the Gulf of Mexico (see Chapter 7.3.4). The potential for biodegradation in 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 of the microbes to clean up (Vergeynst et al. 2018). The issue was therefore studied under the *Strategic Environmental Study Program for Northeast Greenland* (see Box 9.1) and the current knowledge on degradation of oil in cold waters (<5 °) is discussed in Wegeberg et al. (2018a).

9.2 Response and preparedness

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The most serious threat to the environment from oil exploration / exploitation activities in the sea off Northeast Greenland will be a large oil spill (see Chapter 8.1). This could derive from a blowout of a well, from pipeline rupture, when loading tankers and from accidents with the tankers transporting oil during the production phase. Minor accidents might also occur from ships, fuel tanks etc. (see Chapter 7.2 and 7.3).

Oil spilt in the marine environment will change its original properties when entering the environment because of evaporation, natural dispersion, water-in-oil emulsification and other weathering processes.

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 (see Chapter 7.3.5). Although oil in ice is not expected to weather, oil spill response during freeze-up and breakup is considered to be especially challenging.

One of the more severe marine oils spills in a sub-Arctic climate was the oil spill event in Prince William Sound in Alaska in 1989. The tanker *Exxon Valdez* grounded here and almost 41,000 m^3 of crude oil were released and impacted the marine ecology in extensive areas along the coasts (Shigenaka 2014). In situ burning was used as oil spill counter measure for the first time, but to a limited degree, as the activities were initiated too late.

Another more recent and vast oil spill incident occurred in 2010 when an explosion on the *Deepwater Horizon* drilling rig resulted in a blowout of oil and gas from the *Macondo* well and approximately 780,000 m^3 of oil were released in the Gulf of Mexico. Both mechanical recovery, chemical dispersants and in situ burning were included in the massive oil spill response operations (see Chapter 7.3.4).

Box 9.1

Microbial crude oil degradation in water and sediment from the Greenland Sea

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Introduction

The *Strategic Environmental Study Program for Northeastern Greenland* included a study of the degradation potential of oil in the assessment area (Joensen et al. 2019).This study evaluated the capacity for microbial oil degradation in the marine environment in the assessment area. The total absence of bacterial strains with hydrocarbon degradation capability is unlikely in any location (e.g. Roubal & Atlas 1978), but the metabolic diversity of the hydrocarbon degrader community may range from degradation of only simple *n*-alkanes to very diverse communities that can degrade a multitude of structurally different oil compounds. Natural oil pre-exposure from seeps presumably induces microbial degrader communities with broad substrate diversity by selecting and enriching rare degraders with the necessary metabolic machinery to "handle" a great number of different oil compounds. A central point in marine oil degradation is therefore the degree of pre-expose and the consequent adaptation, so that the degrader community may be able to "handle" a great number of oil compounds with widely different molecular structures. The focus of the study was therefore to determine to which extent oil-degrading bacteria are present in the assessment area. Any indications of natural oil pre-exposure would be important for the strategic environmental impact assessment, as pre-exposure would increase the potential for natural attenuation of oil spills.

Experimental setup

Sediment and/or sea water was sampled at 11 stations within and outside of the licence areas. We carried out four sub-experiments. 1) Sediment from 10 stations was analysed for the contents of natural oil compounds and the contents of oil degrader microorganisms. 2) Six sediments from the continental shelf were spiked with crude oil and/or mineral nutrients to investigate the potential for oil degradation and to which extend this potential is dependent on the addition of mineral nutrients. 3) Crude oil degradation was investigated in seawater from a selected station by comparing the intrinsic degradation and degradation in water spiked with mineral nutrients and/or a dispersion agent. 4) The metabolism of microbial oil degraders at different depths of the water column at three stations was qualitative characterized by extracting microorganisms from water samples and incubating them with crude oil under optimized conditions.

We used different methods to evaluate the experiments. The first approach was to determine the population size of different types of microbial oil degraders and how these populations changed over time. This was done by using a most-probable-number (MPN) method that counts the microbes that can utilize selected oil compounds (*n*-hexadecane, 2,2,4-trimethylpentane, 1,3-dimethylcyclohexane, isobutylbenzene, 2-methylnaphthalene or phenanthrene) for growth. MPN was followed by different ways of interpreting the concentration of specific oil compounds determined by GC-MS (Gas chromatography–mass spectrometry). For characterization of sediment samples (experiment 1), we determined the absolute concentrations of a range of PAHs to investigate in situ oil pre-exposure. For the incubation experiments with water or sediments (experiments 2-4), we determined how the relative concentration of alkanes and series of alkylated PAHs changed over time. Finally, the changes in oil concentration were related to biodegradation by calculating diagnostic oil compound ratios that can discriminate between physical removal of oil compounds and microbial oil removal. The principle of diagnostic ratios relies on the assumption that bacteria degrade isomers within a compound class, typically alkylated aromatics, at different rates, whereas physicochemical processes such as evaporation and dissolution affect the isomers equally (Wang et al. 1998). Biodegradation is therefore reflected in changing isomer ratios whereas physicochemical oil removal will not change the diagnostic isomer ratios.

Characterization of sediments (experiment 1)

The stations were distributed on the continental shelf ranging from close to the coast (stations 49 and 57) over stations on the shelf (stations 27, 29, 36 and 41) to station at the shelf break (stations 12, 15, 20 and 73), see Figure 6.4 in Møller et al. (2019). The concentration of alkyl-PAHs (oil PAHs) were below the detection limit except for C1-naphthalenes (0.010-0.028 mg/kg) and C1-phenanthrenes (0.011-0.020 mg/kg). All stations with detectable C1-naphthalenes (stations 12, 15, 20, 27, 29 and 73) were situated at the shelf break or close to the shelf break. The three stations with detectable concentrations of the less mobile C1-phenanthrene (stations 15, 20 and 73) were the deepest stations right at the shelf break. The concentration of alkyl-PAHs was in all cases low and without heavier alkyl-PAHs, suggesting that the six stations may have had only little pre-exposure to oil. The absence of detectable alkyl-PAHs in the shelf station sediments suggests that these stations have had no oil pre-exposure. Oil-degrading microorganisms were not detected by MPN in any of the sediments, not even degraders of the easily degradable *n*-hexadecane.

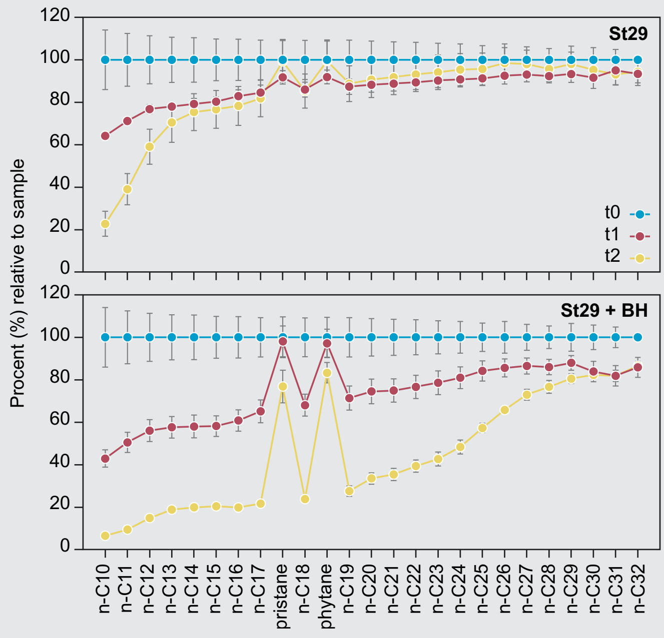

Figure 1.

Microbial oil degradation in shelf sediments (experiment 2)

Six sediments from the continental shelf were spiked with weathered crude oil to test how the potential for oil degradation and populations of degrader microorganisms evolved over time. The sediments were tested both as they were and with addition of mineral nutrients. Cultivable degraders that could grow on 2,2,4-trimethylpentane, 1,3-dimethylcyclohexane, 2-methylnaphthalene or phenanthrene were non-detectable in all microcosms, indicating the absence of specialized oil degraders and the absence of significant oil pre-exposure. There was almost no cultivable hexadecane degraders in microcosms without added nutrients, but hexadecane degraders showed strong growth when mineral nutrients were added. The degradation of oil compounds was similar in the shelf sediments. The branched isoprenoids phytane and pristane and the medium- and long-chain *n*-alkanes showed very little degradation without added mineral nutrients, whereas mineral nutrients stimulated alkane degradation (Figure 1).

Non-biological versus biological oil removal was evaluated by examining diagnostic isomer ratios. The ratios nC17/pristane and nC18/phytane changed only slightly without mineral nutrients, whereas the ratios changed substantially showing alkane biodegradation when mineral nutrients were added (Figure 2). The absence of cultivable 2-methylnaphthalene degraders and phenanthrene degraders, together with very small changes in diagnostic alkyl-PAH ratios (if any), suggest that the potential for PAH biodegradation of in the sediment is very low, even when mineral nutrients are not a limiting factor.

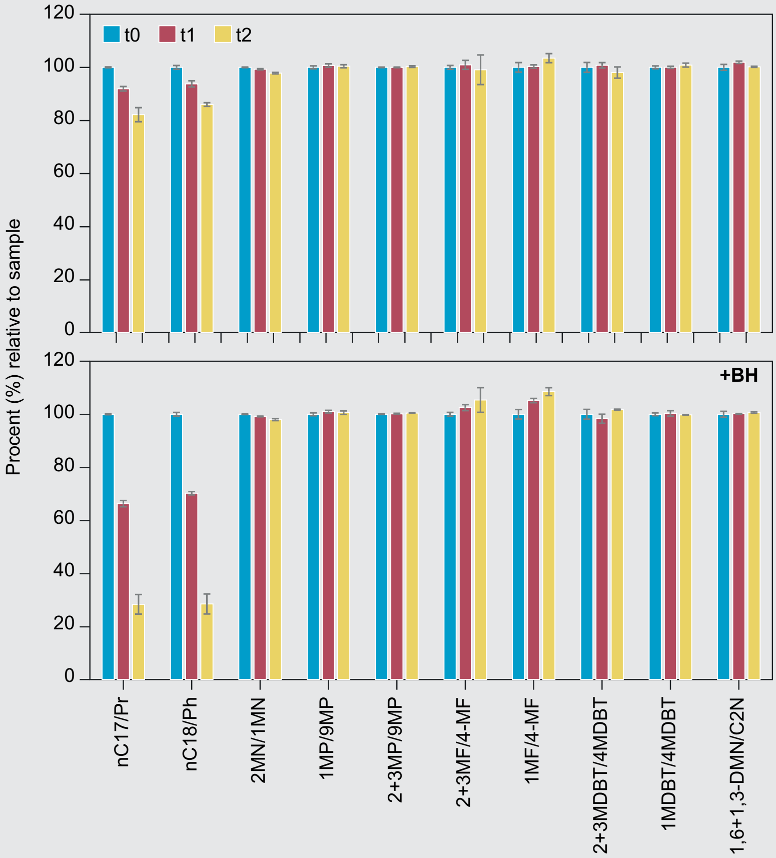

Figure 2.

Effects of nutrients and oil dispersion in water from a shelf break station (experiment 3)

We investigated how oil degraders in the water from station 70 at the shelf break responded to addition of oil, mineral nutrients and a dispersing agent. Without mineral nutrients, there was very little alkane removal and hardly any PAH removal in surface water, and substantial removal of only light *n*-alkanes in deeper water. Addition of mineral nutrients had a strong effect leading to complete *n*-alkane- and isoprenoid removal and removal of a large proportion of the alkylated PAHs (Figure 3). Degradability followed the normal patterns with decreasing removal with increasing number of rings in the PAH molecule and decreasing removal with increasing number of alkyl substituents within classes of PAHs (Wang & Fingas 1995, Wang et al. 1998, Kristensen et al. 2015). Oil removal was supported both by changes in isomer ratios and counts of cultivable oil degraders. The cultivable degrader community had a broad substrate spectrum with the ability to utilize hydrocarbons with different molecular structures that requires many different metabolic pathways. This corresponds well with the fact that petrogenic PAHs (C1-naphthalenes and C1-phenanthrenes) were present in sediments from the shelf break, suggesting some natural oil pre-exposure.

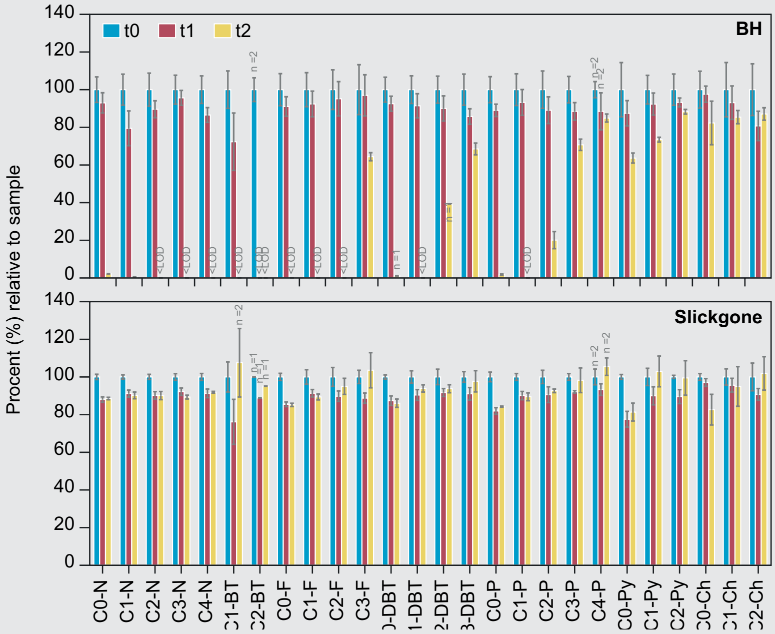

Figure 3.

Mineral nutrient limitation was stronger in the surface water than in the deeper water, probably due to nutrient depletion in the photic zone (Thingstad et al. 2008). The dispersion agent *Slickgone NS* was efficient at dispersing the oil. The increased oil surface area itself, however, did not stimulate degradation in the surface water, and stimulation was barely detectable when *Slickgone NS* was added together with mineral nutrients in microcosms containing water from greater depth.

Metabolic capacity for degradation of structurally diverse oil components in water from shelf stations (experiment 4)

In the fourth experiment, we determined the potential diversity of oil compounds that could be metabolized by oil-degrading microorganisms at the top, middle and bottom of the water column on the continental shelf. Microorganisms were extracted from the water samples and exposed to oil with excess mineral nutrients. All *n*-alkanes were efficiently removed, which was supported both by changes in alkane isomer ratios and large populations of cultivable *n*-hexadecane degraders. The results were more ambiguous for the alkyl-PAHs where changes in concentrations and isomer ratios were similar to abiotic controls. There was only few types of cultivable degraders in the water column compared to station 70, mostly *n*-hexadecane degraders. Lack of oil pre-exposure at the shelf stations, where the water originated, is the most likely explanation.

General conclusions

The concentration of alkyl-PAHs was low in sediments from the shelf break, but light alkyl-PAHs were detectable in trace concentrations, suggesting that the shelf break stations may have had some form of limited oil pre-exposure. Microcosms did show a large potential for biodegradation of many different oil compounds in the water column, even "difficult" compounds such as C1-pyrene and C3-phenanthrene were partially degraded after 90 days. This suggests, that bioremediation of surface spills in this area may have a large potential if the intrinsic microbial degraders can be activated.

Alkyl-PAHs were non-detectable in the shelf sediments, except trace amounts of C1-naphthalenes at the outer stations 27 and 29. The absence of other alkyl PAHs suggests that the shelf stations have had no oil pre-exposure. The potential for biodegradation of weathered PAHs in the shelf sediments was very low, even when mineral nutrients were not a limiting factor, which is in line with the absence oil pre-exposure. Water from within the shelf area also showed low degradability of especially the PAHs, which was confirmed by the absence of specialized oil degraders compared to the water from the shelf break.

The geologically relevant Statfjord model oil (Boertmann & Mosbech 2012) has a high content of paraffins, which makes it relatively easy for the indigenous microorganisms to degrade with respect to the *n*-alkanes and the smaller aromatics, given that there is sufficient mineral nutrients. The slow isoprenoid (phytane and pristane) degradation in many microcosms and the complete lack of cultivable 2,2,4-trimethylpentane degraders, however, suggest that branched paraffins may show higher persistence even when mineral nutrients are not limiting degradation. The lack of cultivable 1,3-dimethylcyclohexane degraders in all microcosms also suggests that the potential for naphthenic compounds is very limited even when the microbial communities have plenty of mineral nutrients and have had some in situ exposure to oil at the shelf break.

It was also clear that in situ concentrations of mineral nutrients are strongly limiting for oil degradation. Oil biodegradation will thus be very limited in the water column without addition of mineral nutrients. Contingency strategies based on the intrinsic potential for microbial oil removal should therefore include strategies for applying mineral nutrients for degradation to be efficient. The dispersing agent *Slickgone NS* was efficient at dispersing the oil under the tested conditions, but may have little effect on oil biodegradation when mineral nutrients are limiting, probably because degradation of the dispersant itself requires mineral nutrients.

In this chapter, measures to respond to marine oil spills are described. The focus is on Arctic and, in particular, Northeast Greenland conditions.

9.2.1 Oil spill response planning

The best way to mitigate oil spills is by prevention and mitigation. To prevent and avoid oil spill accidents from for example exploration drilling, the highest health, safety and environment (HSE) standards and technical standards (BEP and BAT) must be applied together with strict regulations by the authorities, and careful planning of the entire process.

Despite all the mitigation efforts, it is important to be well-prepared for a fast and robust response in case of an oil spill. This includes that the right equipment is in place, and that the oil spill responders are sufficiently trained to use it while avoiding risks for human health. Hence, besides the oil spill response equipment, it is important to consider HSE equipment for personnel as well as the supporting logistics including, e.g., residual/waste handling and containment, vessels (of opportunity).

If an oil spill occurs, the first priority is to stop and contain the out flowing oil, 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 to be protected 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, supports decisions regarding inclusion of mechanical recovery and in situ burning and chemical dispersants in the oil spill contingency plan by assessing the overall environmental mitigation obtained from each technology, segregated by season. The EOS also forms the base for a SIMA (Spill Impact Mitigation Assessment, formerly known as NEBA, Net Environmental Benefit Analysis) in the acute oil spill situation.

In West Greenland, the general practice has been to leave a time window for drilling a relief well before the winter ice stops the activities. If this is applied in the assessment area, the drilling season will be very short and even closed in the northern part of the assessment area, where sea ice is widespread also in summer.

9.3 Offshore oil spill response

In the following, the three overall oil spill response technologies will be described in an Arctic context including environmental pros and cons of the methods.

9.3.1 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 in some cases also act as a natural containment barrier to the oil.

A wide range of different containment booms and skimmers are available on the market. Most of the equipment is developed for open water (0-30 % ice cover) and non-arctic conditions. Such conditions might occur during the summer month in the southern parts of the assessment area. However, rest of the year, and in the northern part, sea ice will influence the response. 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. Also, 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).

Finally, oil in ice/snow is difficult to detect, so it is important to consider methods for detection of the oil.

9.3.2 Chemical dispersants

The principle of chemical dispersant is that by adding a chemical (the dispersant) to the oil slick the natural dispersion of the oil increases. With sufficient mixing energy the oil then breaks up into droplets less than 70 μm across which are mixed into the water column for possible further dilution and degradation (Blondina et al. 1999). A range of different products exist, 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 use of chemical dispersants in the Arctic, some critical parameters must be considered prior to the possible use, mostly in relation to the presence of ice and the low temperatures: In situations with ice, the contact between the oil and dispersant will be challenged, and the unit for spraying the dispersant should be selected carefully to fit the given conditions. The possible fate and environmental effects from dispersants not hitting the oil are still not known. Furthermore, sufficient mixing energy might be hampered by the presence of a dense ice cover. During field test in the Barents Sea, with around 60-70% ice coverage, it was found that applying chemical dispersant with a manoeuvrable arm from a vessel, and subsequently applying additional 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 2007a). 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 2007a). For oil that had been frozen into ice for three month, other research results have shown that the dispersibility of oil did not change during this period (Cedre 2016).

By the chemical dispersion, the oil is removed from the water surface, preventing sea surface-associated organisms to be smothered in oil as well as prevents the oil from beaching. But the concentration of oil will increase in the water column, potentially reaching toxic concentrations for organisms until the dispersed oil is diluted. The dilution rate depends on the dilution capacity of the oil spill site, e.g., water volume and water exchange. Thus, the environmental side effects from the use of dispersants are related to the (initial) increased toxicity in the upper water column from the oil and dispersant and oil / dispersant mixtures.

Another rationale behind using chemical dispersants (or mechanical dispersion, see below) is to facilitate natural degradation and thereby removing the oil from the environment. The potential for oil degradation in the Greenland Sea was studied in laboratory tests (Box 9.1), Johnsen et al. 2019). It was found that the in situ concentration of mineral nutrients was a limiting factor for the biodegradation. For oil dispersed with the dispersing agent *Slickgone NS*, the oil was dispersed effectively but the biodegradation was still limited. Hence, the authors suggested that if chemical dispersant are to be used as an oil spill response method in the assessment area, the strategy should also include 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.

9.3.3 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 – thickness depends on oil type (see Buist et al. 2013) as, for example, a sheen cannot be ignited – which could be achieved by the use of fire resistant booms, or in areas with dens ice cover (> 60-70%) where the ice acts as containment.

Studies have also been undertaken to investigate the effectiveness of herding agents. Herding agents are chemicals that, when sprayed around the oil slick, changes the interfacial tension of the oil/water resulting in a contraction of the oil to ignitable thicknesses (SL Ross & DCE 2015). The use of herding agents might have some potential for improving in situ burning operations, e.g., ignition and burning efficiency. 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 impacting seabed organisms. The environmental impact from the burn residue is still little investigated, however, there seems to be a tendency towards the residue being less toxic than the initial oil (Fritt-Rasmussen et al. 2015).

Based on field trials in Arctic ice-filled waters, in situ burning has shown a great potential, in particular since the cold and ice-filled conditions slow down the oil weathering and thereby expands the window of opportunity for burning. Other field studies under Arctic conditions showed that oil trapped in the ice may 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 being while contained in the ice, and thus the oil was still ignitable (NORCOR 1975). But it is still an open question how in situ burning can be applied and how effective it will be in dynamic drift ice such as the sea ice in the assessment area.

The environmental side effects of the method relates mostly to the generation of soot during burning, but also the residue (floating or sinking) may cause environmental impacts unless the residues are recovered. In the Arctic, the possible soot deposition on ice, resulting in reduced albedo and, hence, potentially increased melting of the ice cover, is an issue to consider.

9.3.4 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 second step where stranded oil and oiled shoreline material are removed and, finally, the third step, where the less contaminated sites are cleaned-up (ITOPF 2018).

In situ burning in the Artic is considered as an offshore response method, but a field study in Greenland has shown that it might be possible to burn a light crude oil at the coastline, and with relatively minor environmental impact. However, more work is required to fully understand the potential for coastline in situ burning and the environmental impacts with respect to, e.g. oil type (Fritt-Rasmussen et al. in prep.)

Ice and snow containing the oil may be scraped or pumped away. Another way to handle oil contained in snow is by burning. In a case where oil content in snow reached 70%, the oil was burned successfully (Buist 2000).

9.4 Oil spill drift simulations

Anders Mosbech (AU), Janne Fritt Rasmussen (AU) & David Boertmann (AU)

DMI has prepared a number of oil drift and fate simulations for hypothetical oil spills in the assessment area in relation to the first version of this SEIA (Nielsen et al. 2008). The purpose was to look into the possible spreading and areas of potential impact from an oil spill in the assessment area.

The simulations were carried out for three hypothetical spill sites, all located on the shelf of the assessment area (Figure 81). The locations were selected by the Geological Survey of Denmark and Greenland (GEUS) to represent potential sites for offshore well drilling. Of these three spill sites, the northernmost, seems today to be the most realistic site for future exploration drilling (Fyhn & Hopper 2020, GEUS 2020). However, the two spill sites further south, may represent sites where large spills may occur from accidents during transport of oil. The oil included in the simulations was Statfjord crude oil. This crude was selected by GEUS, from eight types in the DMI database, as the most representative oil potentially to be discovered in the assessment area. Statfjord crude oil is a paraffinic and relatively light oil type, API density 886.3 kg/m^3, and with a low content of asphalthenes (Faksness 2007). 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 2007). Statfjord crude oil is expected to produce relatively stable water-in-oil emulsions. This emulsifying process will double the volume of the spilled oil within 30 days at sea (Nielsen et al. 2008).

The influence of sea ice on the oil drift is implemented in the model. In presence of sea ice, wind-induced contribution to the oil drift velocity is scaled down by the ice concentration, so that in 100% ice cover, the wind drift is absent and only current drift are present. There is also no downward mixing, since surface waves are dampened strongly in the presence of an ice cover.

For modelling oil drift, three one-month wind periods were selected within the design year July 2004-June 2005 (August, October and April).

A total of 18 oil spill scenarios with continuous release were simulated: 3 release sites, 3 simulation periods (April, August and October) and 2 release depths (surface and seabed). For simulating continuous spills, oil was released at a constant rate during the first ten days of the simulation period. The amount of oil was released at a fixed rate of 3000 tonnes/day (in total: 30,000 tonnes). For comparison, one simulation of an instantaneous surface spill was carried out for each spill site. For simulating instantaneous spills, the amount of oil released was 15,000 tonnes, and the time was October. The amounts included represent very large spills with a very low probability of occurrence (see Chapter 7.3.1). The total simulation length was 30 days for all scenarios.

9.4.1 Sea surface area covered

Generally, no major differences in surface conditions between a continuous surface and a continuous bottom release was seen due to a fast buoyant rise of the oil in the DMI simulations. The slick area after 10 days covered 100-110 km^2, equivalent to a disc with a radius of 5-6 km. After 30 days, the slick radius has increased to 22 km, and the slick typically covered an area of 1400-1500 km^2 of very irregular shape.

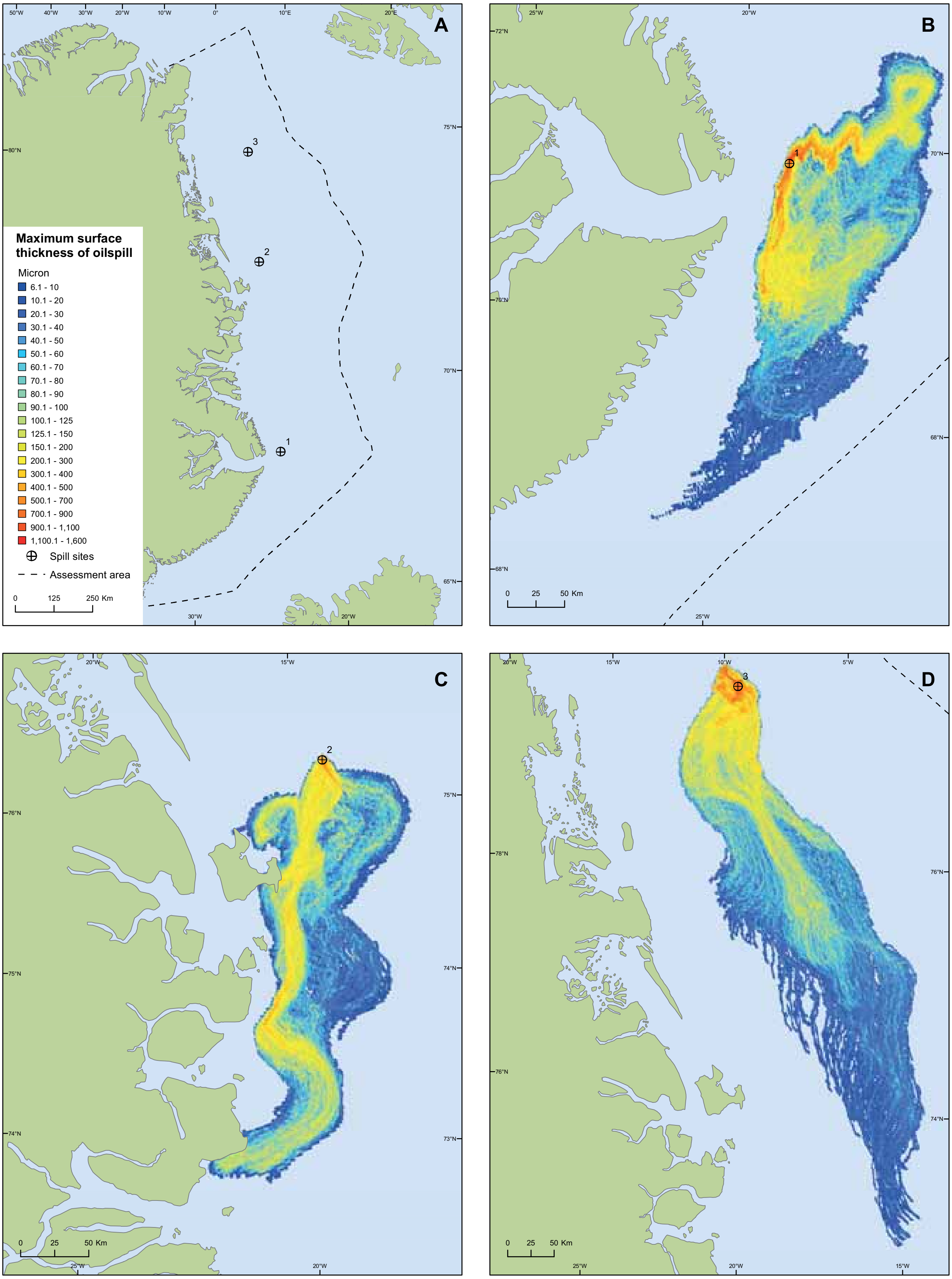

Figure 81. Examples of the DMI oil spill trajectory simulations (Nielsen et al. 2008). The maps B-D show the entire area swept by three different surface spills. The scale indicates the maximum thickness of the sea surface oil layer attained in the different cells during the 30 day simulation periods. Map A shows the four spill sites. Map B shows a continuous spill from site 3 in August 2004. Map C shows a continuous spill from site 2 in April 2005. Map D shows a continuous spill from site 4 in October 2004. Note that the oil spill in map C hits the coasts, the spill in map B almost do and that oil spill in map D is far from any coasts.

In the DMI simulations, most of the oil was still drifting in a thin layer at the surface after the 30 days modelling time. In calm weather, the oil stayed in a sheen at the surface, and the oil was mixed down only during periods of strong wind.

In practice, the oil will form isolated patches within this area, with regions of high concentration interspersed with regions with no oil at a given time. This means that the area actually covered with oil is smaller than figured, but the oil thickness can be higher. The model gives no indication of how much smaller the actual oil-covered area was.

9.4.2 Subsurface concentrations

In the DMI simulations, a maximum of about 12% of the oil was temporarily mixed down. The average mixing depth was 2 m or less. The maximum mixing depth of an oil particle was 11-20 m depending on the site and the wind period. Two April spills ended up in ice covered waters rather quickly, and were thus not mixed down.

9.4.3 Shores affected

By tracking all particles, the relative amount of oil settling on the shore as well as the lengths of shoreline affected were calculated. Only small amounts of oil settled on the coast or on the seabed. For a spill located far offshore, the coast would not be affected in any of the chosen wind conditions. Only two of the spills were predicted to reach the shore: One, from a spill site off Scoresby Sund in October, would reach the southern Blosseville Kyst, and one at approx. 75° 30′ N in April would reach the coastlines between Shannon and Hold With Hope.

9.4.4 The SINTEF oil spill drift simulations

In addition to the DMI simulations, SINTEF also ran simulations of continuous surface oil spills in the Greenland Sea (Johansen 2008). Where the DMI simulations were based on ice and weather conditions in a single "model year" (June 2004-July 2005), SINTEF ran statistical oil drift simulations with the OSCAR model, based on climatological currents and historical wind and ice data (23 years period). A total of 92 scenarios were simulated for each period (April-May, August-September, October-November) to provide data for oil drift statistics. This was accomplished by running four scenarios with spill start within the first month in each of the three periods for each 23 year in the available time series of wind and sea ice coverage. In each scenario, the oil was tracked for 30 days and spill locations and release amounts were the same as for the DMI simulations.

There are some agreements between SINTEF and DMI results for the offshore oil spill drift. However, in the SINTEF simulations, generally, a much larger part of the oil settled on the coast. A spill off the mouth of Scoresby Sund entered far into the fjord system (Figure 82), a trajectory not found by the DMI work. In the SINTEF model there was more than 5% risk of oiling (defined as more than 1 tonne oil per km) of more than hundred km of shoreline for an October/November blowout (Figure 83). The differences found in shoreline oiling between DMI and SINTEF simulations can be related to different weather and ice input data in the models, and differences in model approaches. A significant difference in the behavior of the two models was that the ice edge is not necessarily a complete barrier to oil drift in the SINTEF model.

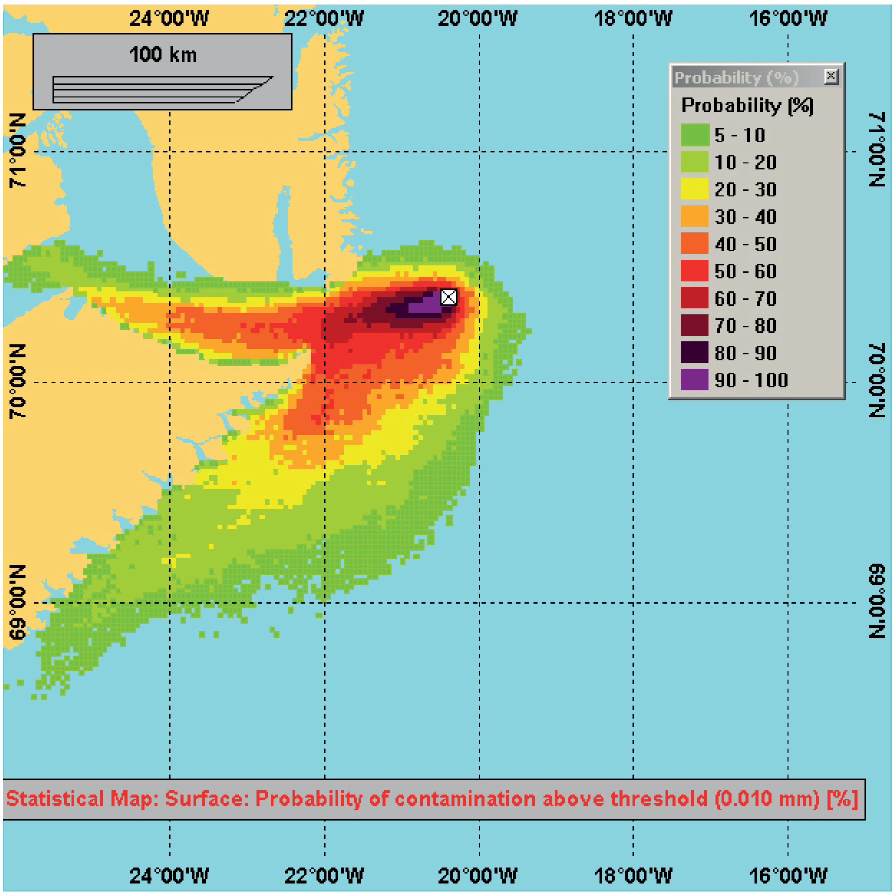

Figure 82. Tracking of an oil spill in October-November from spill site East 1 in the SINTEF modelling (Johansen 2008). The figure shows probabilities of oil on the sea surface.

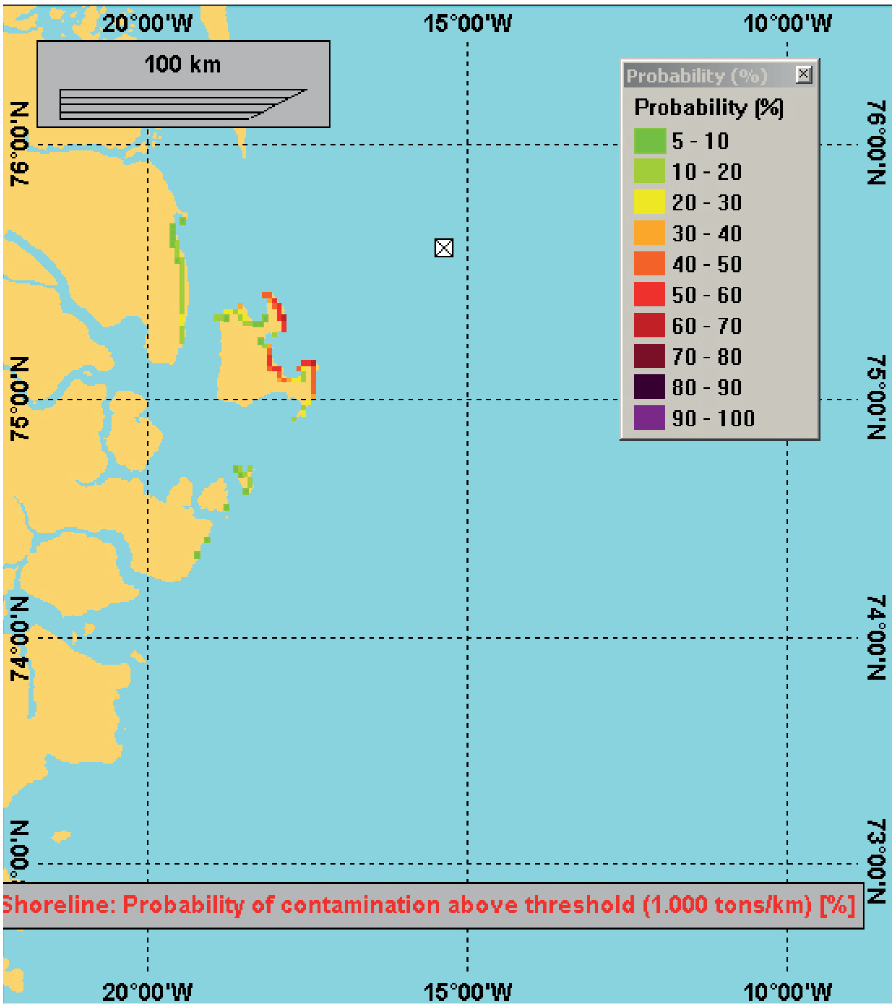

Figure 83. Shorelines affected by oil (more than 1 kg/m) from spill site East 2 in the SINTEF modelling (Johansen 2008). The legend shows the probability of oil on the coast.

To the extent that the current carry the oil under the ice, oil motion and trapping under the ice is also included in the SINTEF model. The SINTEF model has been updated since the work done in 2008 to be more suited for oil spill modelling in cold and ice-covered waters as described in Nordam et al. (2019, 2018). Nevertheless, the SINTEF model results might be more representative for a situation with less ice, which is expected to be more pronounced in the future, and as such, it is more likely the coasts and fjords systems might be affected by an oil spill as simulated by SINTEF.

The oil spill drift simulations presented by DMI and SINTEF were based on a predefined oil type, three predefined spill sites, and to some extent predefined weather and ice conditions. So the results should be considered as examples of what might happen during a large oil spill. However, it can be concluded that following a large oil spill, large sea surface areas will be swept by the oil due to spreading and drifting of the oil. This process however is much influenced by the oil viscosity and a different oil type could, for example, change the outcome significantly. The spreading of the oil is rarely uniform, but with large variations in oil film thickness, 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 30 days after a spill event and long stretches of shorelines can be polluted depending on the ice conditions.

9.5 Concluding remarks on countermeasures

Anders Mosbech (AU, Janne Fritt-Rasmussen (AU) & Jose Nymand (GINR)

Three overall countermeasures are available for combating oil spills in the marine environment: Mechanical recovery, chemical dispersion and in situ burning.

Mechanical recovery is very labour demanding, and field experiments in Arctic conditions have shown that high recovery rates are difficult to achieve. In addition, handling of recovered oil and water is quite difficult in offshore arctic areas. Relying on this method only for large scale oil spills will most likely be ineffective. Mechanical recovery is most relevant for minor spills in the assessment area.

To secure a successful in situ burning, oil slick thickness is one of the most important parameters. Fire resistant booms to contain the oil are not expected to be working in dynamic drift ice conditions. However, ice floes as well as herding agents can act as barriers containing oil into thicker films suited for burning. These methods have proved very successful in experiments (laboratory and field), but are not yet developed and implemented at full operational scale, and especially not for dynamic drift ice conditions. In situ burning might be an effective response option under conditions with static ice, and is expected to have a very limited window of opportunity in the assessment area.

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 (see below). Furthermore, there is a lack of knowledge about possible environmental effects of dispersed oil in the Greenland Sea. Finally, methods for applying dispersants to the oil between ice floes and secure sufficient mixing are still to be developed. 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.

Since the last SEIA for the Northeast Greenland Sea was completed in 2012, the large Arctic Response Technology Joint Industry Project has been undertaken to improve the Arctic oil spill response capabilities (Link). In spite of this effort and other studies in recent years, the available response methods have not yet proven effective during a realistic spill situation in dynamic drift ice as in the assessment area.

In 2017, the Arctic Council's Emergency Prevention, Preparedness, and Response (EPPR) Working Group commissioned a viability analysis to better understand how often weather and sea conditions may hinder or impede marine oil spill response systems in the Arctic. The analysis (Circumpolar Oil Spill Response Viability Analysis – COSRVA) was published in a report and recently, the results of the report was made available in an online portal (Link). COSRVA build on different metocean conditions: wind, waves (sea state), sea ice, air and sea temperature, and visibility. The sea ice dataset was prepared by the U.S. National Snow and Ice Data Center (NSIDC). The analysis can be carried on in areas defined by the user.

From this portal an extract of the viability of ten different predefined oil spill response systems for the assessment area were prepared and compiled in Figure 84. The numbers in the table reflect system operability that includes fraction of time with favourable[4], marginal[5] and impossible conditions. The result does not include information about the systems effectiveness, but solely on operational viability.

The analysis is here performed for an area including the northernmost release site in the oil spill drift modelling presented in Section 9.4. The results show that from November through April, only recovery methods which include the ice as a means of containment are viable and that these methods are operational for less than 20% of the period for mechanical recovery and 4% for dispersion and insitu burning. In November, the conditions will be marginal (blue) for 19% of the time with an ice-classified vessel equipped with skimmer systems adapted to icy conditions and when using the ice as containment. In the same period, only 2% of the time the conditions will be marginal (blue) for applying dispersants from a similar vessel. For the rest of this period the conditions will be impossible for oil recovery (grey). The analysis do not account for the capacity of the equipment or of the efficiency of the methods. Nor do it account for the remoteness of the spill site and the associated challenges bringing recovery equipment and manpower to the spill site.

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.

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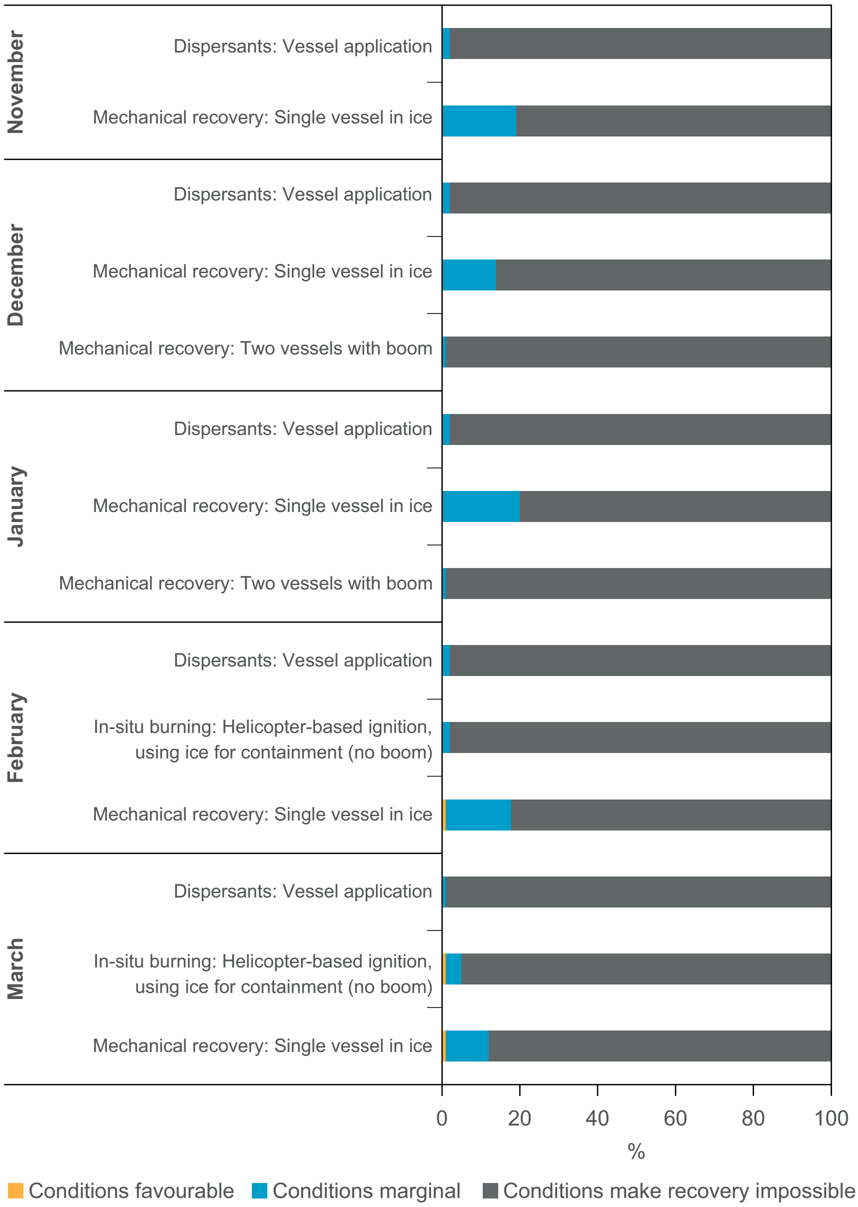
[4] Favourable conditions are when the tactic can be expected to be deployed safely and operate as intended

[5] Marginal conditions are when the tactic can be deployed but operations may be challenged or compromised

Figure 84. The result of the COSRVA-analysis carried out around the northern spill site in Figure 81A (% operability). The figure shows the results from the five winter months and shows only the few methods (out of ten) which may work under these winter conditions.



The 2017 studies found that that there is a potential for biodegradation in the water column at the shelfbreak if the intrinsic microbial degraders can be activated, but the degradation will be hampered by 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.

As oil spill response also is challenged by the dark winter period, the general weather conditions and the remoteness of the assessment area, it is likely that very little – if any – oil can be recovered in case of an oil spill in the ice-covered parts of the assessment area (cf. the COSRVA-analysis described above). The low intrinsic potential for natural degradation of spilled oil adds to increase the environmental impacts in a spill situation.

10 DCE and GINR recommendation on area restrictions

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10.1 Area restrictions

With the new information summarized in this report, it is now well documented that:

A. A large part of the Greenland Sea must be considered critical habitat for nationally and globally red-listed species. The Greenland Sea is also an especially important habitat for a number of high arctic species (see Table 9 and 10 and ecosystem and species accounts in Chapter 3). This applies for example to narwhal (both inshore and offshore) and bowhead whale (East Greenland-Svalbard-Barents Sea stock), globally classified as Near Threatened (NT) and Endangered (EN) respectively (and nationally as Endangered (EN) and Vulnerable (VU)). The drift ice serve as whelping areas for hooded seal, classified as Vulnerable (VU) and harp seal, and is also an important foraging area for polar bears, walrus and ivory gulls, the first two globally classified as Vulnerable (VU) and the latter as Near-Threatened (NT) (nationally as Vulnerable (VU), Near Threatened (NT) and Vulnerable (VU) respectively). With proliferating Arctic climate change and increased annual variability, the western Greenland Sea is expected to become increasingly more important to secure habitats for the high Arctic biodiversity, as the western Greenland Sea will continue to be a main outlet of drift ice from the polar basin for many decades ahead.

B. A large oil spill may cause significant mortality and long-term population effects for seabirds and some marine mammal populations in the Greenland Sea. If an oil spill hits coasts in the assessment area, the experiences from the *Exxon Valdez* spill indicate that impacts can be expected to last for decades (Chapter 7 and 8, Table 19).

C. Drift ice occurs in the northern part of the assessment area year round and in the southern part at least in winter and spring. Climate modelling predicts that the Greenland Sea will continue to be a main outlet of drift ice from the polar basin for many decades. However, the oil industry has not yet presented spill response technology and methods, which can effectively retrieve oil from a large spill in an environment with broken, drifting and refreezing ice conditions (see Chapter 8). The seasonal darkness and the remoteness of the area will further increase this challenge. The potential in the assessment area for natural biodegradation of oil following a large oil spill is moreover meagre (Chapter 8). Depending on oil type and circumstances, the oil will only slowly weather, dilute and disperse in the water column, which means that a large part of the oil may drift out from the spill area. It is likely that oil will be transported south along the Greenland coast with the prevailing current. Finally will oil stranded on the coast be very slowly degraded naturally, and this process may last for decades.

DCE and GINR recommended in their contribution to the oil and gas strategy 2020-2024 (Mosbech et al. 2019): *"A major oil spill in the sea may have major and long-term effects. Oil exploration drilling should therefore focus on safety. So far, practice has been that exploration drilling could only be carried out during the ice-free season and with a safety margin to the expected arrival of sea ice to ensure a sufficiently long operative window in case of blowout and oil spill. It is recommended to continue this practice and continue to set high standards for safety and oil spill response and preparedness in exploration drilling.*

No well-documented methods are yet available for handling major oil spill in drift ice and in the dark. As a result, considerable technological advancement is necessary before it can be considered environmentally safe to explore and exploit oil in Greenland offshore areas all year round.

The development and establishment of oil spill contingency plans and preparedness for the activities of the mineral resource industry is a substantial task, which is, however, also relevant for other ship traffic in Greenland. The development of an efficient strategy for combating oil spill requires technological advancement, research into any harmful effects of the oil and the control methods, analysis of vulnerable biological resources and mapping of the potential for degradation and spreading of oil in the various waters."

DCE and GINR also recommended that the areas north of 80° N in the Greenland Sea (and north of 75° N in Baffin Bay), and in three other areas, should be closed to oil and gas exploration for the next strategy period in order to safeguard the environment (Mosbech et al. 2019). This recommendation was based on an assessment of:

- The documented biodiversity values, which are of global significance.
- The sensitivity of key ecosystem components to a large oil spill and underwater noise.
- The lack of proven technology to significantly reduce underwater noise during exploration, development and production from an oil field.
- The lack of proven technology to manage a large oil spill in a sea covered with dynamic drift ice throughout the year in an area with seasonal darkness.

For this assessment, DCE/GINR have applied three selection criteria to identify areas recommend to be kept free from oil exploration in this strategy period (2020-2024):

Critierion 1: Especially valuable areas. These are the three areas recommended in the contribution to the oil and gas strategy 2020-2024 to be kept free from oil and gas activities (Mosbech et al. 2019). They are especially valuable on a national (and international) scale, in terms of ecological and biological importance and sensitivity to oil spills. One of these areas is located within the assessment area (see below).

Critierion 2: Distance to coast. Areas close to the coast are generally more likely to suffer long-time impact from an oil spill than offshore areas. The distance from the spill to the coast is therefore important, as increased distance also increase the time available to combat drifting oil and to naturally degrade and disperse the oil. When DCE/GINR assessed applications for licence blocks in Baffin Bay and Disko West in 2010 (NERI 2010), special focus was on on the distance to the coast, and it was stated that the protection of the coast from oil spill effects is especially challenging and that the requirements to oil spill response and preparedness should be especially stringent for licence blocks with distances less than 30 km to the coast (NERI 2010).

In the DCE/GINR contribution to the oil and gas strategy 2020-2024 (Mosbech et al. 2019), it was recommended that the demarcation of offshore license areas planned to be opened, should be given a specific environmental assessment, which in particular shall include the distance to the nearest coast, the vulnerability of the coast and the possibility of combating oil spills there.

Critierion 3: Areas covered with ice for a part of the year. While oil exploration can take place only in ice-free seasons, offshore production entails the risk of oil spills year-round (see Chapter 7). 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 spills in drift ice and in the dark. Further, the marginal ice zone and the polynyas in late winter and spring are particularly sensitive to oil spills due to the high primary productivity, which is the foundation of the high arctic marine ecosystems there.

In the DCE/GINR contribution to the oil and gas strategy 2020-2024 (Mosbech et al. 2019), the waters north of 80° N was recommended not to be opened for oil and gas exploration.

10.1.1 International environmental standards for area restrictions in relation to oil activities in seasonally ice-covered waters in the Arctic

In recent years there has been increased international concern for the environmental implications of oil industry activities in Arctic ice-covered waters. Only Russia seems to proceed with offshore licencing in such waters waters, and has currently offshore production in the seasonally ice-covered Pechora Sea.

In the US, there are no lease sales currently planned for the Arctic offshore areas in Alaska (PAME 2020). President Obama stopped considering leasing in Alaska's Arctic waters in 2016, and the Alaska's District Court decision in March 2019 overturned the portion of President Trump's executive order on offshore energy that would have opened the area again. Oil and gas production and exploration from existing licenses is taking place in shallow waters from gravel islands on the Alaska North Slope.

In Canada, the Nunavut Impact Review Board (NIRB) has in 2019 recommended to prolong the 5 year moratorium from 2016 on oil and gas development in Baffin Bay and Davis Strait for a decade (NIRB 2019a): *"Given the importance of the marine environment to the well-being of Nunavummiut, significant gaps in knowledge of the environment necessary to support impact assessment, and an overall lack of regulatory, industry, and infrastructure readiness in Nunavut, the 2016 moratorium on oil and gas development in the Canadian Arctic should remain in place for Baffin Bay and Davis Strait until such time as the key issues set out in this Report can be addressed. The Board expects that it will take at least a decade to complete the research, planning, and consultation identified as necessary prior to undertaking a reassessment by the Minister to determine if the moratorium should be lifted".*

Among 79 NIRB recommendations, several concern the environmental and societal risks related to large oil spills, and it is recommended to address many of these before lifting the current moratorium e.g. recommendation 32 (NIRB 2019b): *"Recommendation 32: Conduct baseline research to assess the capacity and infrastructure required to manage and respond to a well blowout or major spill in the Arctic and to determine whether an effective response can be mounted in remote locations under harsh weather conditions with periods of prolonged darkness and in the presence of ice".*

The European Parliament wrote in their resolution of 16 March 2017 on an integrated European Union policy for the Arctic (Link): *"Calls on the EU to promote strict precautionary regulatory standards in the field of environmental protec-*

tion and safety for oil exploration, prospection and production internationally; calls for a ban on oil drilling in the icy Arctic waters of the EU and the EEA and for promotion by the EU of comparable precautionary standards in the Arctic Council and for Arctic coastal states."

The Norwegian regulation is generally considered setting "the high international environmental standard" for oil producing countries. In the recent update of the management plans for Norwegian waters (Klima- og Miljødepartementet 2020), the parliament decided to keep the Barents Sea closed for oil and gas exploration north of a limit defined by sea ice occurrence in spring. The ice limit was defined by the presence of sea ice in 15% of the days in April, the month with the largest ice extend, based on ice data for the period 1988–2017. This will apply until management plans are updated, in 2024 at the earliest (Klima- og Miljødepartementet 2020):*" Ikke igangsette ny petroleumsvirksomhet i områder der det forekommer havis mer enn 15 prosent av dagene i april, beregnet på grunnlag av isdata for 30-årsperioden 1988–2017"* (p. 132).

However, the scientific recommendations for the update of the integrated management plans from The Norwegian Institute of Marine Research and the Norwegian Polar Institute were to use a limit defined by a frequency of only 0.5% of the days in April (based on ice data for the period 1988–2017) to indicate occurrence of ice. This takes into account the highly variable annual location of the MIZ and the uncertainty regarding the drift and behavior of oil spills in and near icy waters. The result is a limit situated further to the south than the 15% limit (Havforskningsinstituttet 2020, Norsk Polarinstitutt 2020): *"Menneskelige aktiviteter nær iskantsonen som kan gi negativ påvirkning på miljø eller dyreliv er heftet med usikkerhet. Som det presiseres i Faglig Forum's grunnlag for revisjon av forvaltningsplan for Barentshavet er det for eksempel få faktiske analyser om drift av oljesøl inn mot is og i tillegg lite erfaringer med oljesøl i is, så usikkerheten rundt dette er stor og vanskeliggjør risikovurderinger. Siden konsekvensene er heftet med betydelig usikkerhet, men muligens store for økosystemet i Barentshavet knyttet til is, bør sannsynligheten for overskridelse være lav. For å sikre en helhetlig og bærekraftig forvaltning av iskantsonen og dyrelivet som er helt avhengig av dette sårbare og høyproduktive området, har HI derfor anbefalt å avgrense iskantsonen til maksimal sørlig utbredelse observert i perioden 1988-2017, det vil si der man finner 0,5% isfrekvens slik som definert i Faglig forum for norske havområder (2019)"* (Havforskningsinstituttet 2020).

Regarding coastal sensitivity to oil spills, the coast of mainland North Norway is considered vulnerable to oil spills and a 35 km zone from the coast is closed for oil and gas exploration. At coasts considered particularly vulnerable (such as the coasts of the island Bjørnøya) this zone is 65 km (Klima- og Miljødepartementet 2020).

10.1.2 DCE/GINR identification of areas according to the three criteria

On the basis of the three criteria described above and the current international standards, DCE/GINR recommend the following:

Criterion 1: Especially valuable areas
Within the assessment area, the Scoresby Sound area including the fjord complex, the polynya and the coasts of Liverpool Land and northern part of Blosseville Coast has been recommended to be kept free of exploration (Mosbech et al. 2019). The information provided in this updated assessment supports this recommendation (Figure 85).

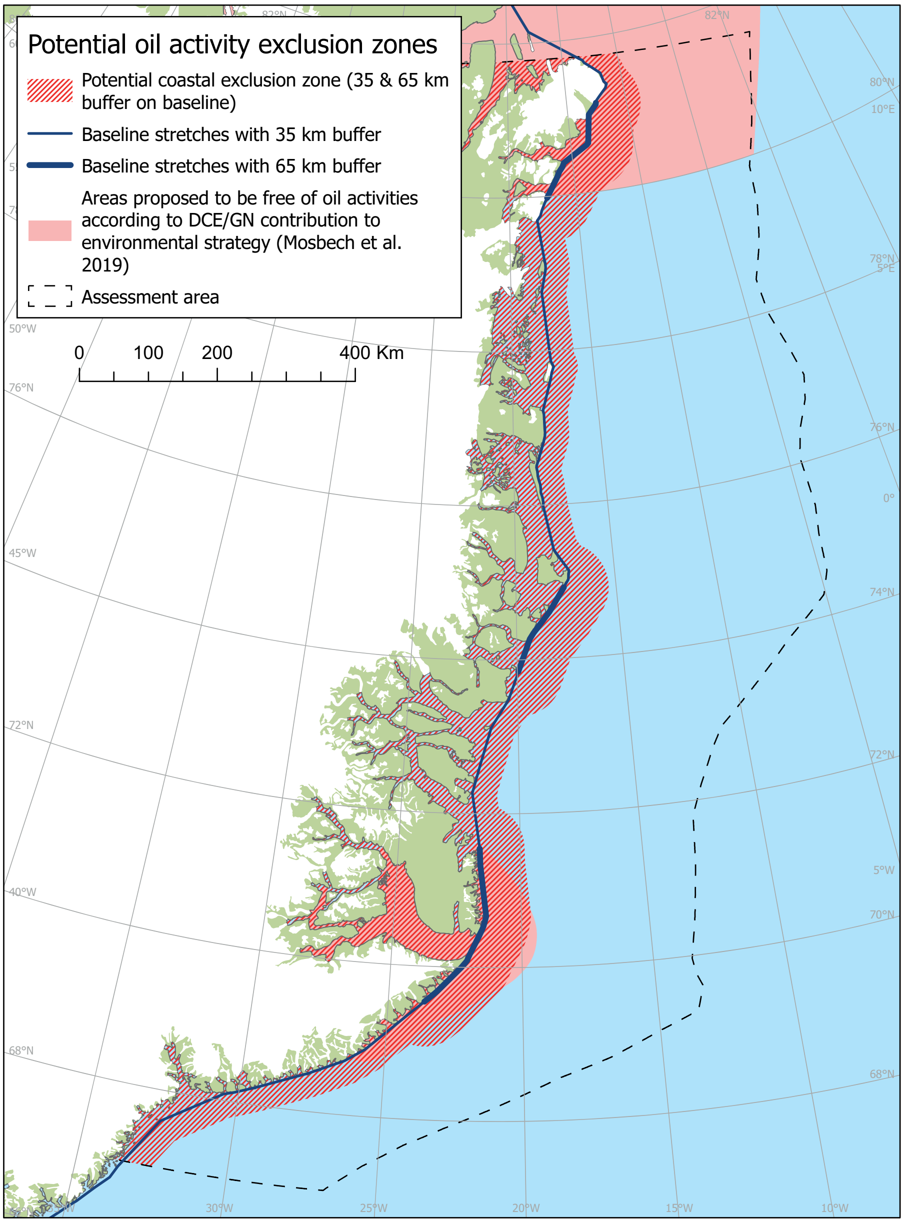

Figure 85. DCE/GINR propose to keep the entire assessment area closed for oil exploration in this strategy period (2020-2024) based on new Norwegian environmental standards (see conclusion). However, using less strict criteria, not fully accounting for the lack of capability to combat oil in ice, a zonation (related to sensitivity of oil spills and disturbing activities) of the assessment area could be applied. This could for example be based on the Norwegian 35 and 65 km exclusion zones shown here and combined with the proposed closed area north of 80° (Mosbech et al. 2019). The 65 km exclusion zone is applied to particularly sensitive coasts.

Criterion 2: Distance to coast

Outside the area identified according to criterion 1, DCE and GINR recommend to apply the Norwegian criteria for distance to coasts in the Barents Sea. Based on these criteria, DCE and GINR recommend an exploration free 35 km coastal zone in most of the area and a 65 km zone off the coast with high numbers of breeding seabirds, walrus haul-outs and areas used by the local human population (Figure 85). The baseline define the coast.

Criterion 3: Ice cover

In Figure 86, the Norwegian criteria for defining an exclusion zone based on ice frequency in March and April is applied. Both the 15% frequency limit decided by the Norwegian parliament, and the 0.5% frequency limit recommended by the research institutions (see above) include the entire assessment area – except for some small areas to the east, which is outside the 15% limit. Figure 86 shows both the March situation, when the ice has its largest distribution off East Greenland and the situation in April, which is the month with maximum ice cover in the Barents Sea.

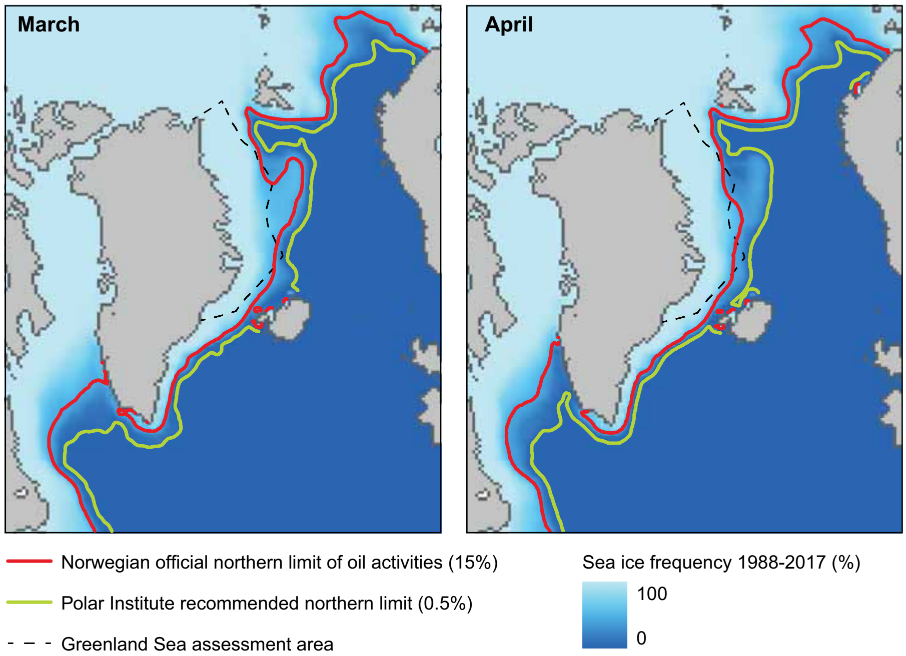

Figure 86. In Norway, the politically agreed northern limit of oil activities is currently set at 15% frequency of ice cover in the month of peak ice cover in the Barents Sea (April), based on a 30 year time series of sea ice data (1988-2017). However, the Norwegian Polar Institute has recently argued that the threshold should be lowered to 0.5% probability of ice cover in April, based on new data on the ecological importance of the marginal ice zone. In the map to the right, we have calculated both of these threshold values for Greenland waters in April, using the exact same methods and data as in Norway (Itkin et al. 2014). Since ice cover in Greenland generally peaks in March, we have also performed the calculation for March (map to the left).

A relevant question is then if the ecological conditions of the Barents Sea and the waters off Northeast Greenland can be compared? The most significant ecological features in the Barents Sea are 1/ the Polar Front, where cold and Arctic waters meet warmer Atlantic waters and 2/ the Marginal Ice Zone (MIZ). The spatial position of the MIZ is highly variable. The primary production is very high at the MIZ in the Barents Sea, attracting fish, seabirdsand marine mammals (Quillfeldt 2017). The Barents Sea moreover supports an extensive fishery. The situation off Northeast Greenland are in some respects similar to the Barents Sea, with a MIZ and with fronts between warm and and cold water bodies. However, the primary production is much lower (see Chapter 3.1) and the fishery is limited (Chapter 6.2.2). A significant difference is the presence of sea ice also in summer at least in the northern part of the assessment area and of large and biologically important polynyas (Chapter 2.3.4). Another important difference is that the high Arctic ecosystem of the Greenland Sea assessment area is almost undisturbed by human activities. The Norwegian regulation focus on protecting an area with high productivity including ecosystem services and socioeconomic interests, while the protection of the assessment area will focus on unique and undisturbed biodiversity.

As there are yet no proven methods available for handling major oil spill in drift ice and in winter darkness, and as research and development of such method are halted after the major oil companies have withdrawn from the Arctic, DCE/GN recommend to apply the Norwegian 15% criteria for ice frequency in the assessment area as a limit for further oil exploration in the present strategy period (2020-2024).

10.1.3 Conclusion on area restrictions

DCE/GINR recommend to consider not to open the Greenland Sea assessment area for oil exploration in the present strategy period (2020-2024). This recommendation is based on the assessment of the biodiversity values, the ice conditions and the lack of capability to handle major oil spills in most situations, as described in the present assessment. DCE/GINR have applied the Norwegian criteria, used in the Barents Sea, for delineating the acceptable ice cover for oil activities in the Greenland Sea. The recommendation is thus considered to be in line with high international (Norwegian) standards. If other criteria are applied or improved oil spill countermeasures in icy waters are developed, the situation will be changed and a new assessment may lead to another recommendation. This could for example – if less strict criteria are applied – include a zonation (related to sensitivity of oil spills and disturbing activities) of the assessment area, where different means of regulation and management of activities are applied (cf. Figure 85).

10.2 Information needs

Following the recommendation above there is a need to develop effective large-scale methods for countermeasures to oil spill in dynamic drift ice. Drift ice occurs in the northern part of the assessment area year round and in the southern part at least in winter and spring. No methods for large-scale countermeasures to spilled oil in drift ice have yet been proven effective, and it is recommended that exploration drilling and production of oil should not be initiated before such methods are developed. In addition, there seems to be a need for developing new technology for safely drilling in heavy drift ice conditions.

The results of the *Strategic Environmental Study Program for Northeast Greenland* have given much better information on the key questions:

- Delineation of seasonal areas to protect marine mammals in relation to noise from seismic exploration and other sources,
- Identification of the areas and periods most sensitive to oil pollution, and
- Evaluation of the net environmental benefit of oil spill countermeasures.

To supplement this information, if oil activities commence, studies to obtain a higher resolution of the sensitivities in time and space would be recommended within a smaller region, including:

- Polar cod ecology: the polar cod is a key ecological element and a clearer understanding of the key spawning areas (under variable and changing ice conditions) and variations in timing (phenology) is needed, because eggs and larvae assemble just below the ice, where they can be exposed to spilled oil and produced water.
- Mapping of sensitive habitats on the sea floor, in particular the distribution of sea pen and coral habitats discovered in 2017 should be further investigated.
- The shelfbreak has been identified as an important ecological element of the assessment area – due to its high production and significant concentrations of several animal species – and there is a need for more detailed understanding of the seasonal variations in sensitivity.
- Studies of the oceanography and ecology of the Scoresby Sund Polynya in order to understand the seasonal sensitivity of this ecological important area.

In addition, it is recommended that the specific chemicals to be used and discharged during offshore operations should be tested and evaluated under Arctic condition, both in relation to toxicity and degradation.

When planning oil activities, it is recommended to initiate Integrated Marine Spatial Planning based on an ecosystem approach (PAME 2019). Present and future uses of the marine environment along with environmental sensitivities should be considered for future research.

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Annex A: List of species: common and scientific names

Birds – common name (alphabetical)	Latin / scientific name	Fugle – dansk navn
Arctic tern	*Sterna paradisaea*	Havterne
Atlantic puffin	*Fratercula arctica*	Lunde
Barnacle goose	*Branta leucopsis*	Bramgås
Black guillemot	*Cepphus grille*	Tejst
Black-legged kittiwake	*Rissa tridactyla*	Ride
Brent goose	*Branta bernicla*	Knortegås
Common eider	*Somateria mollissima*	Ederfugl
European shag	*Phalacrocorax aristotelis*	Topskarv
Glaucous gull	*Larus hyperboreus*	Gråmåge
Great northern diver	*Gavia immer*	Islom
Gyrfalcon	*Falco rusticolus*	Jagtfalk
Harlequin duck	*Histrionicus histrionicus*	Strømand
Herring gull	*Larus argentatus*	Sølvmåge
Ivory gull	*Pagophila eburnean*	Ismåge
King eider	*Somateria spectabilis*	Kongeederfugl
Knot	*Calidris canutus*	Islandsk ryle
Little auk	*Alle alle*	Søkonge
Long-tailed duck	*Clangula hyemalis*	Havlit
Northern fulmar	*Fulmarus glacialis*	Mallemuk
Pink-footed goose	*Anser brachyrhynchus*	Kortnæbbet gås
Red phalarope	*Phalaropus fulicarius*	Thorshane
Red-breasted merganser	*Mergus serrator*	Toppet skallesluger
Red-necked phalarope	*Phalaropus lobatus*	Odinshane
Red-throated diver	*Gavia stellate*	Rødstrubet lom
Ross's gull	*Rhodosthetia rosea*	Rosenmåge
Sabine's gull	*Xema sabini*	Sabinemåge
Skuas	*Stercorarius spp.*	Kjover – flere arter
Snow goose	*Anser caerulescens*	Snegås
Snowy owl	*Bubo scandiaca*	Sneugle
Thick-billed murre	*Uria lomvia*	Polarlomvie

Mammals – common name (alphabetical)	Latin / scientific name	Pattedyr – dansk navn
Bearded seal	*Erignathus barbatus*	Remmesæl
Blue whale	*Balaenoptera musculus*	Blåhval
Bowhead whale	*Balaena mysticetus*	Grønlandshval
Fin whale	*Balaenoptera physalus*	Finhval
Harp seal	*Pagophilus groenlandicus*	Grønlandssæl
Hooded seal	*Cystophora cristata*	Klapmyds
Humpback whale	*Megaptera novaeanglia*	Pukkelhval
Killer whale	*Orcinus orca*	Spækhukker
Long-finned pilot whale	*Globicephala melas*	Grindehval
Minke Whale	*Balaenoptera acutorostrata*	Vågehval (sildepisker)
Narwhal	*Monodon Monoceros*	Narhval
Northern bottlenose whale	*Hyperoodon ampullatus*	Døgling
Polar bear	*Ursus maritimus*	Isbjørn
Ringed seal	*Pusa hispida*	Ringsæl
Sei whale	*Baleanoptera borealis*	Sejhval
South American sea lion	*Otaria flavescens*	Søløve
Southern elephant seal	*Mirounga leonine*	Sydlig søelefant
Sperm whale	*Physeter macrocephalus*	Kaskelot
Walrus	*Odobenus rosmarus*	Hvalros
White-beaked dolphin	*Lagenorhynchus albirostris*	Hvidnæse

Fish – common name (alphabetical)	**Latin / scientific name**	**Fisk – dansk navn**
Amberjack	*Seriola sp.*	Ravfisk
American plaice	*Hippoglossoides platessoides*	Håising
Arctic char	*Salvelinus alpinus*	Fjeldørred
Arctic cod	*Arctogadus glacialis*	Istorsk
Atlantic cod	*Gadus morhua*	Torsk
Atlantic halibut	*Hippoglossus hippoglossus*	Helleflynder
Atlantic herring	*Clupea harengus*	Sild
Atlantic hookear sculpin	*Artediellus atlanticus*	Atlantisk havulk
Atlantic mackerel	*Scomber scombrus*	Makrel
Arctic staghorn sculpin	*Gymnocanthus tricuspis*	Glatulk
Bigeye sculpin	*Triglops nybelini*	Knurulk
Blue whiting	*Micromesistius poutassou*	Blåhvilling
Bluefin tuna	*Thunnus thynnus*	Blåfinnet tun
Capelin	*Mallotus villosus*	Lodde
Greenland halibut	*Reinhardtius hippoglossoides*	Hellefisk
Gelatinous snailfish	*Liparis fabricii*	Ringbug
Greenland shark	*Microcephalus somniosus*	Grønlandshaj
Lanternfish	*Benthosema glaciale*	Isprikfisk
Ling	*Molva molva*	Lange
Lumpfish	*Cyclopterus lumpus*	Stenbider
Monkfisk	*Lophius piscatorius*	Havtaske
Pacific herring	*Clupea pallasii*	Stillehavssild
Ribbed sculpin	*Triglops pingeli*	Knurulk
Polar cod	*Boreogadus saida*	Polartorsk
Redfish	*Sebastes spp.*	Rødfisk
Roughhead grenadier	*Macrourus berglax*	Skolæst
Saithe	*Pollachius virens*	Sej
Sandeel	*Ammodytes spp.*	Tobis
Sculpin	*Myxocephalus Scorpius*	Ulk
Spotted wolffish	*Anarchichas minor*	Plettet havkat
Tusk	*Brosme brosme*	Brosme
Yellowfin tuna	*Thunnus albacares*	Gulfinnet tun
Zebrafish	*Danio rerio*	Zebrafisk

Annex B: Abbreviations and acronyms

AAW	Arctic Atlantic Water
AMAP	Arctic Monitoring and Assessment Programme, working group under Arctic Council
ANS	Aquatic Nuisance Species
API	American Petroleum Institute gravity
APNN	Ministry of Fisheries, Hunting and Agriculture, Government of Greenland
AR	Assessment report
ASP	Arctic Science Partnership
AU	Aarhus University
AVISO	Archiving, Validation and Interpretation of Satellite Oceanograph-ic data
BACI	Before-After-Control-Impact
BAT	Best Available Techniques
bbl	Barrel of oil
BC	Black carbon
BEP	Best Environmental Practice
BFR	Brominated flame retardants
BIOS	Baffin Island Oil Spill study
BMP	Bureau of Mineral and Petroleum, Greenland Government
BTX	Benzene, Toluene and Xylene components in oil, constitute a part of the VOCs
BTEX	Benzene, Toluene, Ethylbenzene and Xylene, constitute a part of the VOCs
CEFE	Centre d’Ecologie Fonctionelle Evolutive, France
CFR	Chlorinated flame retardants
CI	Confidence interval
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
DCE	Danish Centre for Environment and Energy
DDC-CO	Dechlorane Plus
DDT	Dichloro-Diphenyl-Trichloro-ethane
df	Degrees of freedom
DFHA	Department of Fishery, Hunting and Agriculture
DMI	Danish Meteorological Institute
DPC	Danish Polar Centre
dw	Dry weight
EAC	Environmental Assessment Criteria
EAMRA	Environmental Agency for Mineral Resources Activities, Govern-ment of Greenland
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
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
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
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)
LIENS	Littoral, Environment and Societé, France
LRTAP	Convention on Long-Range Transboundary Air Pollution
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 (Government of Greenland)
MMO	Marine Mammals Observer
MMSO	Marine Mammals and Seabird Observer
MOS	Marine Oil Snow
MPM	most probable number
NAO	North Atlantic Oscillation
NEBA	Net Environmental Benefit Analysis
NAFO	The Northwest Atlantic Fisheries Organisation
NEG	Northeast Greenland
NEW	Northeast Water Polynya
NOW	North Water Polynya
NGO	Non-Governmental Organisation
NMDA	N-methyl-D-aspartate
NPP	Net Primary Production
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
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
PSW	Polar Surface Waters
PTS	Permanent elevation in hearing threshold shift
RAW	Return Atlantic Water
rms	Root mean squared
RoHS	Restriction of Hazardous Substances Directive
RSF	Resource Selection Functions
S	Salinity
SBM	Synthetic based drilling mud
SCCP	Short-chained chlorinated paraffins
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
SSOR	Subsurface Oil Reservoirs
SVHC	Substances of Very High Concern
T	Temperature
TAB	Thule Air Base
TAC	Total Allowable Catch
TBT	Tributyltin
TEK	Traditional Ecological Knowledge
TOPAZ	The MyOcean Arctic Forecasting Center, Norway
TPH	Total Petroleum Hydrocarbons
TPT	Triphenyltin
TTS	Temporary elevation in hearing threshold
TUNU	TUNU Euro-arctic marine fishes – diversity and adaptation, The Arctic University of Norway
uPDW	upper Polar Deep Water
UNECE	The United Nations Economic Commission for Europe
USCG	United States Coast Guard
USEPA	United States Environmental Protection Agency
US-NMFS	US National Marine Fisheries Service
UW	University of Washington
VEC	Valued Ecosystem Components
VOC	Volatile Organic Compounds
VME	Vulnerable marine ecosystems
VSP	Vertical Seismic Profile
WAF	Water-accommodated fraction
WBM	Water based drilling mud
WSF	Water Soluble Fraction
ww	Wet weight

Annex C: Strategic environmental study plan

The information needs identified in the previous edition of this strategic environmental impact assessment (SEIA) were assembled into a study plan in 2013 – the *Strategic Environmental Study Plan for Northeast Greenland* – which should provide the necessary environmental information for planning and regulating oil exploration activities and oil spill response in the western Greenland Sea.

The study plan described the major information gaps at the overall strategic level, corresponding to those identified in the SEIA, and proposed high priority-studies to fill in these information gaps.

The study plan included projects on marine ecology, biodiversity as well as toxicology and degradation of oil and contaminants, an oil spill sensitivity atlas and finally this updated SEIA. The projects focused on the entire Greenland Sea assessment area, and took advantage of international research initiatives like the Norwegian projects on marine discharge effects of petroleum-related activities (Research Council of Norway 2012), and the Arctic Science Partnership (ASP) between GINR, Aarhus University and University of Manitoba/Arctic Net. Thus providing strong linkages and synergies between relevant arctic research institutions.

Three key questions

With increasing oil exploration activities in the Greenland Sea more information on the ecology and temporal and spatial sensitivity of this very little studied marine ecosystem was needed for environmental planning and regulation, in order to meet the goal of minimal environmental impact.

Information was most urgently needed to properly deal with the following three operational key questions:

#1: How to conduct and regulate increased **seismic** activities in the Greenland Sea so that significant impacts from **underwater noise** on marine mammal populations are avoided or minimized?

While the present knowledge had been considered adequate for regulating seismic activities at the current level of activity in the Greenland Sea, there was, with expected increasing seismic activity, a high level of uncertainty and a risk of significant impacts on certain whale populations. This should be addressed with specific studies.

2: How to regulate **discharge of drilling mud and chemicals** from exploration drilling in the Greenland Sea, so it is certain that significant impacts are avoided, and the best solution is selected based on specific information on toxicity and degradation in the High Arctic environment?

While the general OSPAR guidelines have successfully minimized the footprint of the oil industry in temperate regions, there was uncertainty whether these guidelines in their present form were adequate in high arctic regions. The BMP strategy on the discharge issue (Link) reflects this concern, which is also on the agenda in OSPAR committees. There was a need for specific studies to address toxicity and degradation rates in the high arctic Greenland

Sea, before applications for discharge could be considered in a proper science-based evaluation process.

#3: How to minimize the environmental impacts if an **oil spill** occurs based on:
- Planning of exploration activities so the most sensitive areas and periods are avoided.
- Planning of oil spill preparedness and response, so efficient and environmentally beneficial response options for the Greenland Sea are available and can be selected operationally using a Net Environmental Benefit Analysis (NEBA).

While the available biological environmental information compiled in the previous SEIA for the western Greenland Sea gave an overall picture of the most sensitive areas and periods, there were large caveats and lack of important detailed spatial information. This lack of information could cause increased ecological damage in case of an oil spill, because the optimal response strategy could not be selected. Therefore there were a need for specific detailed information on biological hotspots and their sensitivity as well as for the environmental implications of the different response options and shoreline clean-up strategies. Specifically, there was a need for information on the environmental implications of use of dispersants and in situ burning, which potentially could be important response options in the Greenland Sea.

With these three key questions as a starting point, the study plan was developed with workshops to identify the projects which could help address the questions based on a broad ecological knowledge.

A short justification for the selected projects are given below listed under a number themes:

Project theme: Identification of offshore hot spots; biodiversity, productivity and food chain relations
To support the understanding of the High Arctic marine ecosystem and assess the potential for cascade effects induced by discharges from oil exploration activities or oil spills, knowledge on the pelagic productivity and food web is essential.

Specifically there were a need for identification of areas and periods where there are zooplankton or fish larvae concentrations in the upper water column with implications for the use of oil spill dispersants. It was proposed that an interdisciplinary survey was planned and performed based on modelling potential areas of high sensitivity using the existing knowledge.

The pelagic ecosystem is fundamentally supported by planktonic organisms. Zooplankton has an important role within marine food webs since it provides the principal pathway to transfer energy from the primary producers, phytoplankton, to consumers at higher trophic levels, e.g., fish and their larvae, marine mammals and seabirds. Most of the higher trophic levels in the arctic marine ecosystem rely on the lipids that are accumulated in species of especially the copepod genus *Calanus*. Although copepods are typically predominant in Arctic marine systems, there is a broad assemblage of other holoplanktonic groups and their role has yet not fully been understood.

The assessment area is highly heterogeneous in terms of ice cover and thus also primary productivity may be highly patchy resulting in hot spots. Large parts of the area is dominated by heavy drift ice throughout most summers, leading to relatively low productivity, and causing logistical challenges for scientific studies. Existing studies have thus concentrated on three areas where the open-water season is longer and productivity is (expected to be) higher: (i) the Northeast Water Polynya (NEW), (ii) the extensive fjord systems along the East Greenland coast, where only Young Sound has been subject to detailed scientific studies, and (iii) the marginal ice zone in the Greenland Sea. To supplement the existing knowledge the major activity of this study proposal were a 3 week ship based survey around 1st September, closely integrated with synoptic aerial surveys for seabirds and marine mammals. Thus, the proposed study was an integrated biological oceanographic ship based and airplane based survey, linking the physical oceanography with the lower trophic levels and the distribution of fish (including acoustic fish abundance survey) seabirds and marine mammals.

The project was conducted in 2017 combined with aerial surveys of marine mammals and seabirds and pelagic ecology coupled with a number of other projects.

Project theme: Fish; diversity, abundance and identification of key spawning areas

The most important fish species seen from an ecological point of view, is the polar cod. It is a key species in the marine food web, serving as a primary food resource for seabirds and marine mammals. Polar cod will be very susceptible to oil spills in ice covered waters and potentially also to release of untreated production water. Information on abundance, location of spawning areas, and vulnerability of egg, larvae and adult fish to oil components in the water will be highly relevant as background information in NEBAs and when EIAs of exploration drilling and establishment of production facilities shall be prepared.

The fish fauna of the waters off NE Greenland is poorly known in all aspects – diversity, abundance, range of species, ecology etc. There are no commercially exploited stocks in the assessment area, except for Greenland halibut in the waters close to Iceland. However, this may change with increasing water temperatures, thus a better baseline on the fish fauna was needed.

It was proposed to conduct a study with focus on the ecological most important species: the Polar cod. The project identified the species composition, abundance and distribution of the fish fauna in the assessment area in the Greenland Sea, to support the identification of the areas that are most vulnerable to oil spill. The project combined acoustic survey, bottom trawl hauls and sampling of environmental DNA (eDNA).

Project theme: Benthic flora and fauna; biodiversity, productivity, food chain

Intertidal and subtidal zones

In case of an oil spill, the risk of the oil beaching is imminent. Hence the intertidal and subtidal zones are especially exposed to effects of oil spills and based on experience from e.g. the spill in Prince Williams Sound (*Exxon Valdez*) these habitats are also having the most long-lasting impacts. Thus to identify important or critical areas a robust baseline knowledge on tidal and subtidal community diversity and structure is essential.

Shorelines with a rich primary production are of high ecologically importance. The vegetation of the shoreline zones, the macro-algae, is benthic and perennial and hence provides a key baseline. The tidal and subtidal canopy of macro-algae is important for higher trophic levels of the food web by providing substrate for sessile animals, shelter from predation, protection against wave action, currents and desiccation or directly as a food source. Because of strong biological interactions in rocky intertidal and kelp forest communities, cascades of delayed, indirect impacts of oil spills (e.g. biogenic habitat loss and changes in prey-predator balances due to species specific mortality) may be much more severe than a direct impact of oil contamination.

Investigation of the marine benthic flora in the assessment area were scarce and had mainly been conducted as random floristic studies in late 1800 and early 1900. A few more recent and systematic studies of the macro-algal flora had been conducted at Mestersvig and in Young Sound. However, no studies on macroalgal communities had been performed on the Greenlandic east coast. It was thus proposed to study the algal communities at different latitudinal coastal sites to support identification of the most important and sensitive areas as well as shoreline clean-up strategies.

Benthic macro-fauna
The benthic macro-fauna is a key element in the functioning of the marine ecosystem. The macro-fauna process a major fraction of the organic material settling from the water column and thereby link primary production in the water column to higher trophic levels as the benthic organisms provide a vital food source for fish, birds and marine mammals. The benthic habitats and benthic communities of the assessment area have not presently been mapped and the biodiversity, community structure and the sensitivity to environmental stressors like offshore activities is not well known.

The environmental focus in the exploration phase is the impact of discharges during exploratory drilling and the potential impact of oil spills.

To minimize the impact of discharges during exploratory drilling the operating companies must undertake environmental baseline studies at their drilling sites. These studies include benthic sampling and under water video surveys. Based on these studies especially sensitive habitats like cold water corals and sponge gardens will be identified and discharges in these areas can be avoided. Furthermore the environmental baseline studies will also contribute to the general mapping of the benthic communities in the activity areas.

However, systematic sampling of benthic fauna at a regional scale is necessary for mapping community heterogeneity, which knowledge is essential to regulate and evaluate the scope of the drilling site environmental baseline studies, as well as optimizing sampling design if needed. Therefore a benthic sampling program in conjunction with studies of hydrography, water chemistry, pelagic biology, birds and mammals was proposed.

Benthic fauna identification support system
As part of the environmental baseline studies performed by the companies around the drilling locations, the benthic data collected to describe the benthic fauna communities in the areas are submitted to the database for biological data housed and maintained by DCE/GINR. However, the knowledge for identification of the benthic fauna connected to soft bottom, epi- and infauna in the assessment area, is sparse, difficult to access, and at the same time the investigations conducted so far indicate a high species diversity. These are factors contributing to complicate identification work and increase the need for quality assurance to avoid submission of erroneous identification. DCE thus recommended that the quality assurance on identification work was improved, by amending the DCE biological database to include search functions to:

- Check the identification correctness in a checklist based on earlier registrations of the species in the area.
- Verification of species identifications based on photo material of identified species collected in Greenland

These actions will assure that the continuously gathered data and knowledge will be available and provide as a tool and assistance for species identifications to the oil companies and their consultants. The possibility to have species identifications verified will strengthen the quality assurance of data submitted to the DCE/GINR biological database. Therefore a project delivering ID support and database development was proposed.

Project theme: Marine birds; identification of offshore hot spots, coastal abundance and foraging areas, top predators

Seabirds are very susceptible to oil on the water, and high mortality has been observed where oil spills have affected areas where seabird concentrates on the water. Information on seabird concentrations areas (hot spots) and the factors governing their presence is therefore essential operational environmental information. Seabird concentrations on coastal waters in NE-Greenland are known around breeding colonies, which are located in high concentrations at polynyas, and from spring staging areas also mainly in polynyas.

However, while the knowledge on location of breeding colonies is fairly good, the number of birds in the colonies is mostly rough estimates as many have been observed only during surveys from aircraft. There were furthermore limited knowledge on the key foraging areas used by the colonies.

There were also limited information on concentrations of seabirds at sea off NE Greenland. However, some information existed from the seismic surveys and from tracking studies of e.g. little auks. In the migration season concentrations must be expected as vast numbers from breeding sites on Svalbard and to a lesser degree also from Russia migrate through the region both in spring and autumn. Important questions to answer were if these migrating seabirds stage in the area, and if they do when, where and why will important concentrations occur?

Knowledge on seabird occurrence is essential for preparing EIAs, contingency plans and oil spill sensitivity maps and projects on offshore concentrations and key foraging areas were proposed.

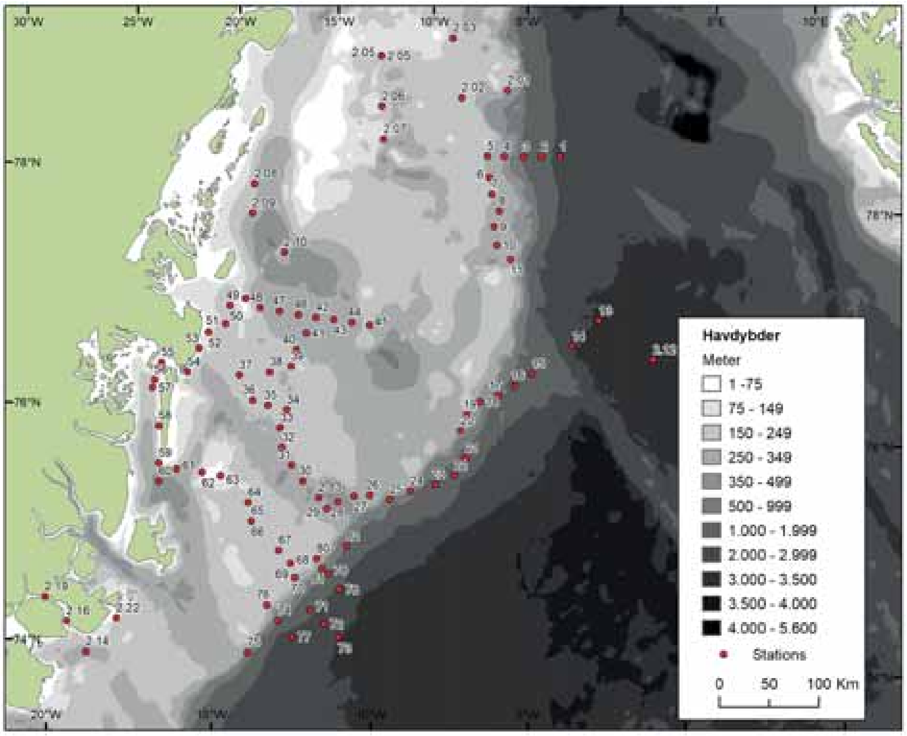
Project theme: Marine mammals (seals, whales, walrus, polar bear); hot spots, distribution and habitat use, top predators, effects of seismic exploration

Marine mammals are generally sensitive to noisy activities like seismic surveys and to oil spills, and oil activities may scare away populations from critical habitats, permanently or temporarily depending on the activity.

The most sensitive among the resident species in NE Greenland are walrus, narwhal and bowhead whale. Among the summer visitors, especially blue whales will be sensitive.

The most important knowledge gaps related to narwhals and bowhead whales: abundance, distribution, habitat use, concentrations areas (hot spots) etc., and effects of seismic surveys, which is essential background information for the environmental management of the operations.

Figure 1. Map showing the area surveyed in August and September 2017. The red dots indicated sampling stations, and seabirds and marine mammals were recorded on the legs between these stations. The legend show depth of the sea (havdybder).



Passive acoustic monitoring: To mitigate the effects of an oil spill, it is important to understand the distribution and seasonal occurrence of marine mammals in the area. A study of passive acoustic monitoring (PAM) with a widely spread array of acoustic recorders across the license area was proposed to provide insight to the seasonal occurrence and spatial distribution of the marine mammal species that are acoustically active. The calling rate of marine mammals provides information on behaviour and interspecific communication. It was also proposed to use PAM to investigate the effect of seismic activities by analysing the calling rate of marine mammals during seismic activities and without.

Aerial surveys: This project utilized visual aerial surveys to study the occurrence of marine mammals in the East Greenland licensing area. The information obtained have provided a baseline for managing seismic and oil exploration activities in the Greenland Sea and it is an important first step towards

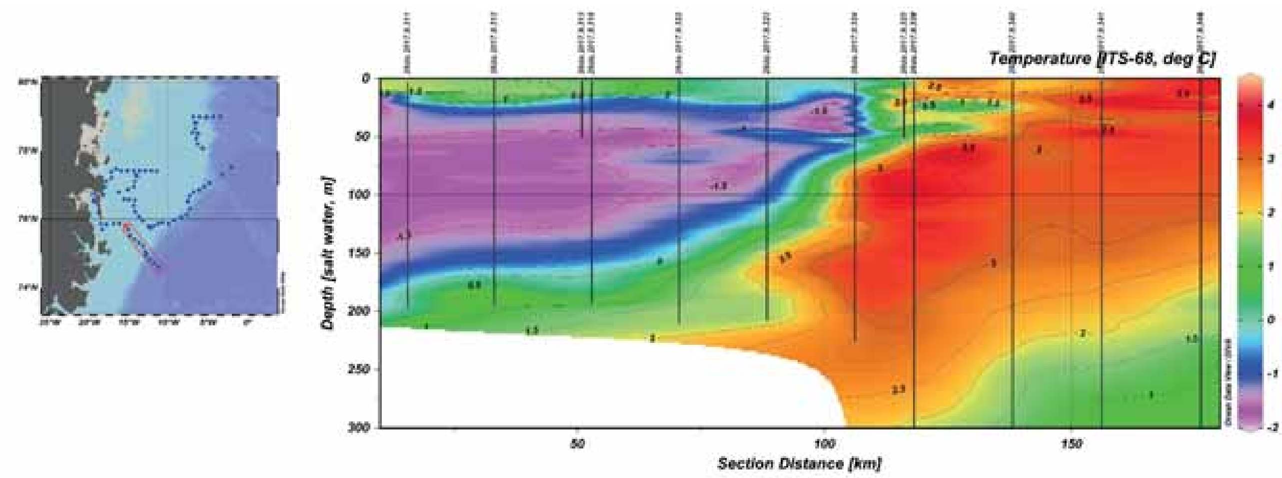


Figure 2. This figure shows the temperature in the water column (cross-section) along a transect from the continental shelf and over the continental slope (the transect is indicated by a red rectangle on the small map). A sharp temperature gradient is visible where cold polar water closest to Greenland (blue) and the warmer Atlantic water (orange) in the deeper part of the Greenland Sea meet. This gradient indicate a dynamic front zone.

identifying areas that are of critical importance to marine mammals in East Greenland.

Bowhead whale: Bowhead whales, narwhals and walrus have discrete populations in the East Greenland assessment area where isolated stocks and subpopulations persist. All three species are to various degrees considered vulnerable to industrial activities. The Northeast Water was hypothesized to be an important wintering area for all three species, but direct evidence of winter abundance of marine mammals was missing from this area. This project aimed at assessing the importance of this northern part of the assessment area as a wintering ground for marine mammals. The objectives of the proposed study were to estimate the abundance of endangered bowhead whales, narwhals and walruses and, if possible, other concentrations of marine mammals, in winter on the Greenland Shelf part (<500 m) in the Northeast Water.

Bowhead whales in the East Greenland assessment area constitute a separate, very small and potentially endangered stock. They are considered to be vulnerable to industrial activities but very little is known about their whereabouts. This project will track individual whales to monitor their seasonal movements within the licensing area. The information obtained will be useful for minimizing conflicts between seismic exploration and bowhead whales in East Greenland.

The project proposed:
- Used satellite tracking to map the seasonal movements of bowhead whales within the assessment area in East Greenland
- Used data on occurrence of bowhead whales to identify important concentration areas for bowhead whales in East Greenland

Effects of seismic exploration on narwhals: Narwhals are considered highly sensitive to human activities. This project focused on the effects from seismic shooting on narwhals.

The projects proposed aimed to:
- assess the short-term effects of sound from seismic airgun pulses on narwhals in a closed fjord system in East Greenland,
- acquire knowledge about narwhal movements in response to airgun pulses that can be applied to disturbance scenarios in both East and West Greenland as well as in offshore areas,
- provide an empirical basis for regulation of activities linked to seismic exploration in areas with narwhals,

Figure 3. Gardens of cold water corals *Keratoisis* sp. at 1100 m depth on the eastern margins of the continental shelf. Note that tentacles on the polyps are open and actively filtering. The hexactinellid sponge below is an *Asconema*, probably the species foliatum.

- examine the reception of high-frequency sounds from narwhals on acoustic recorders located close to where narwhals tracked by satellite transmitters will pass.

Harp seal pups: Harp seals and hooded seals give birth on the pack ice in the assessment area during March and early April. Studies using satellite-linked data recorders have been carried out on adult harp- and hooded seals and on hooded seal pups from the Greenland Sea populations, but not for harp seal pups. To gain knowledge about the habitat use, movements and diving behaviour of harp seal pups from the Greenland Sea population satellite-linked data-loggers were attached to harp seal pups, by gluing them to the fur. The data-loggers collected data about dive-depths, time spent at various depths and on the sea ice (haul-out behaviour) and data about the temperature at depth. The position of the tagged seal was determined based on the uplinks from the transmitter to the satellites.

Ringed seal: The ringed seal is a key species in the marine ecosystem. They are the main prey for polar bears and hence largely determine the distribution of this top predator. To gain knowledge about the habitat use and movements of ringed seals that inhabit the waters off NE Greenland various satellite relay data loggers (SRDLs) were glued to the fur of ringed seals. These state-of-the-art data-loggers collect position data, behavioural data (time spent on the ice, time spend at various depths and various dive characteristics) and oceanographic data on temperature and salinity at depth.

Polar bear: The sub-population of polar bears in East Greenland utilizes the fast ice and offshore pack ice along the entire East Greenland coast, including the Fram Strait, the Greenland Sea, and the Denmark Strait. The size of the population is unknown despite a subsistence harvest, and there is limited exchange with other populations. In this study it were proposed to capture and satellite track polar bears in the assessment area, and to assess the population

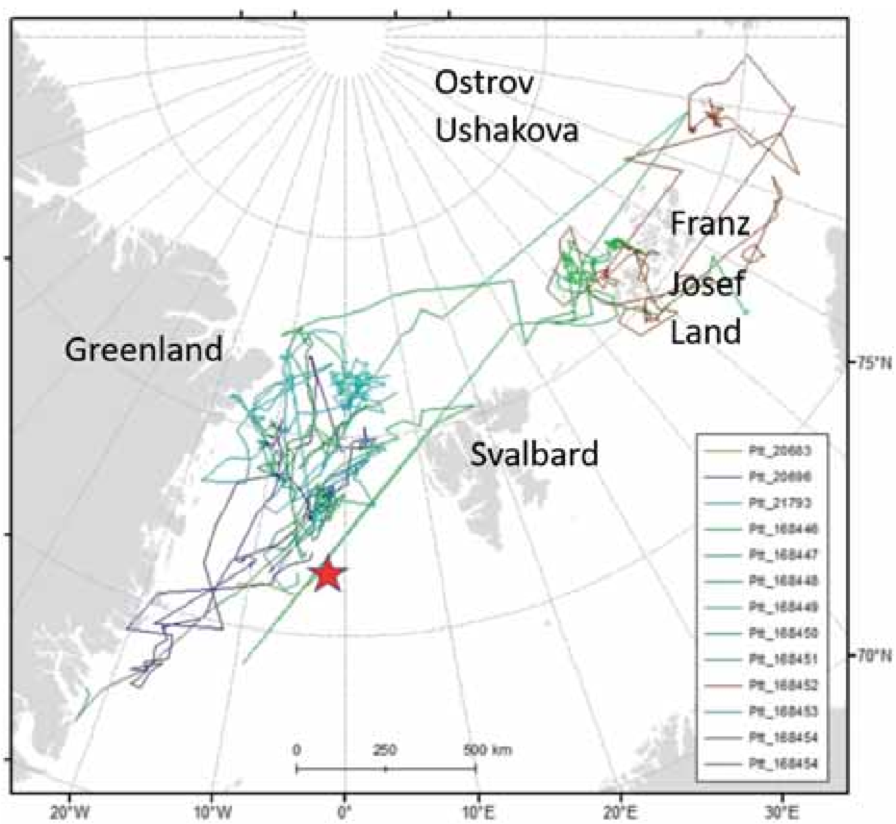


Figure 4. Tracking 12 bowhead whales from June 2017 for a period of one year (although not all were tracked for the full year). The star marks the spot where they were tagged.

size of the East Greenland sub-population using an aerial survey and predictive spatial modelling.

Project theme: Development of methodology for evaluating chemicals in drilling fluids and mud used and potentially discarded in high Arctic waters

While the general OSPAR guidelines have successfully minimized the footprint of the oil industry in temperate regions, there is uncertainty whether these guidelines in their present form are adequate in high arctic regions. The recent draft DCE/BMP strategy on the Environmental Assessment and disposal of drilling fluids and drilling chemicals reflects this concern, which is also on the agenda in OSPAR committees. At present standard toxicity test are used in the OSPAR classification, but there is a need for specific studies to address toxicity and degradation rates at relevant temperatures in the high arctic Greenland Sea before applications for discharge can be considered in a proper science-based evaluation. This will enable regulation of discharge of drilling mud and chemicals from exploration drilling in the Greenland Sea, so there is certainty that significant impacts are avoided, and the best solution is selected based on specific information on toxicity and degradation in the high arctic environment. The purpose of the project was to strengthen the basis for evaluation and regulation of chemicals in drilling fluids and mud for use and discharge of in high arctic water.

Project theme: Microbial degradation of oil, including evaluation of dispersant application

It is important to understand to what extend microbes could play a key role in the degradation of an oil spill in the offshore oligotrophic waters in the assessment area. It could be an optional strategy for remediation of an oil plume to use and potentially enhance the intrinsic bioremediation potential of microorganisms to degrade the oil. Such strategy depends on a number of environmental factors, including presence of microorganism representatives

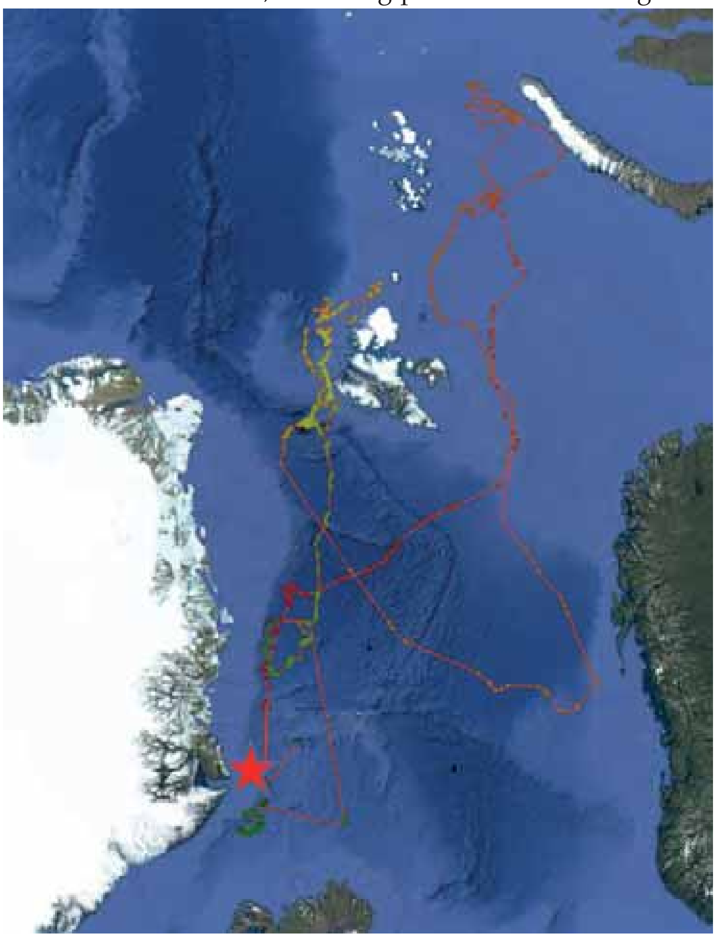


Figure 5. The route of a harp seal tracked over one year.

that degrade hydrocarbons or are stimulated by the presence of oil in cold environments, thus a favourable response of indigenous microorganisms to an increased concentration of hydrocarbons and/or dispersant. Another important factor is nutrient limitation. In the case of the Macondo accident in the Gulf of Mexico, microbial respiration within the slick was enhanced by approximately a factor of five and an incubation experiment to determine hydrocarbon degradation rates confirmed that a large fraction of this enhanced respiration was supported by hydrocarbon degradation. Extrapolating these observations to the entire area of the slick suggested that microbes had the potential to degrade a large fraction of the oil as it arrived at the surface from the well. However, a concomitant increase in microbial abundance or biomass was not observed in the slick, suggesting that microbial growth was nutrient limited.

Identifying presence of microorganisms already adapted to degradation of hydrocarbons as well as a possible degradation rate in relation to nutrient availability and application of dispersant in the assessment area would add valuable information regarding the area's ability of bioremediation, and hence to analysing response strategies.

Project theme: In situ burning (ISB) of oil spills in high arctic ice covered water

Oil spills in high Arctic waters with sea ice are connected with great challenges and are often more difficult to handle than oil spills in open waters. This is primarily due to the ice, as it complicates the accessibility to the spill site and makes conventional methods impossible/less efficient e.g. the application of chemical dispersants to the oil and the following mixing is made difficult by the presence of sea ice, which also challenge/preclude mechanical recovery of the oil. The remote location, darkness for many months of the year and lack of infrastructure also add to the challenges of dealing with an oil spill in the Greenland Sea. For removal of oil spill in waters with drifting ice in situ burning (ISB), where oil is burned directly on the sea surface, is the response technique with the most promising potential. During burning the oil is often kept together by fire resistant booms or, in icy waters, ice floes can be used, to secure an ignitable thickness and a continuous slick. The presence of ice, can also contribute to reducing the weathering of the oil, thus enlarging the window of opportunity for an ISB operation. Burning effectiveness higher than 90 % has been found under the right circumstances (fresh oil and thick oil slick) but also weathered oils can be ignited with high removal effectiveness. In spite of the research during the last 30-40 years there is still a need for more knowledge to manage the method wisely in an oil spill response. This also includes knowledge about the composition and toxicity of the residues from an ISB-operation in ice covered waters which is largely unknown.

Therefore a project was proposed which included controlled laboratory experiments to investigate the composition and environmental effects of ISB residues. These results could make the basis for conditions for acceptance of the method to be included in an oil spill contingency plan for offshore activities in the NE Greenland.

If the oil becomes trapped under the drifting sea ice, almost nothing can be done to respond to the oil spill. Therefore a second ISB project was proposed to investigate the possibility of igniting oil trapped under the sea ice through a hole bored in the ice. This has the potential to improve the possibilities of responding to an oil spill in areas with dense ice cover.

Project theme: Oil spill sensitivity atlas
Danish Centre for Environment and Energy (DCE) and Bureau of Minerals and Petroleum (BMP) have developed an Environmental Oil Spill Sensitivity Atlas covering West Greenland off shore waters and coastal areas, and here mapped areas particularly sensitive to oil spills. In this project it was proposed to extend the atlas to cover Northeast Greenland. The atlas is prepared to provide oil spill response planners and responders with tools to identify resources at risk, to establish protection priorities and to identify appropriate response and clean-up strategies. The atlas enables oil companies and authorities to incorporate environmental considerations into exploration and contingency plans.

The atlas will provide an overview of such aspects as the occurrence of wildlife, human resource use (fishing and hunting) and archaeological sites that are particularly sensitive to oil spills. Furthermore it contains information regarding the physical environment – coastal types, oceanography – logistics and oil spill response methods. Based on these parameters as well as the total environmental information the coastline oil spill sensitivity is classified in 4 categories (low, medium, high and extreme).

Annex D: Strategic Environmental Study Program for Northeast Greenland, summary of the project results

This annex gives a summary of the results of the projcts under the *Strategic Environmental Study Program for Northeast Greenland.*

The overall plan was to provide the necessary environmental information for planning and regulating oil exploration activities and oil spill response in the western Greenland Sea (See Annex C). The plan included projects on marine ecology, biodiversity as well as toxicology degradation of oil and contaminants, an oil spill sensitivity atlas, and an updated SEIA (present document). The plan focused on three key questions:

1. How to conduct and regulate increased seismic activities in the Greenland Sea so that significant impacts from underwater noise on marine mammal populations are avoided or minimized?
2. How to regulate discharge of drilling mud and chemicals from exploration drilling in the Greenland Sea, so it is certain that significant impacts are avoided, and the best solution is selected based on specific information on toxicity and degradation in the high Arctic environment?
3. How to minimize the environmental impacts if an oil spill occurs based on:
   a. Planning of exploration activities so the most sensitive areas and periods are avoided.
   b. Planning of oil spill preparedness and response so efficient and environmentally beneficial response options for the Greenland Sea are available and can be selected operationally using a Net Environmental Benefit Analysis (NEBA).

Mapping ogf biodiversity and identification of ecological hotspots

A number of the projects were dedicated to defining which areas are of particular importance to ecosystems and key species in the area (described in sections 1.1-1.11). They yielded important knowledge of areas in particular need of protection, and when these areas are vulnerable to activities related to oil and gas exploration and exploitation.

The western Greenland Sea (off Northeast Greenland) is important for a number of high Arctic mammals, especially bowhead whale, narwhal, walrus, harp seal, ringed seal, hooded seal and polar bear, as well as Arctic seabirds such as ivory gull, Sabine's gull, thick-billed murre, northern fulmar and little auk. Their presence and numbers were surveyed from the air in summer and winter. By continually monitoring mammal communications using acoustic buoys, a better understanding of the presence of whales throughout the year was obtained. To understand how animals use the habitats and their migrations, several species were tracked using data loggers (GPS transmitters and geolocators). Results are avialable or will be available in the following publications:

The lower levels of the food chain can also be vulnerable to oil activities, and the distribution of marine mammals and sea birds depend on the availability of such foods in the sea. The marine food chains were therefore studied during an expedition with the research vessel 'Dana' (Figure 1). Samples and measurements of phyto- and zooplankton and fish were taken in the water column, along with video recording and sampling from the sea bed. Moreover were ocenographic parameters such as water temperatures and salinity measured.

The many results has provided new knowledge about the assessment area, and supplemented by satellite image analysis and results from other studies, some remarkable new results have been found on the distribution of key species and biodiversity. The most important results are summarised in the following sections, 2.1 – 2.11.

Phytoplankton

The highest production of phytoplankton was found where the upper water layers mix with water from the deeper parts above the shelf break/continental slope), and where a dynamic front zone is located. The upper 100 m of the water column on the bank was dominated by low-nutrition polar water from the north, whilst the deeper water in the column consisted to a larger degree of Atlantic water from the east and southeast (Figure 2). Results can be found in Møller et al. (2019).

Zooplankton

The same pattern was also found in the next link of the food chain, where the highest densities of zooplankton were found in the dynamic front zone along the continental slope. It was also apparent that Arctic species dominate in the polar water, whilst Atlantic species were more numerous close to the deeper areas of the Greenland Sea. A large element of the dominant zooplankton was still present in the upper water layer in September. This is of major importance to larger animals such as birds, fish and bowhead whale. Results can be found in Møller et al. (2019). **1.3 Fish**: A total of 36 different species of fish were collected. The fish were generally small, and only a few species and individuals of commercial interest were collected. Arctic cod was by far the most common species among adult fish and larvae. It was found in the highest densities along the continental slope, where the density of plankton was also highest – a key element in the food chain here. Close to land above the continental shelf, the density of Arctic cod was lower and the fish fauna was dominated to a greater degree by others species. Results can be found in Jørgensen et al. (2019) and Bouchard (2020).

Benthic fauna

Surveys of the seabed fauna and surface sediment at depths of between 66 and 1460 m were conducted. The seabed consisted of clay and was very uniform throughout most of the sampling stations. Almost 100% cover of small stones was found at many stations. This indicates erosion rather that sedimentation takes place – the light sediments have been washed away by the currents. Genarally, few animals were found, mainly annelids and crustaceans. In West Greenland the biomass of annelids and crustaceans is around 10 times higher, and the density of individuals is around 4 times higher. But the biodiversity in the two systems are almost the same. Results can be found in Hansen et al. (2019a).

Cold water coral

Of particular interest and importance for the conservation of the area were some larger species of animals (epibenthic megafauna) and cold water corals. These were recorded using underwater video and samples. They included the over 2 meter high giant sea pen (*Umbellula encrinus*) and bamboo corals (*Keratoisis*) located in dense "gardens" at depths of approx. 1000 m on the soft bed of the continental slope (see Figure 3). These organisms have a very high conservation value and are extremely sensitive to mechanical disturbance of the seabed, e.g. trawling. The estimated age of some of the individuals of the two species was >40 and >100 years for the sea pen and bamboo coral respectively, and their growth is extremely slow. This indicates that the area is totally undisturbed, making it unique in a global perspective. The bamboo coral gardens and their associated epifauna constitute biomass hot-spots. The gardens of bamboo corals are preserved in pristine and undisturbed conditions, they are extremely important for the seafloor biodiversity, and they are extremely vulnerable. They are therefore of particular conservation concern. As far as is known, this is the first record of cold water corals on the continental shelf off Northeast Greenland. See also Box 3.2 in the present report and Hansen et al. (2019).

Bowhead whale

Bowhead whales in the area belong to a population found in the sea from East Greenland, past Svalbard to Franz Josef Land. At the end of the 20th century, this population was very small and regarded as critically endangered, but is now under recovery. The sea off Northeast Greenland has always been an important habitat for this species, which is why it was selected as one of the species whose occurrence was to be studied in more detail. A number of bowhead whales were observed in the 'Northeast Water' polynya in 2009, why this area was surveyed in 2017 with two counts, one in March during the winter, and one in August/September during the summer. Both counts resulted in an estimated population of approx. 300 whales, a number which indicates the importance of the area to this species. Twelwe bowhead whales were fitted with data loggers as part of another project, which made it possible to follow their movements for up to one year (Figure 4). These whales stayed mostly on the continental shelf off Northeast Greenland – including several in the Northeast Water. Two of them also undertook long journeys past Svalbard and all the way east of Franz Josef Land to the island of Ostrov Ushakova (Figure 4). Results can be found in Hansen et al. (2019b) and in Figure 4.

Surveys using acoustic buoys (passive acoustic monitoring) placed on the continental shelf were included in the studies. The results showed that bowhead whales are present all year round, and that they move from the coastal areas in the summer to the outer extremes of the assessment area in the winter.

These studies yielded considerable new knowledge of the occurrence of bowhead whales in the sea off the Northeast Greenland. They make use of most of the continental shelf in the summer, and are found along the outer edge of the drift ice and over the continental slope in the winter. Results can be found in the presnet report (Box 3.12) and in Videsen et al. (2019).

Narwhal

Narwhals were sighted several places during the aerial surveys, and they were especially numerous in three areas. Dove Bugt was one of them, where systematic counts were conducted in 2017 and 2018. They resulted in population estimates of 2387 and 1087 respectively. The acoustic buoys mentioned under bowhead whale (above) also recorded narwhals. The buoys furthest out towards the continental slope recorded narwhals in the winter especially, while those closer to the coast only recorded them in the summer. Results can be found in Box 3.13 and in Williams et al. (2017).

Seals

The movements of twenty ringed seals and twenty harp seals were tracked by satellite in 2017. Several ringed seals were stationary, but a few young individuals undertook long journeys (Figure 5). They were tagged in the Dove Bugt area, and one swam all the way to Newfoundland. Another swam to Ittoqqortoormiit, where it was caught by a local hunter in November 2017.

Twenty young harp seals were tracked from April 2017 for up to one year. They swam all the way along the ice edge to the north and east, ending up during the summer and autumn in the Barents Sea. Some remained there until April, but several began to return to their breeding grounds as early as from March. Results can be found in Rosing-Asvid & Dietz (2018), Rosing-Asvid & Zinglersen (2018).

Polar bear

Twenty adult female polar bears were equipped with satellite transmitters in April 2018 in the areas near Danmarkshavn in Northeast Greenland. They were followed for up to 127 day and during the analysis period, the bears moved extensively over the northeast and central eastern coastline and offshore into the assessment and the area where five licences previously were granted. Bears used both fast ice and pack ice. A key finding was that both inshore and offshore collared bears used the previous license round area. The offshore bears spent between 6-27% of their time within the previous license round area during April 2018-Sept 2019. Half of the ten inshore bears with functional satellite transmitters spent between 1-15% of their time within the previous license round area during the same period while the remaining five did not visit the license area. Of the 5 females that were captured with cub of the year, 3 of them moved offshore into the license round area and used the region extensively. Results can be found in Section 3.8.1 in the present report.

Ivory gull

Ivory gull is a high Arctic species that is specialised in finding food in drift ice. Numbers are low, and it is considered as 'Near Threatened' on the IUCN Red List, primarily because its main habitat – the drift ice – is dimishning. Breeding colonies in Northeast Greenland were surveyed from the air in 2019. In total approx, 2000 gull were counted in 25 colonies. Ivory gulls were tracked from a breeding colony at Station Nord using GPS data loggers, and some of the birds moved up to 500 km away from the colony to feed, while others moved to ice-free areas and a glacier fronts close to the colony. Ivory gull were also observed during the Dana survey in 2017 and these mainly occurred in the multiyear ice areas. Results can be found in Boertmann et al. (2019a, b) and Frederiksen et al. (2019).

Thick-billed murre

There are two small breeding colonies of thick-billed murre in East Greenland (near Ittoqqortoormiit). Recent counts show that both are in decline. On Svalbard, there are large breeding colonies of thick-billed murre on Svalbard (819,000 pairs). The birds from these colonies migrate to the southwest in the autumn, and a large number all the way to West Greenland to spend the winter. The young are flightless when they leave the colonies together with the male bird, which also becomes flightless due to moult of the flightfeathers.

During this three week phase these birda are highly vulnerable to oil pollution. It was therefore important to find out whether these birds move through the oil exploration areas in the assessmsnt area. The results from the ship and the aerial surveys showed that the main migration passes to the east of the continental shelf, and that there were very few murres in the survey area in August/September. The result complies with recent tracking results of breeding murres from Svalbard. The results can be found in Boertmann et al. (2019a) and in Møller et al. (2019).

Little auk

There are huge breeding colonies of little auk around the mouth of Scoresby Sund, where estimated 3.5 million pairs breed. Tracking using geolocator data loggers has shown that they migrate towards the north to the Greenland Sea after breeding. Tracking from Svalbard shows that birds from there also use the Greenland Sea in the autumn. The 2017 survey in August and September showed that the little auk is the most numerous avian species in the Greenland Sea in the early autumn, when high densities were found over the continental slope in particular, but are also spread over the entire continental shelf. The results can be found in Boertmann et al. (2019a) and in Møller et al. (2019).

Identifying important areas for hunting and fishing

Identifying important areas for hunting was conducted in partnership with 10 hunters from Ittoqqortoormiit and 10 from the Tasiilaq area. Using handheld GPS devices, they gathered data using a specially-designed app, called Piniariarneq (hunting expedition). The app makes it possible for hunters to record their hunting expeditions from start to end in a manner that includes data on route, form of transport, animals caught and observed, and geotagged photos, videos and notes. Based on these data, information from interviews with the hunters and identifying hunting locations for quota-controlled species (special report form data), we have identified some of the most important hunting areas in East Greenland. In this context, we define an important area for hunting as 1) where game is plentiful, 2) where hunting is frequent, 3) where many different species are hunted, 4) where hunting takes place through several seasons, or 5) a place that cannot be substituted because a given species is only found there, or special circumstances mean that it can only be effectively hunted there. We identified and described 12 important hunting areas in the Ittoqqortoormiit area, with another nine important areas in the Tasiilaq area. See the results of the study in Flora et al. (2019).

The effects of underwater noise

Studies of narwhals affected by controlled seismic sound waves and ship noise have provided important new knowledge on how they are affected by noise. When seismic activities are conducted in marine areas, a sound source emits powerful sound waves towards the seabed, and the echoes from the various layers underground are received and recorded. Such sound waves can be harmful to marine mammals. We know that these sound waves can scare away marine mammals and can mask their communication. Narwhals used in the study where fitted with noise recorders, pulse recorders and GPS transmitters to gather precise data on their reaction to noise. The results unanimously indicate that narwhals are affected by seismic sound waves. They reduced noise production considerably compared to the normal level when a seismic survey ship were at a distance of 13 km. The distance at which narwhals are affected by commercial seismic surveys will be even greater. They resumed their natural noise production once the ship and the noise it generated left the area. A number of analyses and post-calibration of equipment are needed before the final conclusions can be drawn from the studies. See preliminary results in Box 3.13 in the present report.

Oil spills and contaminants: Effects and biodegradability

A number of projects have sought to improve our understanding of the potential for biodegradability of contaminants and how to combat oil spills in the marine environment of the high Arctic.

Studies with water and sediment samples from the Greenland Sea collected during the August-September expedition in 2017 showed that there was a potential for biodegrading oil in the water column, if the natural microbial biodegraders can be activated. But it was also apparent that the lack of nutrients in the water column restricted the processes. Microbial oil biodegradability in the Greenland Sea will thus be very limited in the water column, without the addition of nutrients. Strategies for contingency planning based on the potential for microbial removal of oil should therefore include careful consideration of the options for adding nutrients to ensure effective biodegradation. Studies have also been conducted with the dispersion agent Slickgone NS, enabling the oil to disperse into the water column - a method to combat oil slicks. The agent was effective under test conditions. But the trials showed that dispersion will have little effect on biological degradation, because of the limited presence of nutrients.

The hydrocarbons that are relatively resistant to biodegradability (Alkylated PAHs) could not be found in sediments from the continental shelf, which indicates that the stations on the continental shelf (at a depth of less than 400 m) have not been exposed to oil (neither oil spills nor natural seepage). The potential for biodegrading alkylated PAH hydrocarbons in sediments from the continental shelf was therefore very low, even with added nutrients. Light alkylated PAHs were found on the continental slope (at depths above 400 m), which indicates that the stations at the point where the continental shelf meets the continental slope may have had some form of limited exposure to oil, and enhanced ability to biodegrade oil can therefore be expected. See results in Box 9.1 and in Johnsen et al. 2019.

A trial involving exposure of the large, lipid rich Arctic copepod *Calanus hyperboreus* to hydrocarbons in realistic concentrations, showed that they were able to absorb hydrocarbons from the water very quickly. On the other hand, the copepods take a long time to excrete the oil again, and there can therefore be a risk of the hydrocarbons to be passed further up the food chain. See results in Agersted et al. (2018) and Gustavson et al. (in prep.).

Effects of dispersed oil on macroalgae was also studied, and showed a.o. that the algae to some degree survived oiling. See Wegeberg et al. (2020a).

Finally, a number of trials are still in progress. These involve in-situ burning of spilled oil on the sea surface, as a method of combating oil spills at sea. Analyses of the smoke from burning oil in the laboratory showed that dioxins were not produced. The potential of burning oil from pockets in the ice has also been studied on small laboratory scale. The trials highlighted certain factors that will be decisive for the success of the method, but conclusive results await final data processing.

After oil has been burned, a viscous residue is left on the sea surface. This may under some instances sink, and thereby affecting the seabed. The toxic effect of this residue is presently being studied on two different high Arctic mussels, along with the potential for biodegradability in the seabed sediment.

The project also included purchasing equipment for studying oil spills to the Greenland Institute of Natural Resources. The equipment will be available for future surveys in an emergency situation. It includes a handheld sensor for detection of oil pollution, and a specially-designed sampler for taking water samples in the event of an oil spill in the sea.

Strategic environmental impact assessment of oil activities in the Greenland Sea

An important use of the results from the above described studies is to contribute to an updated version of the strategic environmental impact assessment (SEIA) of oil activities in the Greenland Sea. This assessment gathers information that can be used for management of the area. The new results considerably enhance the knowledge-base to evaluate and regulate future oil exploration in the assessment area, and especially to make regulation more precise in terms of time and space. For example: areas can now be designated as important for narwhal and bowhead whale, along with areas that are particularly sensitive to oil spills due to high biological production and the presence of seabirds. The studies have also contributed new knowledge of the seabed in the assessment area. This is unique in that it has never been affected by human activities, making it highly vulnerable to future activities impacting the seabed. Other important new knowledge (or confirmation of previous observations) include: high biological production in the water column over the continental slope and in some coastal areas; low production over the continental shelf; large concentrations of seabirds, both in some coastal areas and offshore; high concentrations of narwhals in Dove Bugt and of bowhead whales in the Northeast Water.

Important for the updated SEIA is also the new knowledge on natural biodegradability of oil, and the studies of dispersing and in-situ burning of oil as methods to combat oil spills in ice.

All the new knowledge obtained by the research projects will be incorporated into the updated strategic environmental evaluation, and will provide an improved basis for evaluating and regulating future oil activities in the sea off Northeast Greenland. Moreover, the new knowledge gained can also be used for nature protection planning and for oil spill contingency planning in the area.

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GREENLAND SEA – AN UPDATED STRATEGIC ENVIRONMENTAL IMPACT ASSESSMENT OF PETROLEUM ACTIVITIES

2ND REVISED EDITION

This report is an updated strategic environmental impact assessment of activities related to exploration, development and exploitation of oil and gas in the Greenland See off northeast Greenland. The original version from 2012 needed an update before the area will be subject to new licencing rounds in 2021 and 2022. The report includes the results of an extensive research program in the area in 2016-2019, a program initiated to improve the knowledge base for future regulation and planning of oil activities. 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 recommends to consider not to open the assessment area for oil licences in this strategy period (2020-24 strategy).

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