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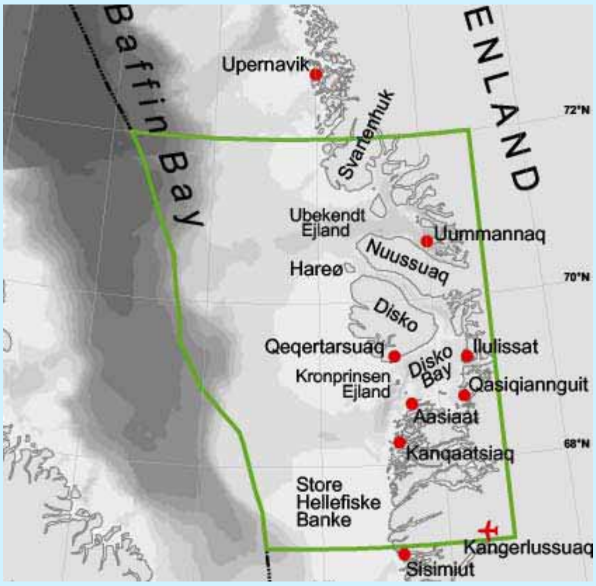

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Data sheet

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Abstract: This publication is a strategic environmental impact assessment of activities related to exploration, development and exploitation of hydrocarbons in the sea off West Greenland between 67° and 71° N (= the Disko West Area).

Keywords: Greenland, Davis Strait, Baffin Bay, Disko, hydrocarbon exploration, hydrocarbon exploitation, strategic environmental impact assessment.

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Contents

Preface

This document is a strategic environmental impact assessment (SEIA) of activities related to exploration, development and exploitation of hydrocarbons in the sea off West Greenland between 67° and 71° N (= the Disko West Area). The area was opened for applications in 2006 and licences are planned to be granted in spring 2007. The SEIA was developed by the National Environmental Research Institute, Denmark in close co-operation with the Greenland Institute of Natural Resources and the Bureau of Minerals and Petroleum of the Greenland Home Rule.

The assessment area is shown in Figure 1. This is the region which potentially could be most impacted by a large oil spill deriving from activities within the expected licence areas, although drift modelling indicates that oil may drift even further.

The assessment area is very important in an ecological context. Biological production in spring and summer is very high, there are rich benthic communities and large and important seabird and marine mammal populations. Fish and shrimp stocks in the area contribute significantly to the fishing industry in Greenland, and local communities utilise the coastal areas through subsistence hunting and fishing.

The expected activities in a 'full life cycle' of a petroleum field are briefly described. Exploration activities are likely to take place during summer and autumn, because harsh weather and sea ice hamper activities in winter and spring. However, if oil production is initiated activities throughout the year will take place. A previous study has pointed out that the most likely scenario for a production field will 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. Produced oil will then be transported by shuttle tankers to a facility outside Greenland, most likely in North America.

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Many have helped and contributed with information in various ways: Poul Johansen, (NERI), Helle Siegstad (GINR), Ole Jørgensen (GINR), Jonathan Carl (GINR), Søren A. Pedersen (GINR/ICES), Erik W. Born (GINR), Ole Tendal (Zoological Museum, Copenhagen), Mitch Taylor (Wildlife Research Section, Department of Environment, Nunavut), Francois Messier (University of Saskatchewan), Ian Stirling (Canadian Wildlife Service), Nick Lunn (Canadian Wildlife Service), Erik Born (GINR), Steven Amstrup (U.S. Geological Survey), Flemming Getreuer Christiansen (GEUS), Martin Sønderholm (GEUS), Peter Munk (Danish Institute for Fisheries Research), Carsten Simonsen (Danish Institute for Fisheries Research) and Kasper L. Johansen (NERI) and Bent Østergaard Olsen (NERI).

Summary and conclusions

The environment

The physical conditions of the study area are described with focus on weather, oceanography and ice conditions. The presence of icebergs and sea ice in winter and spring will make exploration and development difficult and increase the risk of accidents. Updated information on the physical properties of the environment is under preparation and will be included in an information CD prepared by GEUS (the Geological Survey of Denmark and Greenland) and NERI.

The study area is situated within the Arctic region, with all the typical biological properties of this climatic region: low biodiversity but often numerous and dense animal populations; a relatively simple food web from primary producers to top predators, and with a few species playing a key role in the ecology of the region. In the marine environment the most significant event is the spring bloom of planktonic algae, the primary producers in the food web. These are grazed upon by copepods, including the *Calanus* species which represent some of the most important and conspicuous key species in the food web.

Fish, seabirds and marine mammals represent some of the higher trophic levels in the marine environment, where polar bear and man are the top predators. Seabirds are abundant with several species present in the study area. Many species breed in dense colonies along the coasts, seaducks assemble in certain fjords and bays to moult, and in winter millions of seabirds migrate through or winter in the ice-free waters off West Greenland. Many of these moulting and wintering seabirds have their breeding grounds outside Greenland – mainly in Canada and Norway (Svalbard). See Table 2, p. 63.

Marine mammals are significant components of the ecosystem. Five species of seal, walrus, 13 species of whale, and polar bear occur in the assessment area. The assessment area is particularly important to marine mammals in winter, because vulnerable species such as narwhal, white whale (beluga), bowhead whale, walrus, and polar bear occur in significant numbers. See Table 3, p. 74. The whales are moreover suspected to acquire the bulk of their annual food intake in the assessment area.

Use of natural resources is another important issue in the assessment area. Commercial fisheries focus mainly on the large stocks of deep-sea shrimp and Greenland halibut. These two species are extremely important to the Greenland economy. About 35% of the total Greenland shrimp catch and about 80% of the Greenland halibut catch is taken in the assessment area. Other species utilised on a commercial basis include snow crab and Iceland scallop.

Local and subsistence fishery occur throughout the coastal part of the region. Capelin, lumpsucker (mainly caught for the roe), Arctic char and several other species are fished for private consumption or sold to local factories or at local open markets.

Hunting of seabirds and marine mammals is also important in the assessment area. This is carried out mainly on a subsistence basis, but hunting products are also sold at local open markets, and processed and marketed in food stores in towns and settlements all over Greenland.

Tourism is a relatively new and growing industry in Greenland. It may be sensitive to oil spills because the main attraction in Greenland is the unspoiled nature. The most intensive tourist activities in Greenland take place within the assessment area, with the town Ilulissat as centre.

Knowledge on background levels of contaminants such as hydrocarbons 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. A significant amount of data regarding other contaminants in the Greenland environment is available.

Assessment

Exploration

The environmental impacts of exploration activities will mainly be disturbance from activities associated with noise, and the impacts are expected to be relatively small, local and temporary, because of the intermittent nature of the activities. No serious impacts are expected if adequate mitigative measures are applied, activities in sensitive areas are avoided in the most sensitive periods and no accidents such as oil spills occur. The winter is particularly sensitive to exploration activities due to wintering marine mammals, but these are not expected to take place during this season. Temporary impacts of intensive seismic activity could be displacement of Greenland halibut, which again could cause reduced catches in the fisheries near affected areas. Deep-sea shrimp will not be affected by seismic activities. Marine mammals, particularly whales, may also be displaced from feeding grounds and migration routes. However, as seismic surveys are temporary such effects are expected to be of short duration (viz. weeks or a maximum of a few months). There is however a risk of oil spills from blowouts during exploration drilling (see below).

The sound pulse from the seismic array can kill or injure fish egg and larvae within a distance of 5 m. Very intensive seismic surveys coinciding with high concentrations of fish eggs and larvae in the upper part of the water column may impact recruitment to the adult stocks. However, as such high concentrations are not known in West Greenland waters and, moreover, most fish species spawn in a dispersed manner and in late winter or early spring when no seismic surveys takes place, it is concluded that the risk of effects of seismic surveys on fish stocks is negligible.

Development and production

The activities during development, production and transport are on the other hand long lasting and there are several activities which have the potential to cause serious environmental impacts. Careful Health, Safety and Environment (HSE) procedures, and planning and application of Best Available Technique (BAT) and Best Environmental Practice (BEP) can mitigate most of these. Even though discharges and emissions can be limited, knowledge on cumulative and long-term impacts from many of the released substances is still lacking.

Development and production are energy-consuming activities which will contribute significantly to the Greenland emission of greenhouse gases. A single large Norwegian production field emits more than twice the total Greenland emission of today.

The fisheries will be affected by development and production mainly by the presence of the safety zone (of typically 500 m) around the offshore facilities.

Placement of structures and the disturbance related to these have the potential to displace marine mammals in particular. Noise from drilling platforms has displaced migration routes of bowhead whales in Alaska. Dependent on location in the assessment area, displacement of migrating and staging whales (mainly narwhal, white whale and bowhead whale) walrus and seals (bearded seal) must be expected. This can in certain areas limit the access of populations of these animals to feeding grounds important to survival, and also result in reduced availability of quarry species for local hunters.

Intensive helicopter flying also has the potential to displace seabirds and marine mammals from habitats (e.g. feeding grounds important for winter survival) and traditional hunting grounds for local people.

Development and production activities represent an issue which is difficult to evaluate when the level of activity is unknown and cumulative impacts are involved. Overall significance will depend on the number of activities, how far they are dispersed in the areas in question, and also on their duration.

Oil spills

The potentially most serious environmental impacts are related to large accidental oil spills. These may occur either during drilling (blowouts) or from accidents when storing or transporting oil. Large oil spills are rare events today due to ever-improving technical solutions and HSE-policies. However, the risk cannot be totally eliminated and in a frontier area with the presence of icebergs, the possibility for an accident may be elevated.

Oil spill modelling indicates that a spill located far offshore most likely will not affect the coast in any of the selected (likely) wind conditions. Nearshore spills will result in coastal pollution under unfavourable wind conditions, and a spill for example from a tanker wreck at a coastal facility will most likely heavily pollute the coast near the spill site. The shorelines which could be polluted according to the modelling include the outer parts of Vaigat, the southern parts of Disko Bay, the west coast of Disko Island, and up to 100 km north and south of the Disko Bay area.

In general, oil spills occurring in the coastal zone are regarded as much more deleterious than oils spills in the open sea, but there is some reservation attached to this statement in an area such as Disko West. This is due to the presence of winter ice which may trap and transport oil over long distances, but which on the other hand also may limit the dispersion compared with the situation in ice-free waters. Knowledge on the behaviour of spilled oil in ice-covered waters is limited.

The coastal zone is sensitive because of the rich biodiversity present, including concentrations of breeding and moulting seabirds and spawning fish stocks (capelin and lumpsucker). But it is also related to the fact that oil may be trapped in bays and fjords where high and toxic concentrations can build up in the water. Moreover, local fishermen and hunters intensively use the coastal zone. Oil may also be buried in sediments, among boulders, in mussel beds and imbedded in crevices in rocks from where oil may seep, and may create low-level chronic pollution which may persist for decades and cause long-term effects on, for example, birds utilising these coasts.

Effects of an oil spill in the open sea are expected to be less severe than in coastal areas. However, there are some important offshore resources in the area which may be severely impacted – for example, the concentrations of wintering king eiders, white whales and walruses on Store Hellefiskebanke. Attention should also be given to potential oil spills in areas with hydrodynamic discontinuities, particularly during the spring bloom. Fronts, upwelling areas and the marginal ice zone are examples of such hydrodynamic discontinuities where high surface concentrations of phytoplankton, zooplankton, and shrimp and fish larvae can be expected. But generally it is concluded that the impact of an oil spill on the eggs and larvae of the commercially important species - Greenland halibut and deep-sea shrimp - most likely will be low and without significant effects on the recruitment to adult stocks, because only a small fraction of the population will be impacted.

Bird populations particularly at risk of being impacted by an oil spill in the Disko West area include the breeding colony of thick-billed murres at Ritenbenk, the breeding colonies of Atlantic puffins along the outer coasts, and the moulting and wintering populations of king eiders along the west coast of Disko and on Store Hellefiskebanke.

Marine mammal populations are generally regarded as relatively robust to oil spills, mainly because individuals (except polar bears) are not dependent on an intact fur layer for insulation. However, some of the species in the assessment area are particularly vulnerable, because they are sensitive even to slightly increased mortality: the stocks of narwhal, white whale and walrus are all declining. Polar bears are also sensitive to oil spills. Walrus and bearded seal feeding on benthos may also be exposed to oil through their food, if oil sinks and accumulates on the seafloor. Bowhead whales, which occur in low numbers, belong to a stock which now is slowly recovering from heavy exploitation. This recovery may be halted by even a slight increase in mortality.

There are special problems related to oil spills in ice. Sea-ice cover will in the beginning tend to contain and limit the spread of an oil spill compared with open sea. Oil is contained between the ice floes and in the rough underside of the ice. However, oil caught under the ice may be transported in an almost unweathered state over long ranges and may impact the environment, e.g. seabirds and marine mammals, far from the spill site when the ice melts. Oil may also be caught along ice edges, where primary production is high.

Even though seals may tolerate some oil in their fur, such oiling may impact local hunters, as fouled skins are of no use and are impossible to sell.

Oil spill effects on commercial fisheries are mainly linked to the closure of fishing grounds (e.g. for shrimp and Greenland halibut) for longer periods (weeks to months) due to the risks associated with marketing polluted or tainted fish. Effects on subsistence hunting and fishing will include closure of fishing grounds and probably also temporary changes in distribution and habits of quarry species.

Further studies

The assessment has revealed several issues where more knowledge is needed to assess impacts of hydrocarbon activities. These are addressed in a series of studies already initiated or proposed.

In support of this SEIA, the BMP and NERI have initiated a number of background studies in collaboration with the Greenland Institute of Natural Resources and others. The studies are being conducted over the period 2005-2008.

Further studies in relation to the future opening of the northwest Baffin Bay are expected to be initiated to strengthen the knowledge base for planning, mitigation and regulation of oil activities in the assessment area and in the entire Baffin Bay area. NERI is developing a database with relevant environmental data from these background studies as well as other sources. Data include spatial and temporal distribution of key animal species and fishing areas. The data will be made available on DVDs in a Geographic Information System in ArcGIS format in support of the companies' own environmental analyses.

Dansk resume

Denne rapport er en strategisk miljøvurdering af aktiviteter forbundet med olieefterforskning og -eftersøgning i farvandet vest for Disko, Vestgrønland. Nærmere bestemt farvandet mellem 67° og 71° N (Figur 2.1). Dette område betegnes Disko West-området, et navn givet i forbindelse med den udbudsrunde, der blev indledt i 2006. Rapporten er udført af Danmarks Miljøundersøgelser (DMU) i samarbejde med Grønlands Naturinstitut (GN), og arbejdet er finansieret af Råstofdirektoratet.

Det vurderede område er større end det areal, som udbudsområdet dækker. Det skyldes, at der skal tages højde for, at oliespild kan drive meget langt og dermed også ud af udbudsområdet.

Disko West-området er meget rigt i biologisk/økologisk forstand. Primærproduktionen om foråret er meget høj, der er rige dyresamfund på havbunden og der er store og meget vigtige forekomster af både fugle og havpattedyr. Fisk og rejer i området er vigtige ressourcer for næringslivet i land og husholdningsfiskeri og -fangst er ligeledes vigtige aktiviteter i de kystnære områder.

En komplet livscyklus for et oliefelt er så vidt muligt vurderet. 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 tilsvarende forhold.

Vurdering af aktiviteter

Efterforskning

De væsentligste påvirkninger fra efterforskningsaktiviteter vil blive forstyrrelser fra støjende aktiviteter (f.eks. seismiske undersøgelser, boring i havbunden og helikopterflyvning). Der forventes kun relativt svage, midlertidige og lokalt forekommende påvirkninger. De mere alvorlige påvirkninger kan undgås med forebyggende tiltag, som f.eks. ved at undgå aktiviteter i særligt følsomme områder eller perioder.

Vinterperioden er særligt følsom overfor støjende aktiviteter bl.a. på grund af forekomst af hvidhvaler, narhvaler, grønlandshvaler, hvalrosser og remmesæler, men efterforskningsaktiviteter forventes ikke i den tid, hvor disse dyrearter er tilstede.

Intensive seismiske undersøgelser kan formentlig bortskræmme hellefisk fra vigtige fiskeområder og dermed også påvirke fiskeriet negativt. Men undersøgelser af andre fiskearter tyder på at denne påvirkning er midlertidig. Derimod forventes ingen påvirkninger af rejebestandene. Der er desuden en risiko for at havpattedyr kan bortskræmmes fra vigtige fødesøgningsområder og trækruter, men igen forventes påvirkningen at være midlertidig (varighed uger til måneder), fordi aktiviteten ophører.

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 konkluders derfor at seismiske undersøgelser ikke giver anledning til risiko for væsentlige påvirkninger af fiskebestandene.

Den væsentligste risiko for miljøpåvirkninger under efterforskning opstår i forbindelse med oliespild, som kan opstå i forbindelse med udblæsninger under prøveboringer. 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 (dekader), 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.

Energiforbruget ved udvikling og produktion er meget stort, og det må forventes at anlægget af stort oliefelt i Grønland 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 bortskræmmes permanent fra vigtige fourageringsområder eller ved at de ændrer trækruter. I Disko West-området er det især narhval, hvidhval, grønlandhval, hvalros og remmesæl, der er på tale i denne sammenhæng. Dette kan vanskeliggøre fangst på jagtbare arter.

Intensiv helikopterflyvning har også potentialet til at bortskræmme både havfugle og havpattedyr fra vigtige fourageringsområder.

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.

Det skal påpeges, at det er meget vanskeligt at vurdere de påvirkninger eventuel udvikling og produktion kan medføre, fordi 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, hvor kontrollen med borehullet mistes under prøveboring, eller fra uheld i forbindelse med opbevaring og transport af olie, f.eks. i forbindelse med forlis af tankskibe. Store oliespild er meget sjældne nu om dage, 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.

Modellering af drivbanerne for oliespild i Disko West-området viser at oliespild med oprindelse langt til havs med stor sandsynlighed ikke vil nå kysterne, som er særligt sårbare over for olie. Derimod er der stor risiko for at et spild fra en position nær kysten (f.eks. fra et udskibningssted) under uheldige vejrforhold kan forurene lange kyststrækninger på Disko, i ydre Disko Bugt og op til 100 km både nord og syd for Disko Bugt.

Oliespild i kystnære farvande regnes generelt som meget mere ødelæggende end oliespild på åbent hav. Men i et område som Disko West må denne generalisering modificeres. Det hænger sammen med vinterens is, som kan holde på olien og transportere den over lange afstande uden at den nedbrydes, men også kan 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 fravande kan være sårbare over for oliespild er, at olien her kan påvirke områder med høj biodiversitet og med tætte dyrebestande, som f.eks. gydende lodde (ammassat) og stenbider eller områder med store fugleforekomster. Olien kan fanges i bugter og fjorde, hvor høje og giftige koncentrationer af oliekomponenter kan bygges op i vandsøjlen. Der er også risiko for at olie kan fanges i bundsedimenter, i strande med rullesten og i muslingebanker, hvorfra olie langsomt kan frigives til det omgivende miljø med risiko for langtidsvirkninger f.eks. på fuglebestande som udnytter kysterne. Endelig udnyttes de kystnære fravande af lokale indbyggere til fangst og fiskeri.

På åbent hav er fortyndingseffekten og spredningen på vandoverfladen med til at mindske miljøeffekterne af et oliespild. I og nær Disko West-området er der dog områder langt fra kysten, som alligevel er særligt sårbare over for oliespild og hvor væsentlige effekter kan forventes. Det er særligt de lavvandede partier (< 50 m) af Store Hellefiskebanke, der er tale om. Her overvintrer internationalt meget vigtige forekomster af kongeederfugl, hvidhval og hvalros. Et andet sårbart element langt til havs er frontzoner, "up-welling"-områder 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 (inkl. yngel af rejer og fisk) forekommer i den øvre del af vandsøjlen. Et oliespild vil dog næppe påvirke bestandene af rejer og hellefisk, de vigtige arter for det grønlandske fiskeri.

Fugle er særligt sårbare overfor oliespild på havoverfladen, og i Disko West-området er ynglekolonien af polarlomvier ved Ritenbenk og de ynglende lunder på øerne yderst i Disko Bugt udsatte. Det samme er tilfældet med de store forekomster af fældende kongeederfugle langs de ydre kyster af Disko.

Havpattedyr er generelt mere robuste overfor oliespild på havoverfladen. Men indenfor Disko West-området forekommer bestande som er sårbare, fordi de i forvejen påvirkes af andre menneskelige aktiviteter – primært fangst. Det gælder hvidhval, narhval og hvalros, hvis bestande alle er for nedadgående. Hvalros og remmesæl lever desuden af bunddyr, og kan blive udsat for at indtage olie med deres føde. Isbjørne er specielt sårbare, fordi de har en tendens til at rense olie af pelsen ved at slikke den ren og derved blive forgiftet af den indtagne olie. Grønlandshvalerne, der forekommer i området, tilhører en bestand, som først nu er begyndt at vise tegn på fremgang, efter at have været næsten udryddet i begyndelsen af 1900-tallet. Bestanden er stadig lille, og selv en lille ekstra dødelighed, kan tænkes at påvirke bestandens bedring.

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 og også yngel af polartorsk, der netop samles lige under isen.

Fiskeri og fangst kan blive påvirket ved at oliepåvirkede områder lukkes for den slags aktiviteter. Dette gøres for at hindrer at der fanges og markedsføres fisk, der har været i kontakt med olie 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.

Yderligere studier

Da arbejdet med denne miljøvurdering blev indledt, var det klart at der manglede væsentlig viden til at foretage vurderinger af olieaktiviteter i Disko West-området. Flere studier blev igangsat og resultaterne herfra er inddraget, i den grad de var tilgængelige. Men flere undersøgelser er ikke afsluttet endnu, og vil give resultater som skal inddrages i kommende tillæg. Endelig er der flere undersøgelser, der skal sættes i gang, når og hvis konkrete aktiviteter indledes og skal miljøvurderes.

Den nordlige del af Baffin Bugt nord for Disko West-området forventes åbnet for olieeftersøgning, og i denne sammenhæng indledes nye studier med henblik på at samle ny viden til miljøvurdering af aktiviteter i dette område.

Resultaterne af alle disse baggrundsstudier og den eksisterende viden skal samles i en rumlig database, som bliver tilgængelig i elektronisk form for selskaber, der siden hen skal foretage miljøvurderinger af specifikke aktiviteter.

Naalisagaq kalaallisooq

Nalunaarusiaq una Kalaallit Nunaata kitaani, immami Qeqertarsuup kitaaniittumi oliaqarneranik misissuinermut ujarlernermullu atatillugu ingerlatanut tunngatillugu avatangiisinut iliuusissanut naliliineruvoq. Erseqqiannerusumik oqaatigalugu immami allorniusat 67° og 71° N (titartagaq 2.1) akornanniittumi. Tamanna Disko West-imik taagorneqarpoq, taaguut neqerooruteqarnermut 2006-imi aallartittumut atatillugu atsiunneqarsimasoq. Nalunaarusiaq Danmarkimi AvatangiisinutMisissuiffeqarfimmit (DMU) suliarineqarpoq Kalaallit Nunaanni Pinngortitaleriffik (GN) suleqatigalugu.

Naliliiffigineqartoq tamanna imartamit neqeroorutigineqartumit annertuneruvoq. Tamatumunnga pissutaavoq ooliaarluertoqassagaluarpat siaruaaffigisinnaasaa annertoorujussuusussaammat taamalu neqerooruteqarfiusumit anillakaattussaassammat.

Disko West-teertugaq biologiskip/økologiskip tungaanit isigalugu pisoorujussuuvoq. Upernaakkut pinngorartitsineq annertoorujussuusarpoq, immap naqqani uumasoqatigiippassuaqarpoq aammalu timmissanik miluumasunillu imarmiunik pingaarutilerujussuarnit pilerujussuulluni. Tamanna aalisakkanut kinguppaanullu nunami inuuniutinut namminerlu atugassanik piniarnikkullu pissarsiorfittut aammalu sinerissap qanittuani ingerlatanut pingaarutilerujussuuvoq.

Oliasiorfimmi uumasutut ingerlaaseq tamakkiisoq sapinngisamik nalilersuiffigineqarpoq. Kalaallit Nunaannili oliamik qalluineq misilittagaqarfigineqanngimmat ingerlatanut tunngatillugu nalilersuineq toqqartumut tunngatinneqanngillat, kisiannili allani tamaani pissutsinut assingusuni misilittakkanik tunngaveqartinneqarlutik.

Ingerlatanik nalilersuineq

Misissueqqissaarneq

Misissueqqissaarnikkut ingerlatanit sunniutaasut pingaarnerit tassaajumaarput ingerlatat nipiliortut (nunap sajuppillatsittarneratigut misissuinerit, immap naqqani qillerinerit helikopterimillu qulaavaanerit). Ilimagineqarpoq tamaaniittunik sunniinerit annertoorsuunatillu qaangiuttussaajumaartut. Sunniinerit kingunipiloqarnerusinnaasut pinngitsoorneqarsinnaassapput pinaveersaarutaasunik iliuuseqarnikkut, soorlu immap ilaani malussajanerusumi piffissaniluunniit aalajangersuni ajoqusiiffiusinnaanerusuni ingerlatsinaveersaarnikkut.

Ingerlatanit nipiliortunit ajoqusiiffigiuminarnerpaavoq ukiuunera, taamaannikkummi ilaatigummi qilalukkat qaqortat qilalukkallu qernertat, arfiviit, aarrit ussuillu tamanna najortarmassuk, misissueqqaarnernillu ingerlatsineq uumasut tamakkua tamaaniinneranni ingerlanneqartarnissaat naatsorsuutigineqanngilaq.

Sajuppillatsissisarneq atorlugu annertuumik misissuinerit nalunanngitsumik aalisrfinnit pingaarnernit qalerallit qimaatissinnaassavaat taammalillutillu aalisarnermut ajortumik kinguneqassallutik. Aalisakkanulli allanut tunngatillugu misissuinerit malillugit sunniut taamaattoq sivisuujussagunanngilaq qaangiukkumaarlunilu. Tamatumali akerlianik kinguppannut sunniuteqarnissaa ilimagineqanngilaq. M imarmiut neriniarfimminnit ingerlaartarfimminnillu pingaarutilinnit tamaaniittunit tatamititaallunik qimaanissaat aarlerigineqarsinnaavortaaq, kisiannili aamma tassani sunniutip, sivikitsuinnaanissaa, ingerlatallu unitsinneqarpata qaangiutilertornissaa (sivisussusia sapaatip akunnialunnguannit qaammatinut) naatsorsuutigineqarpoq.

Paasineqarsimavoq luftkanonit sajuppillatitsisarluni misissuinermi atorneqartartut issaallatitsineratigut aalisakkat suaat aalisagaaqqallu tukerlaat pisorpallatitsiviusumiit ungasinnerpaamik 5 meterip iluaniittut toqunneqarsinnaasut. Norgemi sajuppillaatitsisarluni misissuinerit annertuallaat aalisagaaqqanik ima amerlatigisunik toqutsisinnaanerat allaat aalisakkanut inersimasunngortussanut sunniuteqarnerlussinnaanera isumakuluutigineqarpoq. Kisianni kalaallit imartaanni taama eqimatigisunik aalisagaaqarfiusartoqarneranik ilisimasaqartoqanngilaq, taamaattoqarnerpaasarfialu upernaakkut sajuppillatitsisarluni misissuinerit nalinginnaasumik ingerlanneqartarnerat sioqqullugu pisarpoq. Taamaattumik sajuppillatitsisarluni misissuinerit annertunerusumik aalisagaqatigiinnut sunniuteqarnavianngitsut inerniliineqarpoq.

Misissueqqaarnermut atatillugu avatangiisinut sunniuteqarsinnaasutut aallerinarnerpaaq tassa misiliilluni qillerinermi supisisarnertigut oliamik aniasoortitsisinnaaneq. Oliamik aniasoornerup kingunerisinnaasai ataani eqqartorneqarput.

Ineriartortitsineq tunisassiornerlu

Misissueqqaarnikkut ingerlatsinerup sunniutigisinnaasaasa akerliannik oliasiorfimmik ineriartortitsinikkut oliamillu qalluinikkut sunniutissat sivisunerusumik (ukiuni qulikkuutaajusinnaasuni) atasarput, aammalu ingerlatat arlallit avatangiisinut sunniuteqarnerlorujussuarsinnaasuullutik. Sunniutaasinnaasut tamakkua pinngitsoorneqarsinnaapput peqqissaartumik pilersaarusiornikkut iliuutsinillu "Health, Safety and Environment" (HSE) akuerisaanik aammalu "Best Available Technique" (BAT) aamma "Best Environmental Practice" (BEP) atuinikkut. Sunniutaasartunulli annertusiartortartunut sivisunerusumillu atasartunut (soorlu imermut tunisassiornermut atorneqartumut) tunngatillugu ilisimasat, aamma iliuutsinut siornatungaani taagorneqartunut tunngatillugu, naammanngillat.

Tunisassiornermik ineriartortitsinermut nukik atugaq annertoorujussuusarpoq taamaattumillu Kalaallit Nunaanni oliaqarferujussuarmik pilersitsineq Kalaallit Nunaata gassinik naatitsivimmeersutut ittunik aniatitsineranut tamarmiusumut annertuumik annertusisitsinissaa ilimagineqarpoq. Assersuutigineqarsinnaavoq norskit oliasiorfii CO_2-mik Kalaallit Nunaata ullumikkut aniatitaata marloriaataanik aniatitsimmata.

Atortut sumut inissinneqarnerata tamakkualu akornusersuutaanerisa miluumasut imarmiut sunnersinnaavaat tatamillutik neriniartarfimminniit qimagulluinnartillugit imaluunniit ingerlaartarfimminnik allanngiuisillugit. Disko West-imi pingaartumik qilalukkat qernertat, qilalukkat qaqortat, arfivik, aarrit ussuillu tassunga atatillugu taaneqarsinnaapput.

Tamatuma aamma uumasunik piniarneqarsinnaasunik piniarnerup ajornarnerulernera kingunerisinnaassavaa.

Annertuumik helikopterimik qulaavaajuarneq aamma neriniartarfinniit pingaaruteqartuniit timmissanik imarmiunik miluumasunillu imarmiunik nujoqqatitsisinnaasunut ilaavoq.

Tamaani ineriartortitsillunilu tunisassiorfiusuni aalisarfiusoq immap naqqani atortulersuutinit (qilleriveqarfinnik ruujorinillu aqqusersuutinik) aammalu napasulianit qilleruteqarfiusunit assigiinngitsunit annikillisinneqarumaarpoq. Nalinginnaasumik isumannaallisaanikkut/matoqqatitsiviusunut qanillinerpaaffissaq tamakkunannga 500 m ungasissuseqartinneqartarpoq.

Erseqqissarneqassaaq ineriartortitsisinnaanikkut tunisassiulersinnaanikkullu sunniutissaajumaartut nalilersuiffiginissaat ajornartorujussuummat, tassami tamakkua annertussusissaat, qanoq sivisutigisumik atanissaat ingerlatallu suunissaat aammalu teknikikkut aaqqiissutit suunissaat ilisimaneqanngimmata.

Oliaarluerneq

Oliasiornmermut atatillugu avatangiisitigut ajoqusiinerpaasussat tassa annertoorsuarmik oliamik aniasoornerit. Tamakkua supisinikkut putumik misiliilluni qilleriviusumik aqutsinerup annaaneqarnerataigut imaluunniit oliamik katersuiffimmi oliamillu assartuinermi ajutoornikkut, assersuutigalugu umiarsuup oliamik asartuutip ajunaarneratigut pisinnapput. Ullutsinni oliamik aniasoorujussuartarnerit teknikikkut isumannaallisaanikkullu nutarteriuarnerit pissutaallutik qaqutigoortorujussuanngorsimapput. Aarlerigiuartariaqarpulli pingaartumimmi "frontier"-områder taagukkani kalaallit imartanisut ittuni iluliarsuarnit aarlerinartorsiortitsiviusuni ajutoornissaq ajunaarnissarlu aarlerigisariaqarnerusarmata.

Disko Werst-imi oliaarluernerup tissukarfigisinnaasaasa missingersuusiornerqarneranni avasiinnarsuarmi oliaarluernerup sineriak oliaarluerfigissallugu isumakulunnarnerpaaq tikissagunanngikkaa takuneqarsinnaavoq. Akerlianilli sinerissamut qaninnerusumi oliaarluernikkut (assersuutigalugu usilersorfimmi) silarlummik eqqorneqarluni Qeqertarsuarmi, Qeqertarsuup Tunuata silasinnerusuani sineriarujussuaq Qeqertarsuup Tunua avannamut kujammullu 100 km angullugu qaangerlugu annertussusilik mingutissinnaavaa.

Sinerissap qanittuani oliaarluerneq imaannarmi oliaarluernermit aseruinerujussuusartutut isigineqarpoq. Kisiannili taamatut ataatsimut isiginninneq Disko West-imut tunngatillugu allatut isigineqartariaqarpoq. Taamaannera ukiumi sikuusarneranut attuumassuteqarpoq sikummi olia uninngatissinnaallugulu allannguuteqartinnagu ungasissorsuarmut angallassinnaavaa, taamaattorli aamma mingutitsinerup siaruarnerunissaralua sikoqanngitsumi aniasoornermut sanilliullugu pakkersimaarnerusimasinnaallugu. Oliap immami sikuusumi aniasoornikup qanoq pisarneranut tunngatillugu ilisimasat massakkut pigineqartut annertunngillat.

Sinerissap qanittuata oliamik aniasoornikkut sunnernerlukkuminarnerusinnaaneranut pissutaavoq tamaani oliap assigiinngitsorpassuarnik eqimasunillu uumasoqarfiit, assersuutigalugu ammassanik nipisannillu imaluunnit timmiarpassuallit eqqorsinnaammagit. Olia iterlanni kangerlunnilu unissinnaqavoq ilagigaalu toqunarluinnartut immap tamaaniittup ikianut tamakkiisumik akuliukkiartuaarssinnaallutik. Aarleqqutigineqarsinnaavortaaq oliap immap naqqani sananeqaatinut, sissami tuapannut uiloqarfinnullu nippussinnaalluni arriitsumillu avatangiisinut qanitaminiittunut akuliussinnaalluni sivisuumik, assersuutigalugu timmissanut sinerissamik atuisunut, ajoqutaalerluni. Sinerissallumi qanittua aamma tamaani najugalinnit piniarnermut aalisarnermullu atorneqarpoq.

Oliamik mingutitsineq imaannarmiikkaangat kimikilliartortarnerata immallu qaavatigut siaruarnerata avatangiisinut kingunipilugisinnaasai annikillisinneqartarput. Disko West-imi tamatumalu qanittuani sinerissamiit avasikkaluaqisumi taamaattoq oliamik mingutitsinikkut immikkut ajoruseruminartunik peqarmat sunniuteqarsinnaanera ilimagineqarsinnaavoq. Pingaartumik Store Hellefiskebankemi ikanneqarfiit (50 m inorlugit itissusillit) tassani pineqarput. Tamaaniipput nunarpassuarnut pingaarutillit mitit qingallit, qilalukkat qaqortat aarrillu ukiiffigisartagaat. Eqqoruminartut allat tassa frontzone-t, ”up-welling”-eqarfiit (sarfap pikialaarfii) sikut tissukartut sinaavanniipput (”marginal ice zone”) uumassusilinnik tunngaviusunik upernaakkut immap qaavani pinngorarferujussuit algenik tappiorarnartunik uumasunillu tappiorarnartunik (aamma kinguppaat aalisakkallu piaraannik tukerlaanik) annertuumik pinngorarfiusut tamaaniipput. Inerniliisoqarporli oliaarluernerup kinguppannik qaleralinnillu, kalaallit aalisarnerannut pingaaruteqarluartunik, ajoqusiinissaa ilimanarpallaanngitsoq.

Timmissat immap qaavani oiliaarluernikkut ajoquserneqarnissaat aarleqqutissaanerusarpoq, Disko West-imilu appat siggukitsut Appani erniorfeqartut qilanngallu Qeqertarsuup tunuata paani qeqertani erniortut ajoqusigaanissaat assut aarlerinarluni. Aamma Qeqertarsuup avalernani mitinut qingalippassuarnut isasartunut taamaappoq.

Miluumasut imarmiut immap qaavani oliamik mingutitsinermit eqqornerlunneqannginnerusarput. Disko West-illi iluani tamakkua ilaqarput inuit ingerlataannit allanit – pingaartumik piniarnermit – sunnersimaneqareernermikkut eqqornerlunneqarsinnaasunik. Tamakkua tassaapput qilalukkat qaqortat, qernertat aarrillu tamaani ikiliartoreersut. Aarrit ussuillu imap natermiunik nerisaqqartuupput taamaattumillu nerisaminnut ilanngullugu oliamik iijoraasinnaallutik. Nannut eqqornerlukkuminartorujussuupput oliaarluernerminnik aluttuisaramik taamalu oliakku iijorakkamikkut toqunartortaqalersinnaasarlutik. Arfiviit tamaaniittut uumasoqatigiinnut 1900-ikkut ingerlanranni nungutaangajalluinnarsimagaluarlutik aatsaat siumut saannialersuupput. Arferit tamakkua ikittuinnaapput aammalu toqorarnerulernerup annikikkaluartup arfeqatigiit naqqikkiartulernerat sunnernerlussinnaavaa.

Immami sikulimmi oliaarluerneq qularnanngitsumik imarnersani sikutallu ataanni katersuutissaaq taamaalillunilu timmissanut miluumasunullu imarmiunut imarnersanik eqalugaasallu piaraannik sikup aterpiannguaniittartunik pisariaqartitsisunut sunniuteqassalluni.

Aalisarneq piniarnerlu oliarasattut taamaattunillu ingerlatsiviusut matuneqarnerisigut sunnersimaneqalersinnaapput. Taamaaliortoqassaaq aalisakkat oliarasattumiinnikut taamaattumiissimasinnaasulluunniit pisaralugillu avammut nittarsaanneqannginnissaat siunertaralugu. Oliaarluernikkut aalisarnerup qaammaterpassuarni mattunneqartarneranut assersuutissaqarpoq. Aarleqqutigineqarsinnaavortaaq oliaarluernerup kinguneranik piniagassat ajornarnerulernerat aammalu puisit amiisa oliakoqalersimarnertik pissutigalugu tunineqarsinnaajunnaarnerat.

Misissueqqinnerit allat

Disko West-imi oliasiornissamut tunngatillugu avatangiisinik nalilersuilluni sulineq aallartimmat ilisimasanik pingaarutilinnik nalilersuinermut atorsinnaasunik amigateqarneq erseqqissivoq. Misissuinerit amerlanerusut aallartinneqarput tamatumanilu paasisat pissarsiarineqarsinnaariaraangata nalilersuinermut ilaatinneqartarlutik. Misissuinerilli arlallit suli naammassinngitsut angusaqarfiujumaarput ilaatinneqartariaqartunik. Kiisalu misissuinerit amerlanerusut aallartinneqartariaqarput ingerlatassat erseqqissut aallartinneqassariarpata avatangiisinullu tunngatillugu nalilersuiffigineqassappata.

Misissuinerni ingerlasuni angusat misissuieqqissaarfigineqareerpata avatangiisinut nalilersuinerup uuma ilassutissaa saqqummersinneqarumaarpoq.

Disko West-ip avannaani Baffin Bugtip avannarpasinnerusortaata oliamik ujarlerfigissaa ammaanneqassasoq ilimagineqarpoq, tassungalu atatillugu misissuinerit nutaat aallartinneqassapput ilisimasanik nutaanik tamaani ingerlatat avatangiisinut tunngatillugit nalilersuiffiginissannut atugassanik.

Tunuliaqutaasunik tamakkuninnga misissuinermit inernerit ilisimasallu pigineqareersut databasemut annertuumut katersorneqassapput ingerlatseqatigiinnit elektroniskimik iserfineqarsinnaanngorlugit taakkua kingusinnerusukkut ingerlatanut assigiinngitsunut tunngatillugu avatangiisinik nalilersuisinnaaqqullugit.

1 Introduction

In 2006 the waters off West Greenland between 67° and 71° N (= the Disko West Area) were opened for hydrocarbon exploration and licences are expected to be granted in March 2007. The area includes the northeastern part of the Davis Strait and the southeastern part of Baffin Bay, with Disko Island as the most prominent landscape on the Greenland coast.

This document comprises a strategic environmental impact assessment (SEIA) of expected activities in the Disko West area. It is developed as a co-operation between the Bureau of Minerals and Petroleum (BMP), the National Environmental Research Institute (NERI) and the Greenland Institute of Natural Resources (GINR). In support of the SEIA a number of background studies have been initiated.

We have in the assessment used many sources of knowledge, including impact assessments of oil activities from more or less similar areas. Especially the recent assessment from the Lofoten-Barents Sea area in Norway (Anonymous 2003) has been drawn upon for comparison of potential impacts, because the environment there is in many respects comparable to West Greenland waters.

Several studies were initiated to supplement the background knowledge and fill data gaps relevant to this assessment. Some of these are still in progress and only preliminary results have been available for this assessment.

This assessment was prepared by Anders Mosbech, David Boertmann and Martin Jespersen (all NERI).

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 licence area and adjacent areas which may potentially be impacted by the activities. It identifies major potential environmental effects associated with expected offshore oil and gas activities. The SEIA will also identify knowledge and data gaps, highlight issues of concern, and make recommendations for mitigation and planning. 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 dealt with by the companies applying for oil concessions.

Finally, an important issue in this context is climate change. This affects both the physical and the biological environment; for example, the ice cover of the Disko West Area is expected to be reduced, which again will impact wildlife dependent on ice, such as polar bears. Much of the data used for this SEIA has been sampled over a number of decades and as oil activities, particularly development and exploitation, may be initiated more than 10 years from now, the situation then may be very different from that when data was sampled.

1.1 Coverage by the SEIA

The offshore waters and coastal areas between 67° N to 72° N (from Sisimiut town and northwards to southern Upernavik district) are in focus, as this is the region which potentially can be most affected by the activities, particularly from accidental oil spills (Figure 1) originating from the licence areas within the Disko West area. The area will be referred to as 'the assessment area'. However, the oil spill trajectory model developed by DMI indicates that oil may drift further, outside the boundaries of this area (Nielsen et al. 2006).

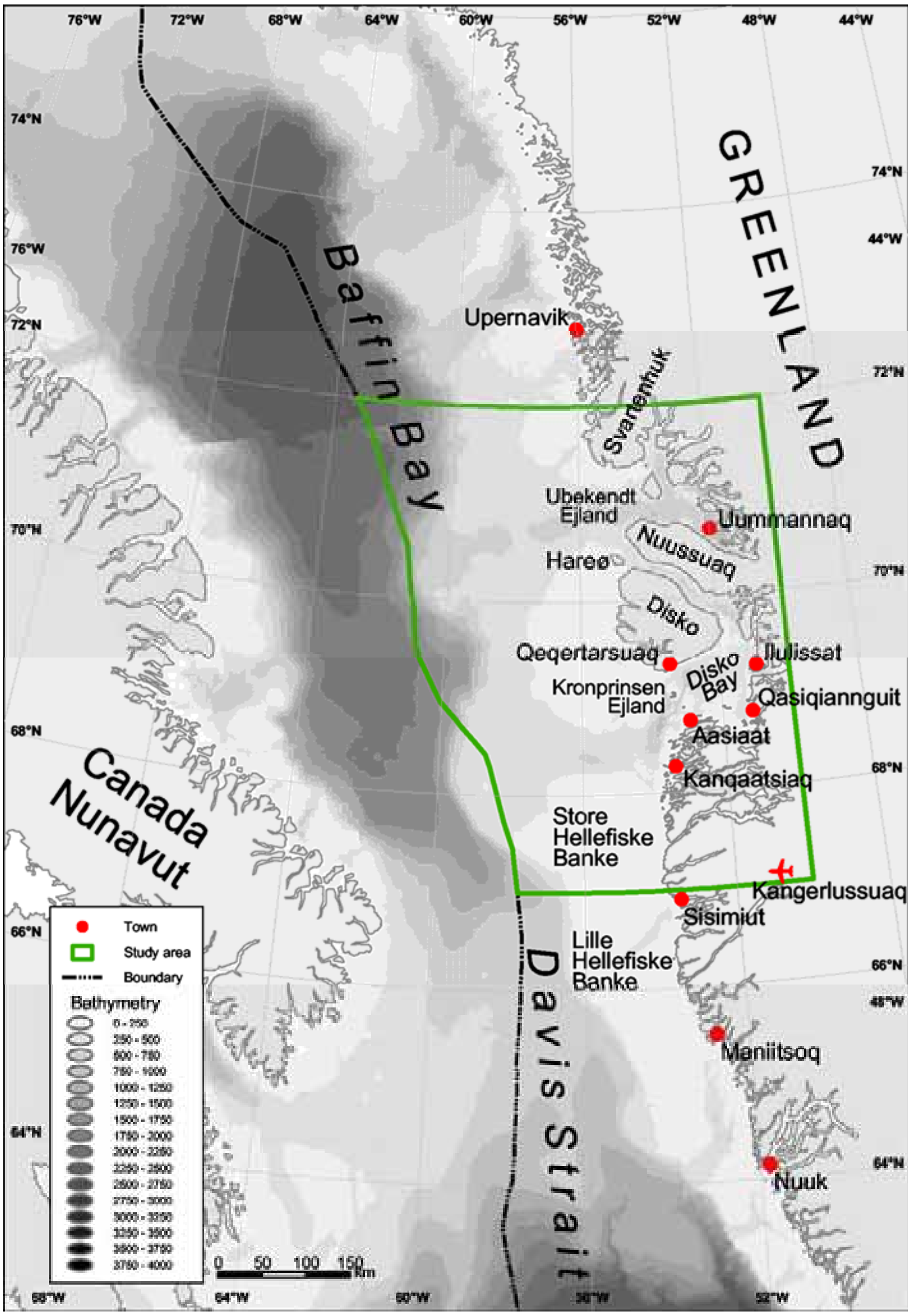


Figure 1. The assessment area and adjacent land areas and waters.

1.2 Abbreviations and acronyms

BAT = Best Available Technique
bbl = barrel of oil
BEP = Best Environmental Practice

BMP = Bureau of Mineral and Petroleum, Greenland Homerule Government
BTX = Benzene, Toluene and Xylene components in oil
DMI = Danish Meteorological Institute
EIA = Environmental Impact Assessment
FPSO = Floating Production, Storage and Offloading unit
GEUS = Geological Survey of Denmark and Greenland
GINR = Greenland Institute of Natural Resources
GBS = Gravity Based Structure
HSE = Health, Safety and Environment
ICES = International Council for the Exploration of the Sea
LRTAP = Convention on Long-Range Transboundary Air Pollution
MARPOL = International Convention for the Prevention of Pollution from Ships
NAO = North Atlantic Oscillation
NERI = National Environmental Research Institute, Denmark.
OSPAR = Oslo-Paris Convention for the protection of the marine environment of the Northeast Atlantic
PAH = Polycyclic Aromatic Hydrocarbons
PLONOR = OSPARs list over substances which Pose Little Or No Risk to the Environment
PNEC = Predicted No Effect Concentration
ppm = parts per million
ppb = parts per billion
SEIA = Strategic Environmental Impact Assessment
TPH = Total Petroleum Hydrocarbons
USCG = United States Coast Guard
VOC = Volatile Organic Compounds
WSF = Water Soluble Fraction.

2 Summary of petroleum activities

All activities of an oil/gas field include several phases which to some degree overlap. The phases include exploration, field development and production, and finally decommissioning. The main activities during exploration are seismic surveys, exploration drilling and well testing. During field development, drilling continues (production wells, injection wells, delineation wells), and production facilities, pipelines and shipment facilities etc. are constructed. Production requires maintenance of equipment and, during decommissioning, structures and facilities are abandoned or removed. These phases will occur over many years, usually several decades. For example, in the North Sea, oil exploration started in the 1960s and petroleum activities still continue today.

The purpose of seismic surveys is to locate and delimit oil/gas fields, to identify drill sites and later during production to monitor developments in the reservoir. Marine seismic surveys are usually carried out by a ship towing a sound source and a cable with hydrophones which receive the echoed sound waves from the seabed. The sound source is an array of airguns that generates a powerful pulse at 10-second intervals. Sound absorption generally is much lower in water than in air, causing the strong noise created by seismic surveys to travel very long distances, and the potential for disturbance of marine animals is high. Regional seismic surveys are characterised by widely spaced (many kilometres) survey lines, while the more localised surveys (2D and 3D seismics) usually cover small areas with densely spaced lines. Vertical seismic profiles (VSPs) are essentially small-scale seismic surveys carried out during exploration drilling. They are highly localised and of short duration (a few days), and their effects will be covered by the discussion of seismic surveys in general.

Exploration drilling will follow the seismic surveys. Offshore drilling takes place from drill ships or semi-submersible platforms and, to date, both types have been used in Greenland waters. Jack-up rigs, on the other hand, stand on the seabed, and most of the potential oil exploration areas in West Greenland waters are too deep for this kind of rig. It is assumed that the drilling season in the waters west of Disko Island is limited to summer and autumn by the presence of ice and harsh weather conditions during winter and spring. Drilling requires the disposal of cuttings and drill mud. In the strategic EIA of the Lofoten-Barents Sea area it is assumed that approx. 450 m^3 cuttings are produced and approx. 2,000 m^3 mud is used per well (Akvaplan-niva & Acona 2003). Energy consumption is very high during drilling, resulting in emissions of combustion gases such as CO_2, SO_2 and NOx.

Many other activities take place during the exploration phase and may have environmental impacts; among these is helicopter transport.

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

Field development also includes extensive drilling activities: delineation wells, injection wells, etc., and drilling will take place until the field is fully developed. An oil development feasibility study in the sea west of Disko (APA 2003) 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. From the production facility crude oil subsequently has to be transported by shuttle tankers to a transshipment terminal, most likely in Canada.

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

Concerns during production relate to the large amounts of production water, which can contain oil residues and other chemicals, which have to be disposed of, and again to the large amounts of greenhouse and other combustion gasses from machinery and the flaring of excess gas.

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

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

Serious and acute environmental concerns arise during accidents and off-normal operations. A large oil spill has the potential to impact the environment over an extensive area and for many years particularly in the coastal marine environment.

3 Physical environment

The assessment area lies within the Arctic climate zone, which means that the average July temperature does not exceed 10° C. The Arctic zone is divided into the low Arctic (average July temperature higher than 5° C) and the high Arctic (average July temperature below 5° C). The northern part of the assessment area is close to the high Arctic. The most significant feature in the physical marine environment is the presence of icebergs and sea ice throughout a large part of the year (Section 4.5) and inland permafrost is widespread. The assessment area is north of the Polar Circle; therefore, continuous daylight is present for a period in summer, and in winter there is a period of near continuous darkness.

The offshore parts of the assessment area are the northeastern Davis Strait and southeastern Baffin Bay. The shelf is the rather shallow waters (depths less than 200 m) near the coast. This shelf includes several large shoals or banks, which typically range between 20 and 200 m in depth (Figure 1). In the southern part of the assessment area the shelf is up to 120 km wide, while in the northern part it is narrower and less well defined towards the deep sea. The shelf is traversed by deep troughs, which separate the fishing banks. There is deep water down to 2,500 m to the west of the shelf.

3.1 Weather

The weather conditions in the area are influenced by the North American continent and the North Atlantic Ocean, but also the Greenland Inland Ice and the steep coasts of Greenland have a significant impact on the local weather. Many Atlantic depressions develop and pass near the southern tip of Greenland and cause frequently very strong winds off West Greenland. Also more local phenomena such as fog or polar lows are common features near the West Greenland shores. The probability of strong winds increases close to the Greenland coast and towards the Atlantic Ocean. Detailed descriptions can be found in the sensitivity map of the region prepared by NERI. Link to sensitivity map

3.2 Oceanography

3.2.1 Currents

Along West Greenland the West Greenland current flows with two principal components. Closest to the shore, water from the East Greenland Current (with cold polar water) moves northward. On its way, this water is diluted by run-off water from the various fjord systems. The other component is from the North Atlantic Current deriving from the Irminger Sea. This relatively warm and salty water can be traced all the way along West Greenland from Cape Farewell to Thule (Qaanaaq). See Figure 2. The East Greenland Current component loses its momentum on the way northward, and at the latitude of Fylla Bank (64° N) it turns westward towards Canada where it joins the Labrador Current.

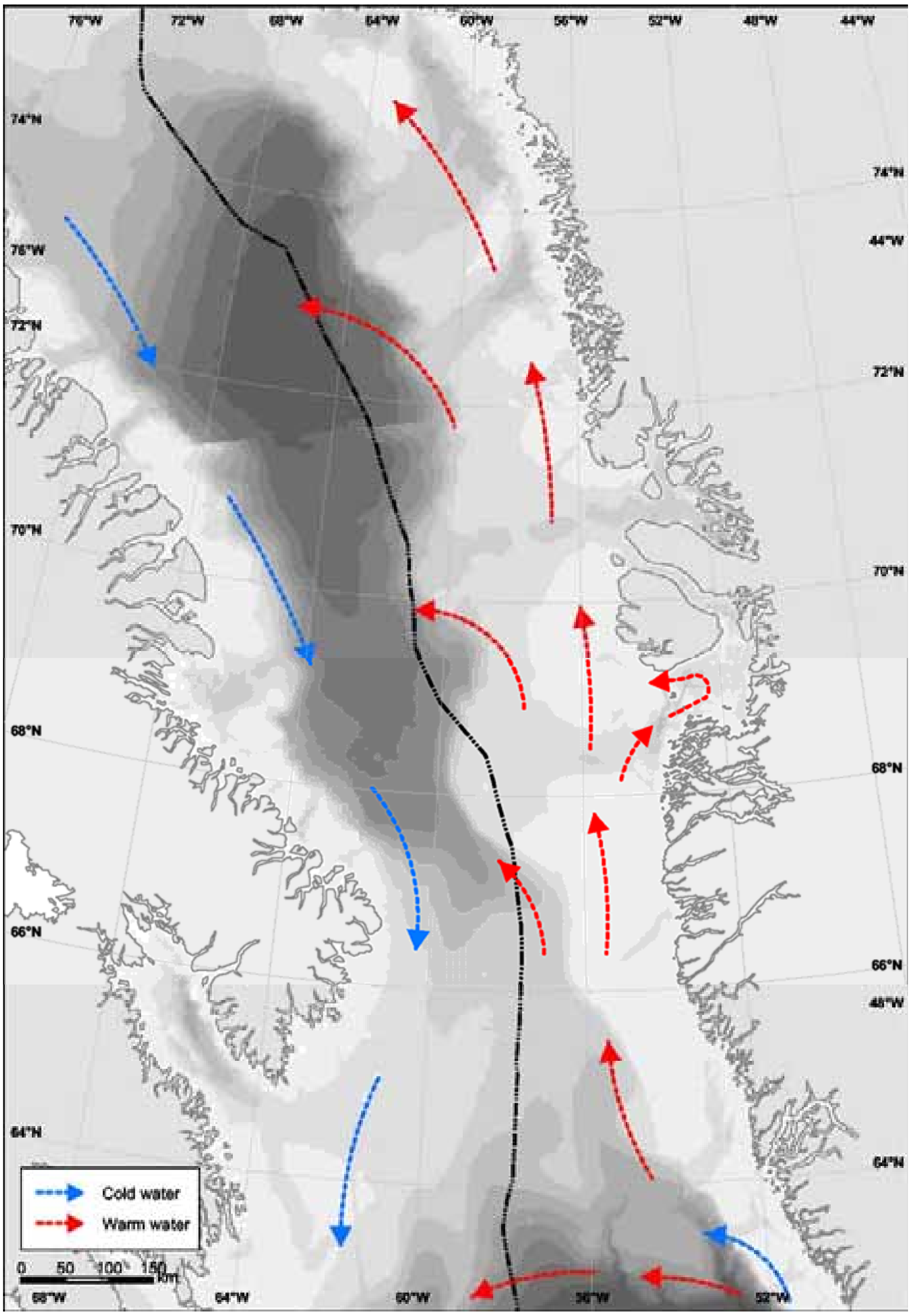


Figure 2. Overall current pattern in Davis Strait and Baffin Bay. Red indicates relatively warm water from the Atlantic, which mixes with relatively cold water (from the East Greenland Current) along the West Greenland coast to form the West Greenland Current. The cold water moving southwards in eastern Baffin Bay is the Baffin Current, which further south becomes to the Labrador Current.

The polar water inflow is strongest during spring and early summer (May-July). The inflow of Atlantic water masses is strongest during autumn and winter explaining why the waters between 62° and 67° N usually are ice free during winter time.

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

3.2.2 Hydrodynamic discontinuities

Hydrodynamic discontinuities are areas where different water masses meet with sharp boundaries and steep gradients between them. They can be upwelling events where cold nutrient water is forced upwards to the upper layers, fronts between different water masses and ice edges inclusive the marginal ice zone. Upwelling occurs often along the steep sides of the fishing banks driven by the tidal current, with upwelling thereby usually alternating with downwelling. Hydrodynamic simulations performed as part of this assessment programme reveal a significant upwelling area around Hareø in the mouth of Vaigat and a prominent upwelling area at the northeast corner of Store Hellefiskebanke, where a deep wedge cuts southwards between the bank and the coast.(Figures 3 and 4). Further model simulations south of the assessment area predict that upwelling also occurs west of the banks and, to a lesser extent, in the deep channels separating the banks (Pedersen et al. 2005).

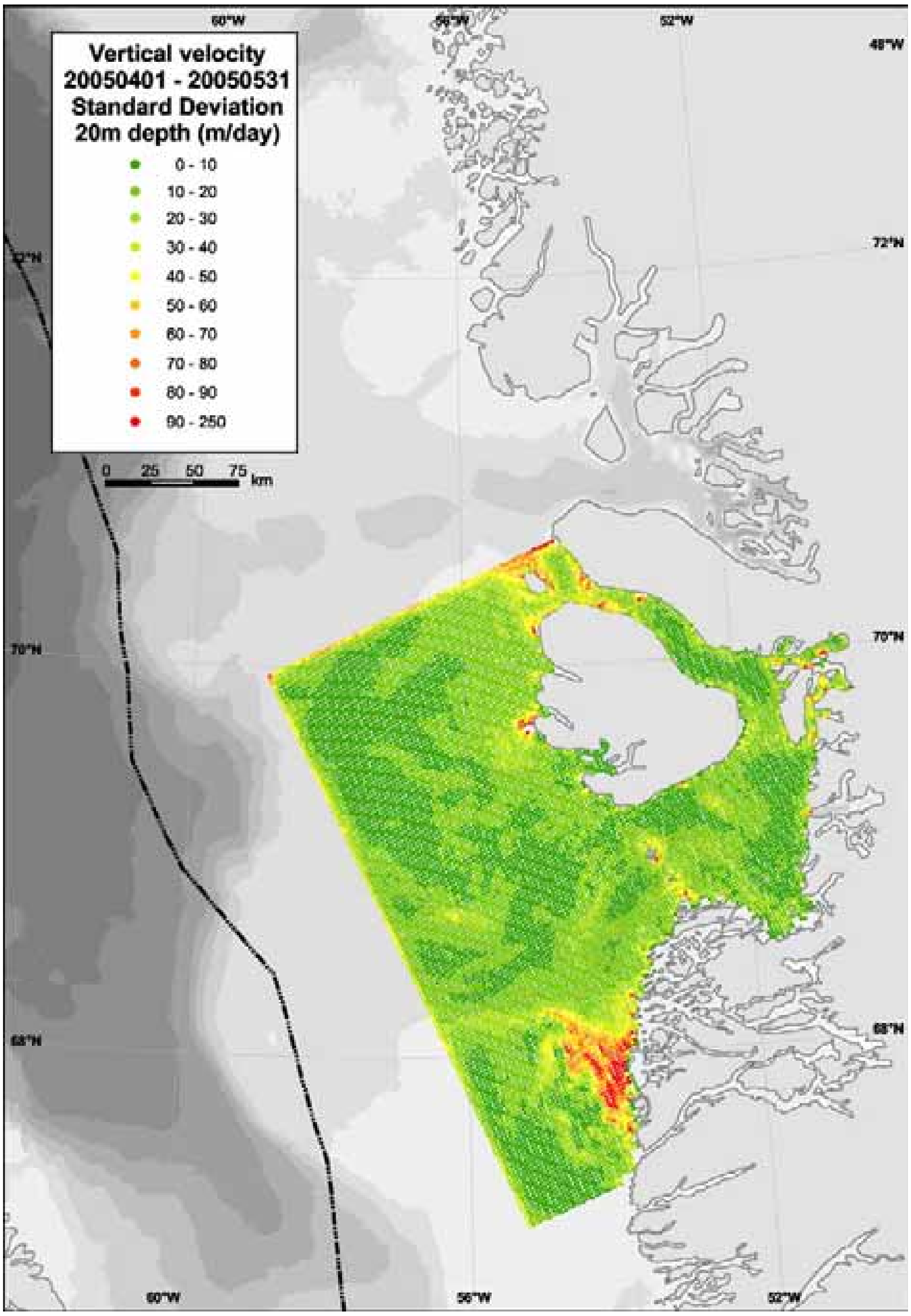
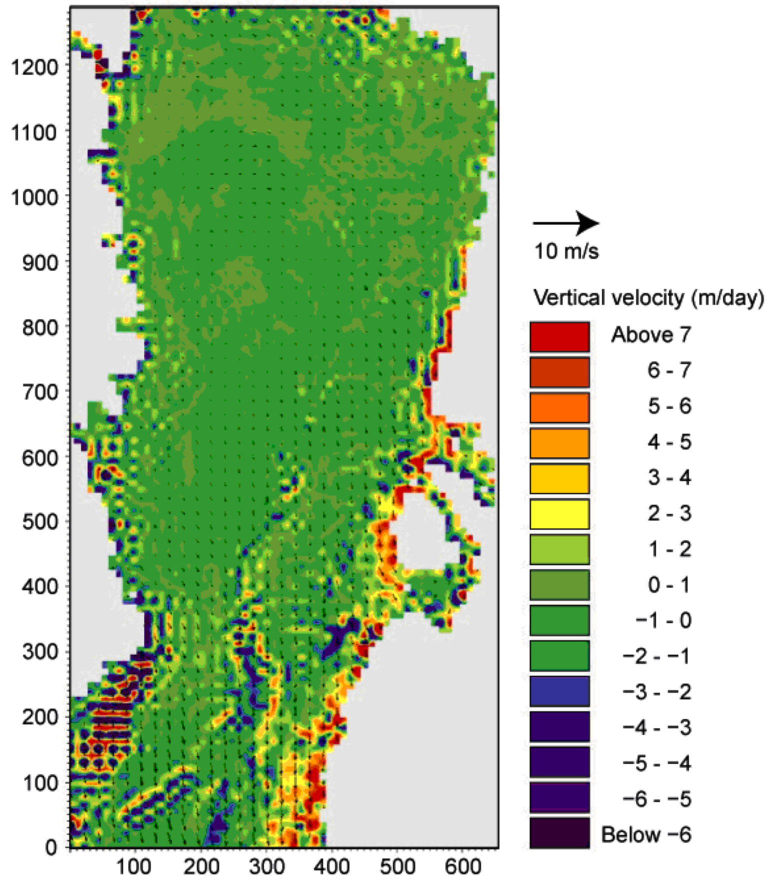


Figure 3. Areas with high rates of upwelling and downwelling as indicated by the standard deviation of the vertical speed. The standard deviation is calculated based on all the raw hourly data from the fine scale DMI-model (DIS) within the period from 20050401 to 20050531 (at 20 m depth), in total 1463 time steps of 1 hour (NERI/DMI).

Figure 4. Model results, when using a Hybrid Coordinate Ocean Model (HYCOM), showing the daily mean value of vertical velocity at 20 m. depth, and wind speed in Baffin Bay. The present figure show daily mean value on the 24th of April, 2005, but it shows a frequent model feature during spring. The colour scale shows the daily mean value of upwelling velocity (m day-1), and the arrows show wind speed. Large vertical velocity suggests up/down-welling or large mixing at 20 m. depth. For this specific date there is strong upwelling along the Greenland west coast, especially near the Store Hellefiskebanke, which has an approximate coordinate on the map at (300,300). Large vertical velocities as presented here is a very common model feature during late winter and spring 2005. The present model set up is described in detail in Ribergaard et al. (2006).



3.3 The coasts

South of Disko Bay the coasts are dominated by bedrock shorelines with many skerries and archipelagos. Small bays with sand or gravel are found between the rocks in sheltered areas. In western Disko Bay and further north, the coasts are straighter and often made up from sediments like sand or gravel. On Disko Island and Svartenhuk Peninsula there are several large river deltas with extensive tidal flats.

In terms of shoreline length, the 'rocky coast' is by far the dominant shore type (61%). 'Rock' is the dominant substrate (71%); 'inclined' is the dominant slope (58%) and 'semi-protected' is the dominant exposure type (60%). The majority of the coasts within the 'archipelago' shore type are rocky coasts. Together the 'archipelago' and 'rocky coast' shore types constitute 72% by length of the total investigated shoreline within the assessment area (Mosbech et al. 2004).

3.4 Ice conditions

Two types of sea ice occur in the assessment area: fast ice, which is stable and anchored to the coast, and drift ice, which is very dynamic and consists of floes in varying size and degree of density. The drift ice is often referred to as 'The West Ice' because it is formed to the west of Greenland. In addition to sea ice, icebergs originating from calving glaciers are very frequent. The description of ice conditions given here is based on a DMI contribution to the Oil Spill Sensitivity Atlas covering the assessment area (Mosbech et al. 2004). As part of the preparations for oil activities in the assessment area, BMP has initiated a number of new studies of sea ice distribution, and thickness and movements of ice floes; so the information on ice condition presented in this section will soon be updated and will be available on the information CD prepared by GEUS and NERI.

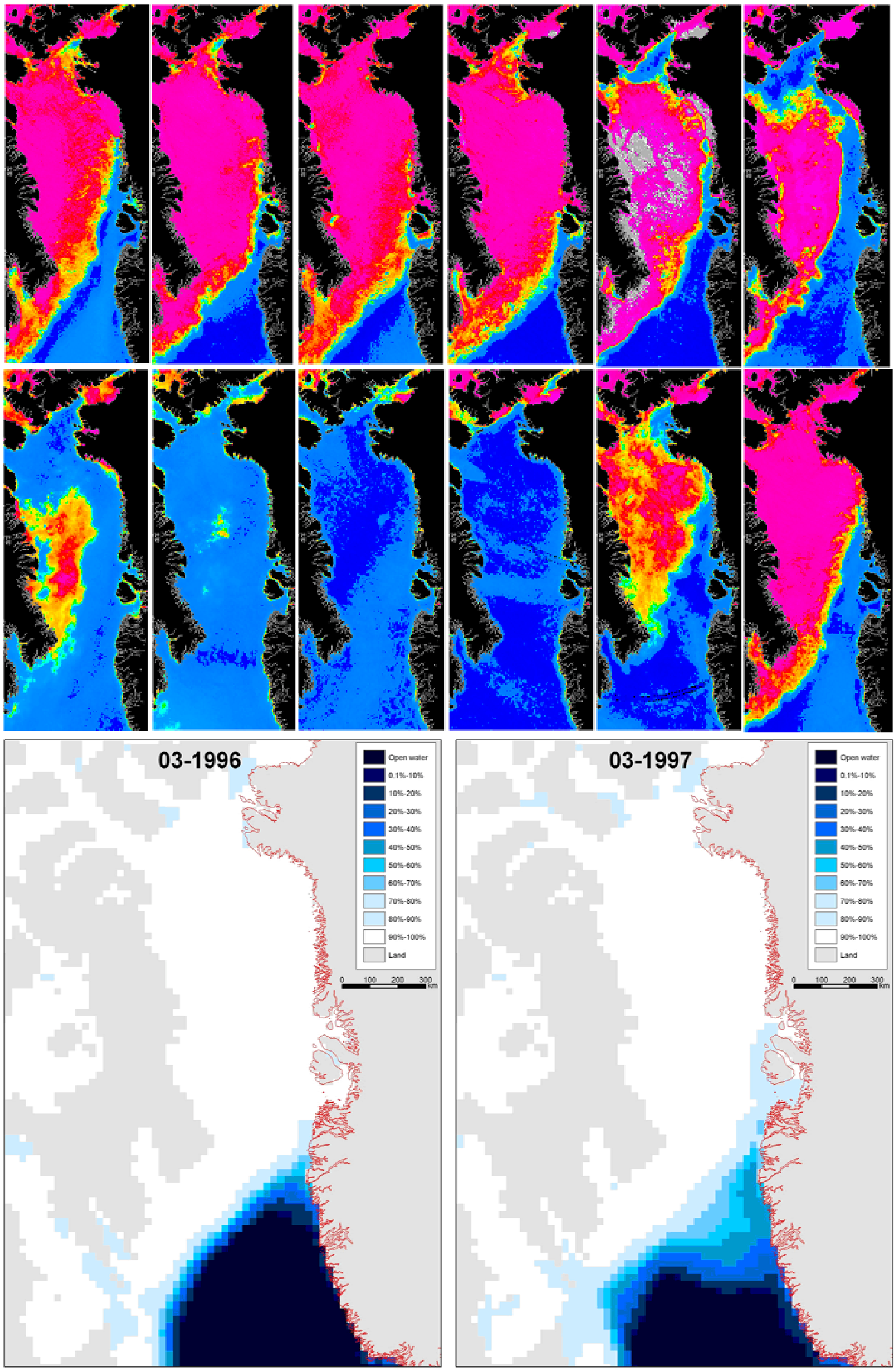
The West Ice

The ice conditions between 60° N and 72° N are primarily determined by the relatively warm north or northwest flowing West Greenland Current and the cold south flowing Baffin Current. The West Greenland Current delays the time of ice formation in the eastern Davis Strait and results in an earlier break up than in the western parts. The Baffin Island Current conveys large amounts of sea ice from Baffin Bay to the Davis Strait and the Labrador Sea for most of the year, especially during the winter and early spring months. During this period sea ice normally covers most of the Davis Strait north of 65° N, except areas close to the Greenland coast, where a flaw lead (open water or thin ice) of varying width often appears between the shore or the fast ice and the drift ice offshore as far north as latitude 67° N. South of 65-67° N, sea ice-free areas dominate throughout the year. The marginal ice zone of the drift is normally oriented to the southwest towards Hudson Strait or the Labrador Coast. In the beginning of the melt season a wide lead- or polynya-like feature often forms west of Disko Island and in front of Disko Bay. The eastern part of the Davis Strait, south of Disko Island, is free of sea ice during this period (Figures 5 and 6) whereas drifting ice dominates to the west and north.

The predominant sea ice type in the Davis Strait and Baffin Bay is first-year ice. Small amounts of multi-year ice of Arctic Ocean origin drift to the western parts of the area from Lancaster Sound or Nares Strait; however, the multi-year ice from these waters does not usually reach the West Greenland shores. At the end of the freeze-up season, first-year ice in the thin and medium categories dominates in eastern parts (up to about 100 km from the Greenland coast). The western and central parts of the Davis Strait and southern Baffin Bay are dominated by medium and thick first-year ice categories, mixed locally with small amounts (1-3 tenths) of multi-year ice.

The dominant size of ice floes range from large floes of about 1 km wide to vast floes larger than 10 km. Near the marginal ice zone in the Davis Strait, the size of the common floes are reduced to less than 100 metres as a result of melting and break up by waves. These floes are often consolidated, forming extensive areas without any open water. In recent years both the extension of the winter ice and the ice cover period have been reduced (Stirling & Parkinson 2006).

Figure 5. Monthly sea ice cover in 2004 and maximum (March) extend of sea ice in 1996 and 1997. Based on Multichannel Microwave Radiometer (AMSR and SMMR) and Defence Meteorological Satellite Program (DMSP). There has been less ice cover in the recent decade.



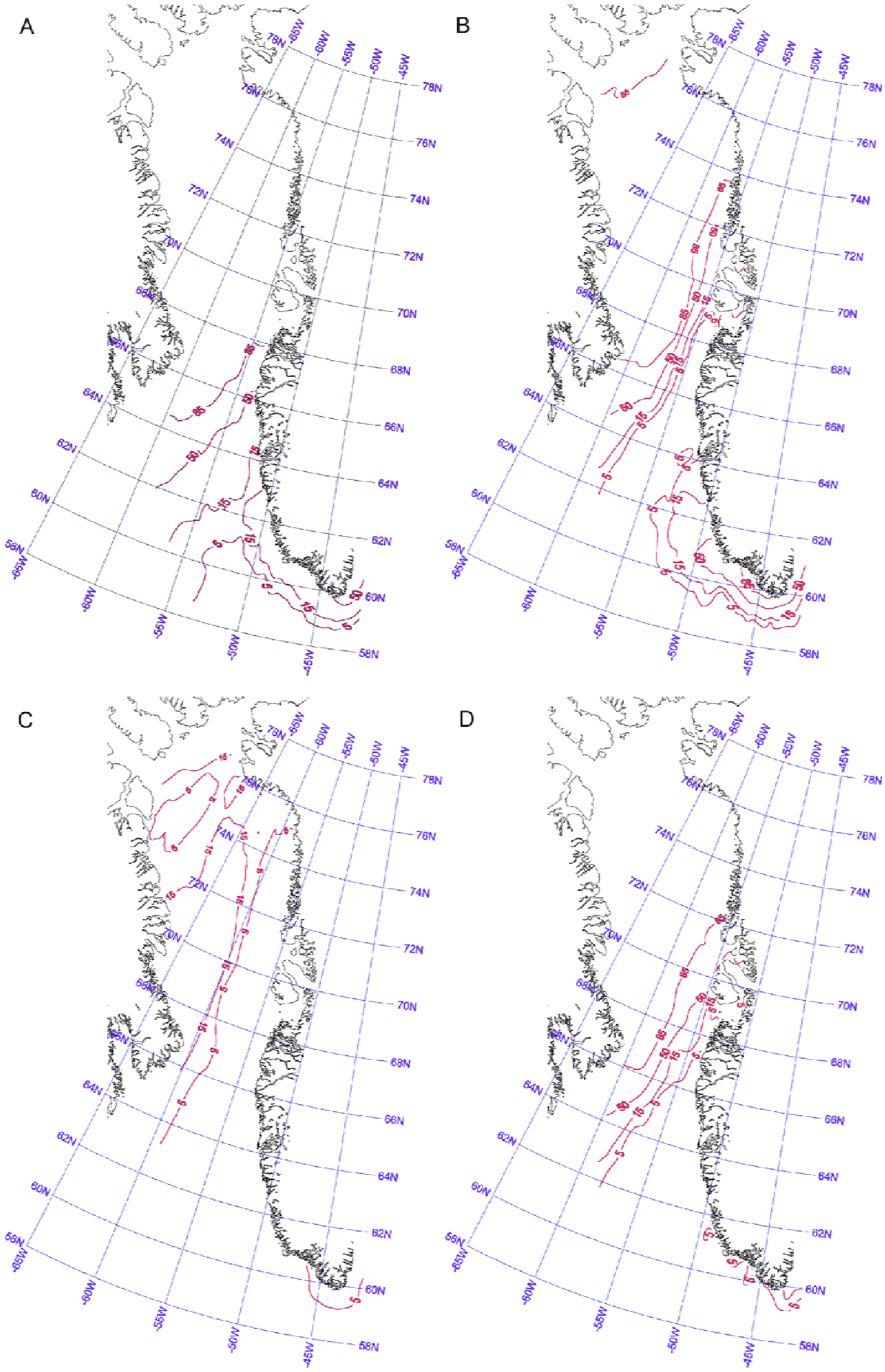


Figure 6. Probability of sea ice in West Greenland waters based on data from the period 1960-96. (A) March 1st, (B) June 4th, (C) September 3rd and (D) December 3rd (Data sources: Danish Meteorological Institute and Canadian Ice Service).

3.4.1 Sea ice drift

The drift pattern of the sea ice off West Greenland is not very well known. The local drift is to some extent controlled by the major surface current systems, the West Greenland Current and Baffin Island Current; however, the strength and direction of the surface winds also affect the local drift of sea ice, especially in the southern waters.

Isolated from the offshore ice conditions, sea ice forms locally throughout the winter in most of the fjords and coastal waters of the region. Generally freeze-up begins at the inner parts of the fjords in November or December, but very low temperatures can significantly affect the ice formation, or a formed ice cover can be reduced by very strong winds in the fjords throughout the winter.

In recent years ice has not formed, or only reduced amounts and for limited time periods, in Disko Bay and in Uummannaq Fjord. Although large local differences are to be expected, the southern shorelines (Disko Bay) are generally free of sea ice from late May until November or December. Towards the north (Uummannaq Fjord) the ice-free periods generally persist from mid-June until November.

In April 2006 two satellite transmitters were deployed on the sea ice, west of Nuussuaq Peninsula. Their purpose was to track the movements of the drift ice. One was tracked until June, when it had moved approx. 500 km in total (entire length of track line), but overall it had only moved 66 km towards the southwest. The second transmitter was only tracked for a couple of days, when it moved 21 km towards the south (Figure 7).

3.4.2 Polynyas

Polynyas are open waters in otherwise ice-covered waters. They are predictable in time, and are of a high ecological significance.

The entire open water area along the southwest Greenland coast acts as a large polynya despite that is open to the south, but further north along the coast there are several areas where open water is always present, or at least in spring. During a typical spring these are progressively included in the open waters advancing from the south. The most significant polynyas are found in fjord mouths where the tidal currents keep the water free of ice, as for example in the mouth of Vaigat. Also the open waters in the Disko Bay mouth may be a polynya, although they are often connected to the open waters further south.

3.4.3 Icebergs

Icebergs differ from sea ice in many ways:

- they originate from land
- they produce fresh water on melting
- they are deep-drafted and with appreciable heights above sea level
- they are always considered as an intense local hazard to navigation and offshore activity

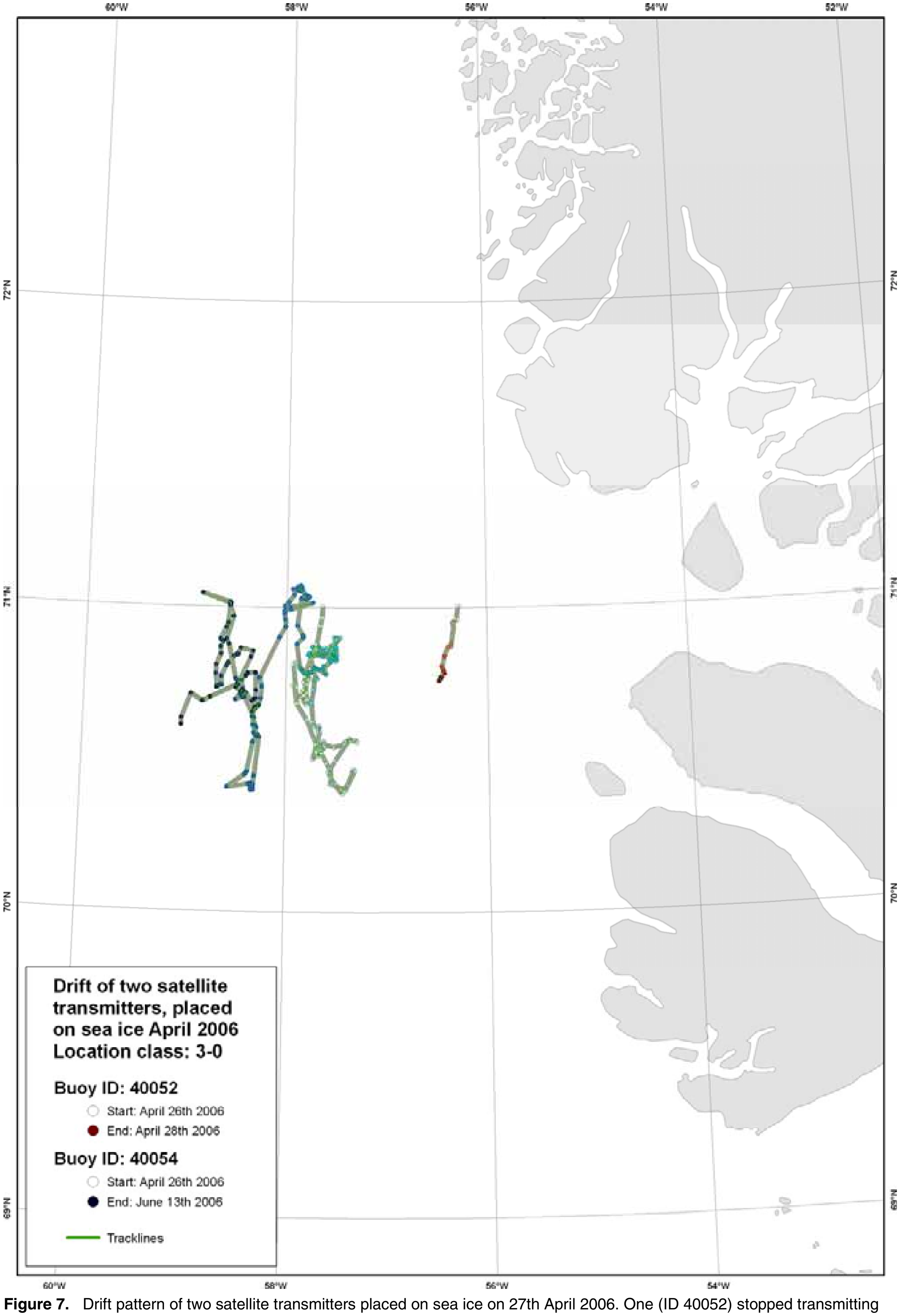


Figure 7. Drift pattern of two satellite transmitters placed on sea ice on 27th April 2006. One (ID 40052) stopped transmitting after 2 days when it had moved 21 km southwards. The other transmitter ID 40054)) was tracked until June 13th. The drift track is app. 500 km, but over all it moved 66 km towards southwest (Study carried out at the request of BMP and GEUS).

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

Type	Height (above sea level)	Length
growler	less than 1 m	up to 5
bergy bit	1 to 5 m	5 to 15 m
small iceberg	5 to 15 m	15 to 60 m
medium iceberg	16 to 45 m	61 to 120 m
large iceberg	46 to 75 m	121 to 200 m
very large iceberg	Over 75 m	Over 200 m

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

Iceberg sources

Glaciers are numerous in West Greenland; however, the productive glaciers are concentrated between Nares Strait and Disko Bay. Although icebergs occur throughout the West Greenland waters between 60° N and 72° N, they are rare in some areas, e.g. off Sisimiut. In other areas, e.g. in Disko Bay, hundreds of icebergs are always present (Figure 8).

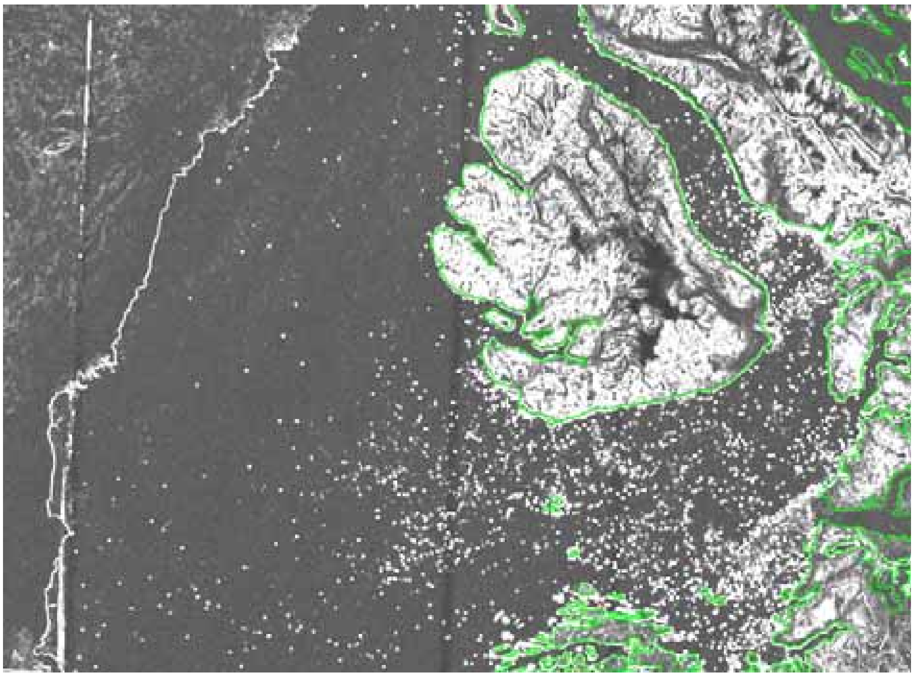


Figure 8. Radarsat PMR-filter image from June 14th 1999 20 UTC of the Disko Bay area showing the distribution of large icebergs (white dots).

Melville Bay north of Upernavik municipality is a major source of icebergs. Over 10,000 icebergs are calved from 19 major glaciers each year (Figure 9). Some of these are capable of producing icebergs of about 1 km in diameter. Several active glaciers in Uummannaq Fjord and Disko Bay produce 10-15,000 icebergs per year, and they are very important for the iceberg input to the northern Davis Strait and Baffin Bay. The most active glacier is located near Ilulissat, moving at the rate of 20 m/day. This glacier produces over 20 km^3 of ice per year. The total annual production of icebergs calved in the Baffin Bay and the northern Davis Strait is estimated to be about 25-30,000; estimates however vary, up to as high as 40,000. Surveys conducted by the USCG International Ice Patrol decades ago indicate that the total number of icebergs in Baffin Bay and the northern Davis Strait are of the same order of magnitude. Almost no icebergs are produced south of Disko Bay. Here the fjords are longer, narrower and shallower than in the northern areas of the Greenland west coast, and the calving is in the form of growlers and bergy bits rather than icebergs. Growlers and bergy bits nearly always melt before reaching the open sea.

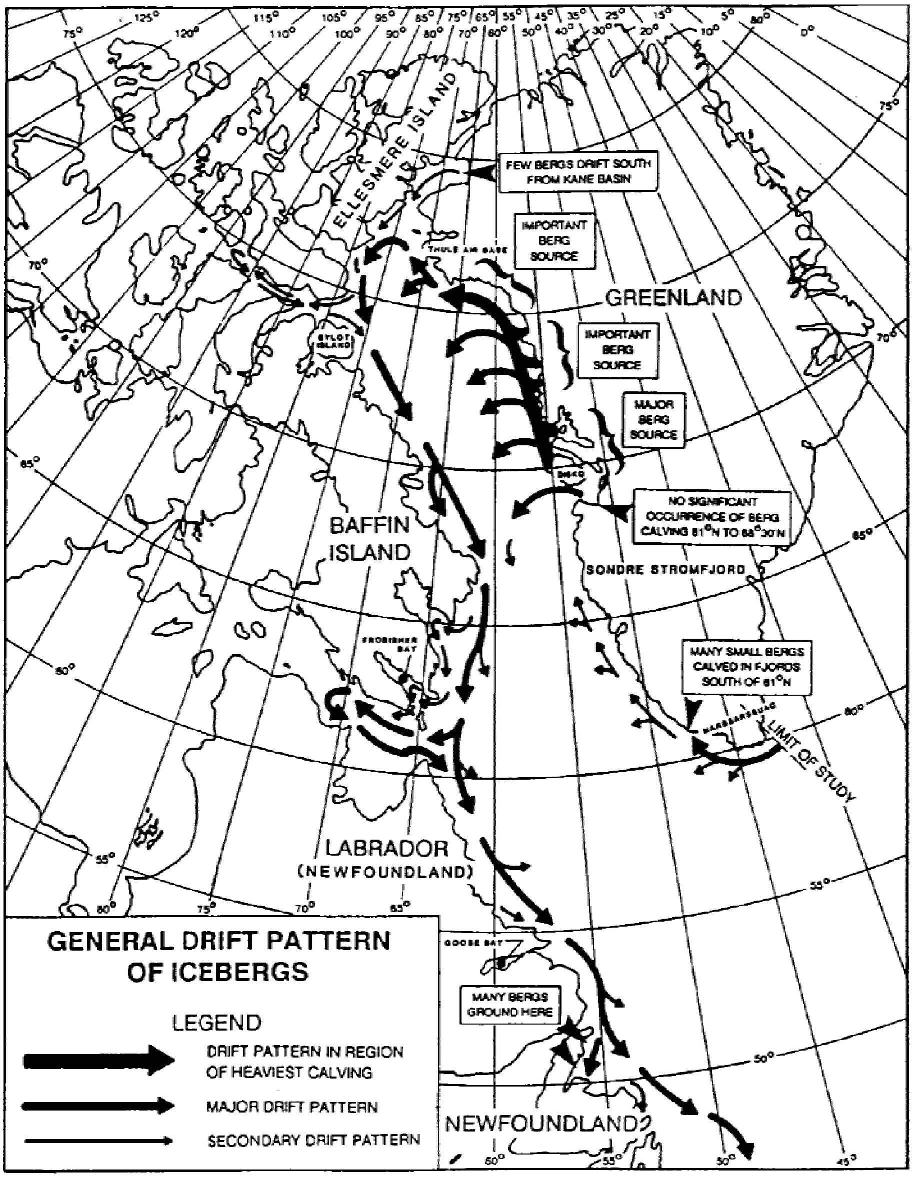


Figure 9. Major iceberg sources and general drift pattern in the West Greenland Waters. (US National Ice Center, Washington DC).

Iceberg drift and distribution

On a large scale the basic water currents and drift of icebergs in Baffin Bay and the northern Davis Strait are fairly simple. There is a north-flowing current along the Greenland coast and a south-flowing current along Baffin Island and the Labrador coast, giving an anti-clockwise drift pattern. However, branching of the general currents causes variations, and these can have a significant impact on the iceberg population and their residence time. Although the majority of icebergs from Disko Bay are carried northward to northeastern Baffin Bay and Melville Bay before heading southward, icebergs have also been observed to be diverted into one of the west-branching eddies without passing north of 70° N. Most of the icebergs from Baffin Bay drift southward in the western Davis Strait, joining the Labrador Current further south, although some may enter the eastern Davis Strait area west of Disko Island instead. Icebergs produced in Disko Bay or Baffin Bay generally will never reach the Greenland shores south of 68° N. Many icebergs produced in the Disko Bay enter the Davis Strait, partly to the north of Disko Island through Vaigat and partly along the southern coast of Disko Island. Some icebergs manage to drift towards or into southern Disko Bay from the Davis Strait due to the onshore component of the currents west of Aasiaat. Icebergs south of Sisimiut are of East Greenland origin.

In a study in the late 1970s, the lowest iceberg densities in West Greenland were found at the northern part of Lille Hellefiskebanke and at the southern part of Store Hellefiskebanke between 65° and 66° N. Iceberg densities increased both towards north and south. The density of icebergs in Disko Bay was significantly higher than outside the bay, with maximum concentrations of icebergs occurring in the northeastern part of Disko Bay (Figure 8). The iceberg density generally was highest in early summer, except in the area near Disko Bay where the highest density was seen in late summer, probably due to higher calving activity of the glaciers during the summer months. A similar distribution can be derived from data from USCG International Ice Patrol and the Canadian Ice Service and can also be observed by shipping companies operating in the area.

Iceberg dimensions

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

In the eastern Davis Strait the largest icebergs were most frequently found south of 64° N and north of 66° N. South of 64° N, the average mass of an iceberg near the 200 m depth contour varied between 1.4 and 4.1 million tonnes, with a maximum mass of 8.0 million tonnes. Average draft was 60-80 m and maximum draft was 138 m. Between 64° N and 66° N, average masses were between 0.3 and 0.7 million tonnes. The maximum mass was 2.8 million tonnes. Average draft was 50-70 m and maximum draft is estimated to be 125 m.

The largest icebergs north of 66° N were found north and west of Store Hellefiskebanke. The average iceberg mass was about 2 million tonnes with a maximum mass of 15 million tonnes. In Disko Bay, the average mass of icebergs was in the range 5-11 million tonnes with a maximum recorded mass of 32 million tonnes. Average draft was 80-125 m and maximum draft was 187 m. It is worth noting that many icebergs are deeply drafted and, due to the bathymetry, large icebergs will not drift into shallow water regions.

Maximum draft can be evaluated by studying factors which limit the dimension: glacier thickness, topographic factors which cause icebergs to be calved in ‘small’ pieces, and thresholds in the mouths of the fjords with glaciers. The measurements of iceberg drafts north of 62° N indicate that an upper limit for a draft of 230 m will only be exceeded very rarely;

however, no systematic 'maximum draft measurements' exist and the extremes remain unknown. Several submarine cable crushes or breaks have occurred at water depths of about 150-200 metres; the maximum depth recorded was 208 metres, southwest of Cape Farewell. The large icebergs originating in Baffin Bay are expected to have a maximum draft of about 250-300 metres. The largest icebergs recorded in a study in Baffin Bay in 1997 were characterised by a draft of more than 260 metres, a mass of up to 90 million tonnes and a diameter of more than 1,400 metres. Icebergs from the productive Ilulissat glacier pass a sill which allows for a maximum draft of 250 m.

4 Biological environment

The arctic sea off West Greenland is compared to temperate latitudes characterised by a relatively low number of species which however often occur in very high numbers and densities. This means that the food web is less complex than food webs at lower latitudes. The primary production is high and comparable to or even higher than the production at much lower latitudes, but due to the presence of winter ice and the marked variation in solar radiation is it highly seasonal with an intensive phytoplankton spring bloom (Söderkvist et al. 2006).

The following description is divided in sections which cover important ecological components of the biosphere in the assessment area.

4.1 Primary production

The development of the phytoplankton (microscopic algae) spring bloom gives a peak in the primary production in the water column, and it is the single most important event determining the production capacity of arctic marine food webs (Söderkvist et al. 2006). The onset of the bloom varies between years depending on duration of the winter ice cover, oceanography and meteorological conditions. But when the water column is stabilised and stratified, the spring diatom bloom develops exponentially and quickly depletes the surface layers (the euphotic zone) for nutrients. It usually starts in late April and develops through May (Figure 10). A review of the existing data and literature clearly illustrates that the surface distribution of phytoplankton and the occurrence of *Calanus* copepods (a key player in arctic marine food webs) can be used as proxy for high biological activity of the higher trophic levels as well (Söderkvist et al. 2006).

The primary production is initiated by sunlight and a stratified water column in spring, and the production usually depletes the water from nutrients thereby inhibiting the production over some time. At ice edges the spring bloom is often earlier than in ice-free waters due to the stabilising effect of the ice on the water column. However, at sites where nutrients continuously are brought to the uppermost water layers, for example by hydrodynamic discontinuities such as upwelling or fronts, primary production hot spots may occur throughout the summer. Other examples are glacier fronts where the freshwater plume stabilises the water column and brings nutrients to the active layers. Upwelling areas are for example found at the northeastern corner of Store Hellefiskebanke, in outer Disko Bay and around Hareø, and off the most significant glacier front situated in Jakobshavn Isfjord in interior Disko Bay. Seabirds and marine mammals often occur and congregate along ice edges and in the marginal ice zones. Ice edges are not stable in time, and their distribution varies according to oceanographic and climatic conditions. Upwelling areas may, besides enhanced production, also retain copepods which again are utilised by fish larvae (Simonsen et al. 2006). Upwelling events can be predictable in time and persistent over long periods, although those driven by the tidal currents vary with the tidal cycle, and others are wind driven and vary with the wind conditions. Fronts are often short-term phenomena and less predictable in time and space, but are extensively utilised by seabirds, which are able to search large areas and locate such phenomena (Söderkvist et al. 200&).

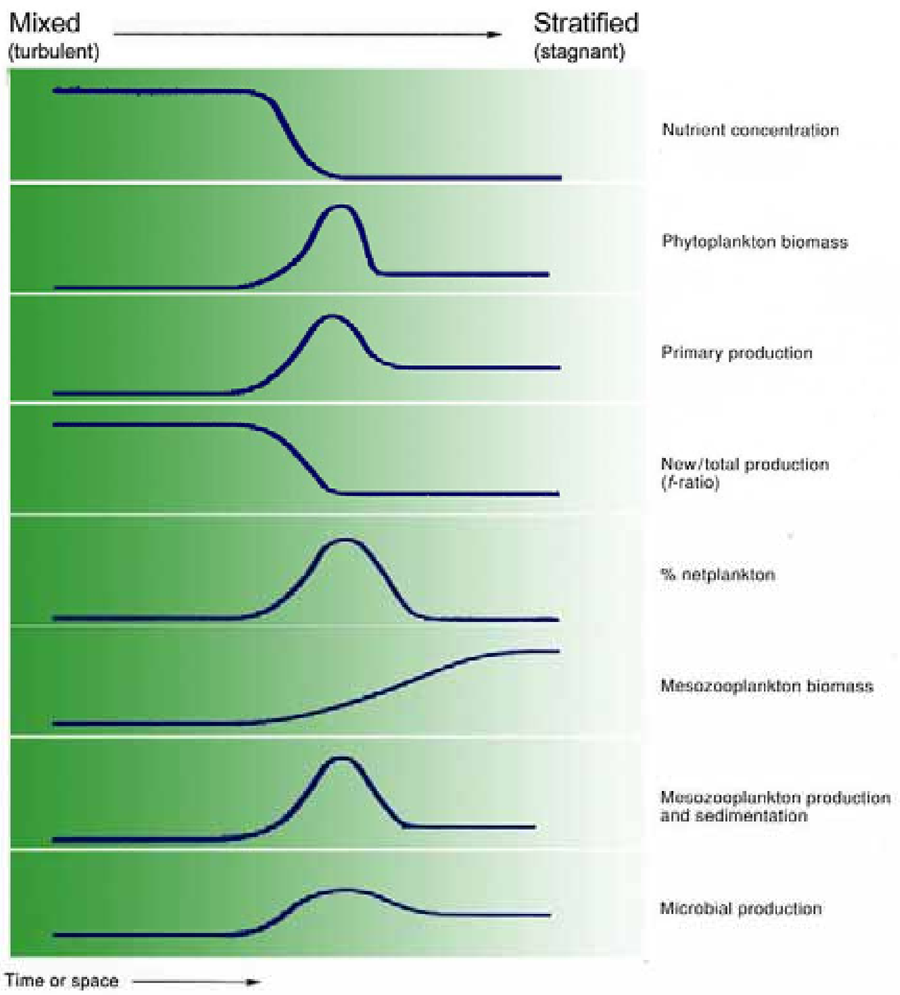


Figure 10. Hydrographical discontinuities are often sites of enhanced biological activity. This can be defined in time, e.g. the shift from mixed water in the winter to stratified water in the spring or in space when two water masses meet or at the marginal ice zone where the frontal zone will provide better growth conditions for plankton and the succeeding links in the food web (Legendre & Demers 1984).

The underside of the sea ice has it own special biological community with algae, invertebrates and fish. In spring when the light increases, this community can be very productive. There is no knowledge on this environmental component for the assessment area.

4.1.1 Polynyas, shear zones and marginal ice zone

Polynyas are predictable open-water areas in otherwise ice-covered waters in winter and spring. In polynyas the primary production starts much earlier than in ice-covered areas; they are often therefore preferred feeding areas for marine mammals and seabirds. However, also the mere presence of open water makes polynyas attractive for resting seabirds and for mammals which are dependent on open waters for breathing. Many migrating seabirds also use polynyas as staging grounds on their way to the breeding grounds further north.

Shear zones are where the solid coastal ice meets the dynamic drift ice. Cracks and leads with open waters are frequent in such areas and may attract marine mammals and seabirds. When the West ice reaches the coasts of the assessment area a shear zone and polynyas (e.g. in the mouth of Vaigat) are usually present.

At the marginal zone of the West Ice, primary production during the spring bloom is very intense and this attracts species higher in the food web including seabirds and marine mammals.

In the spring, April-May 2006, a multidisciplinary ecological survey was conducted in the assessment area with focus on the marginal ice zone. The programme included aerial surveys of seabirds and mammals covering the entire region (Figure 11); ship-based surveys including counts of marine mammals and seabirds alongside biological oceanographic sampling on transects from open water and into the drift ice at the marginal ice zone; and satellite data on primary production obtained from the same period. The research vessel did not have ice-breaking capabilities and generally ship transects did not proceed when ice cover was above 8/10. However, in some situations, when ice thickness and size of floes were manageable for the vessel, samples were taken at locations with ice concentration higher than 8/10. The vessel survey covered Disko Bay, Vaigat, and areas west of Disko and south of Disko including the northern half of Store Hellefiskebanke (Figure 12). From the vessel, oceanographic profiling of the water column and biological sampling were conducted at 116 sampling stations. Sampling included CTD measurements, i.e. depth distribution of salinity and temperature, flourometer measurements i.e. indicating depth distribution of chlorophyll a fluorescence, and water samples for nutrients and chlorophyll as well as net hauls for zooplankton composition and biomass. All these data are in the process of being analysed; however, preliminary results are presented here in the Figures 13 - 15.

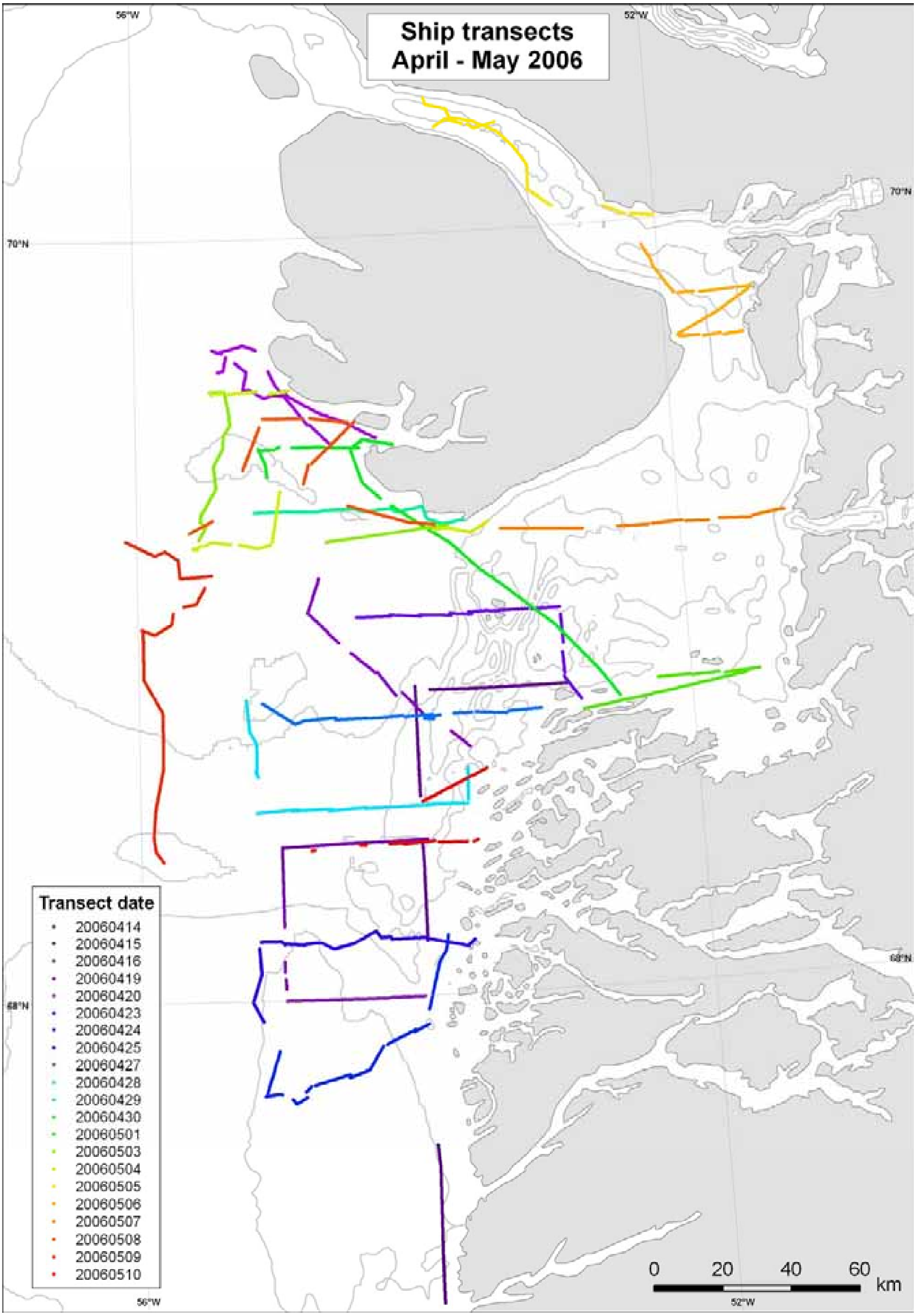


Figure 11. The ship based transects, sailed during the marginal ice zone project in April and May 2006.

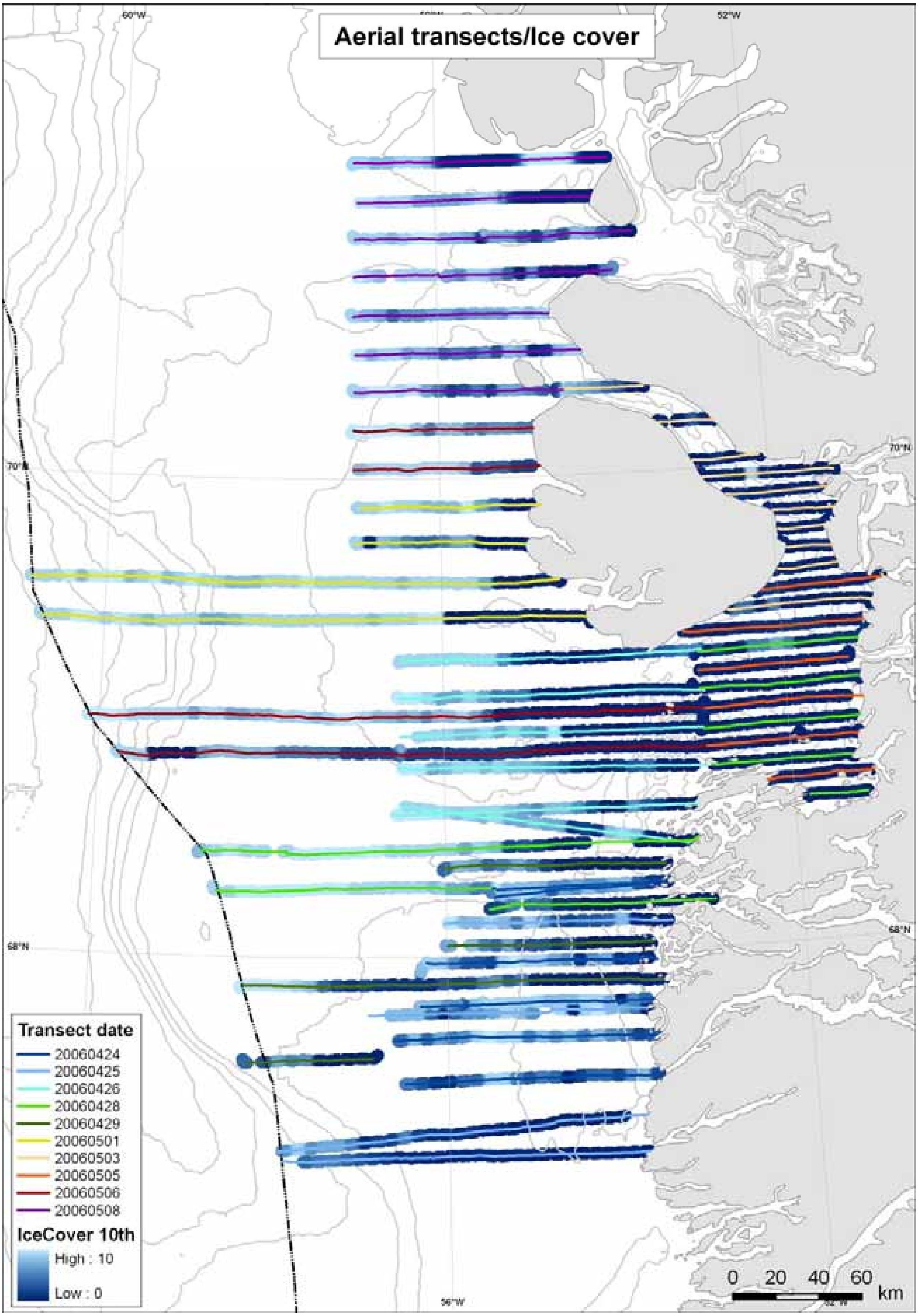


Figure 12. The aerial transects flown during the marginal ice zone project in April and May 2006. Ice cover recorded along the transects indicated.

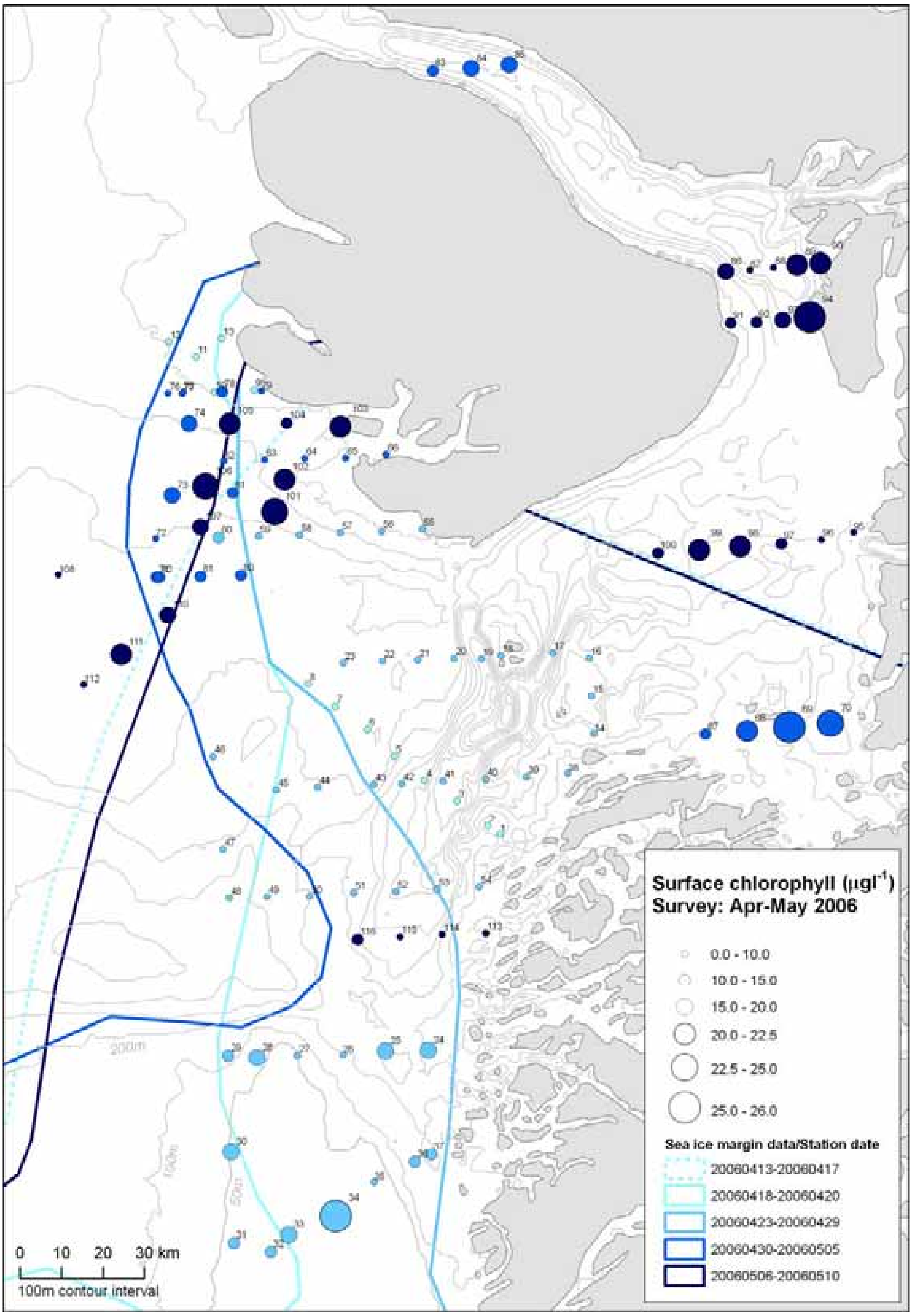


Figure 13. Surface concentration of chlorophyll (mg m^{-3}) at each station, which is at about 1 m. depth. The number associated to each circle represents the station number; the size of the circle corresponds to a certain concentration interval, given by the legend in the lower right corner, and the colour of the filled circles give time period when the observation was collected. The lines indicate the location of the ice edge for different time periods, and the colour for each particular line corresponds to a certain time interval, given by the legend in the lower right corner. For guidance; the typical winter concentration in the region 0.05 mg m^{-3}, and 2 mg m^{-3} during the early stages of plankton bloom. The observations are collected during a time period when the bloom goes from an early stage to large plankton bloom. In late April high values are observed on the Store Hellefiskebanke. In May there are relatively high levels in the central and southern parts of Disko Bay as well as west of southern Disko (west of Disko Fjord). Chlorophyll levels were relatively low at the Disko Bay entrance (Aaasiaat -Qeqertarsuaq) (not shown), and west of the entrance.

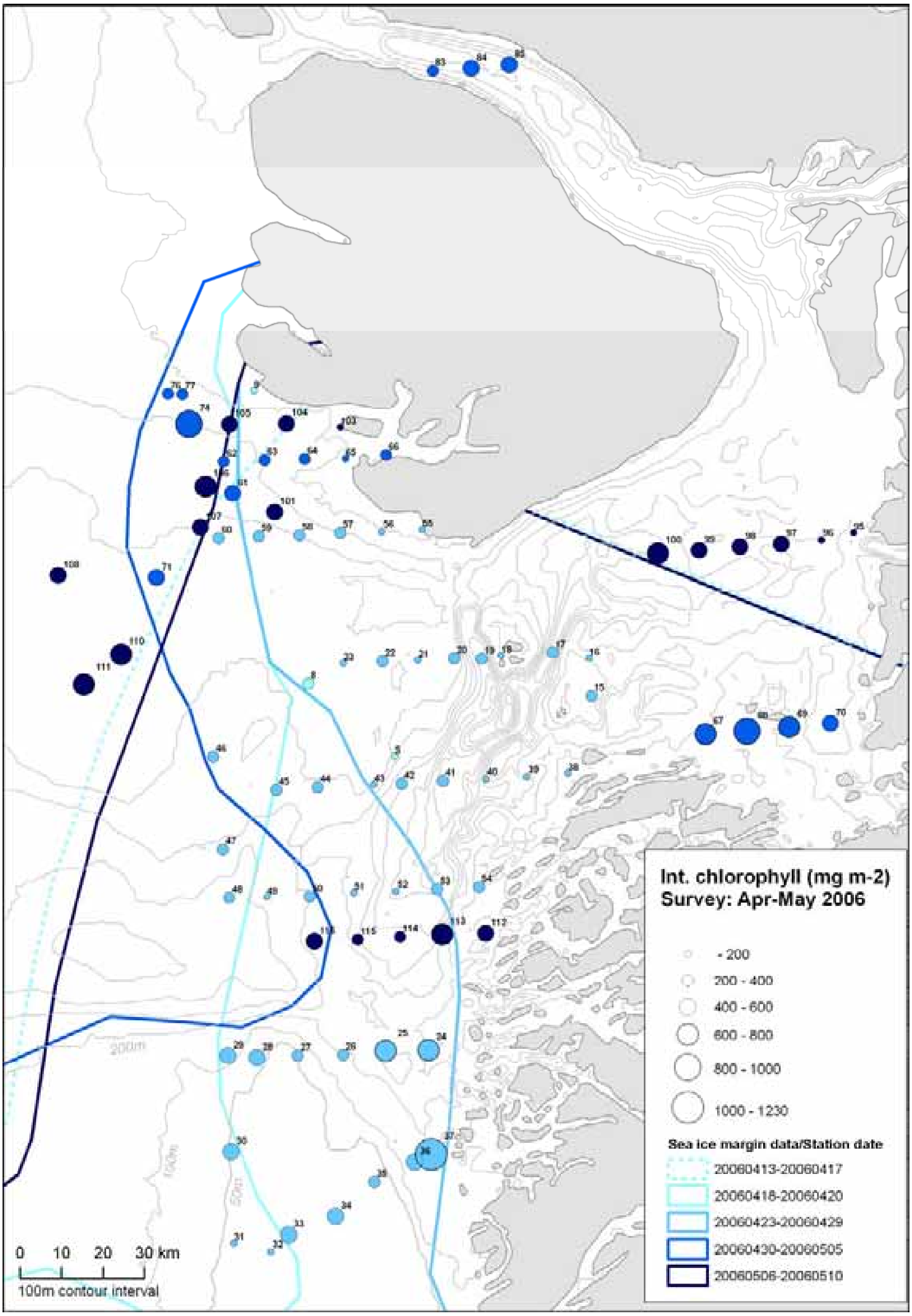


Figure 14. Vertical integration of chlorophyll from surface to max sampling depth (mg m^{-2}) measured during the survey in April and May 2006. The number associated to each circle represents the station number; the size of the circle corresponds to a certain concentration interval, given by the legend in the lower right corner, and the colour of the filled circles give time period when the observation was collected. The lines indicate the location of the ice edge for different time periods, and the colour for each particular line corresponds to a certain time interval, given by the legend in the lower right corner. In general, the integrated chlorophyll shows a similar pattern as the surface values of chlorophyll. Differences between surface and integrated chlorophyll are found in the deep water "wedge" between the bank and the coast east and northeast of Store Hellefiskebanke there was a tendency to higher levels in the deep water layers (integrated chlorophyll) compared to the surface chlorophyll. The low values observed at westernmost stations located within the ice (stations 11-13, 72, 75, 76, and 108) may be due to high ice concentration.

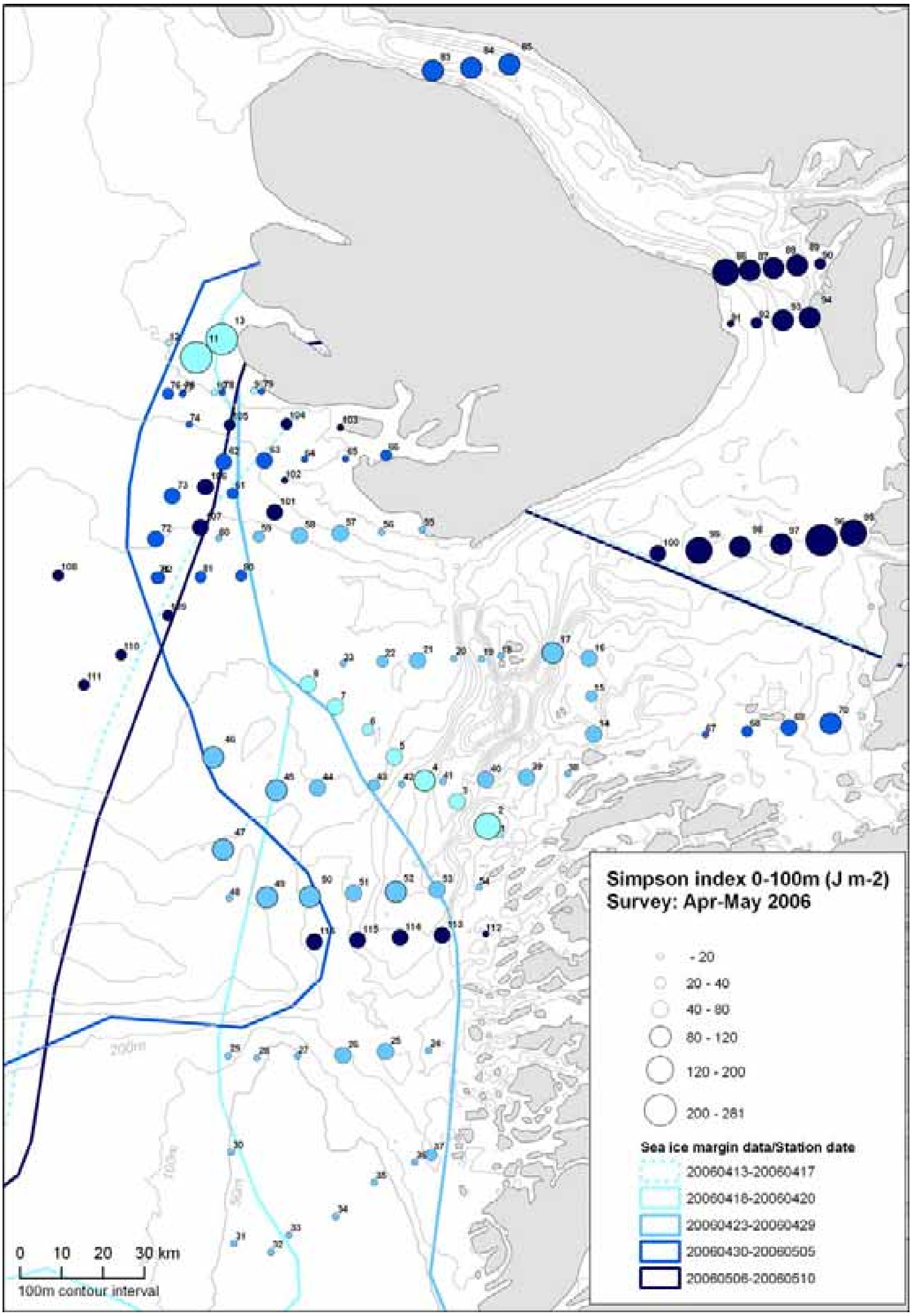


Figure 15. Simpson index, which is a measure of the strength of the vertical stratification, measured during the survey in April and May 2006. The number associated to each circle represents the station number; the size of the circle corresponds to a certain interval, given by the legend in the lower right corner, and the colour of each filled circle give time period when the observation was collected. The lines indicate the location of the ice edge for different time periods, and the colour for each particular line corresponds to a certain time interval, given by the legend in the lower right corner. A high value of the Simpson index means that the upper water column is well stratified and that it takes more energy to mix the upper waters, compared to locations with low Simpson index value. A low Simpson value may be explained by strong vertical mixing or low fluxes of heat and salt. In regions with high Simpson index the primary produces will remain near the surface where there are sufficient light to grow, while in regions with low Simpson index the primary producers are easily mixed down to greater depths with no or very weak sun light. The highest values of the observed Simpson index are found in Disko Bay and at the northernmost stations west of Disko Island. Low values of the Simpson index are found at Store Hellefiskebanke, west of Disko Island, and at the entrance of Disko Bay.

4.1.2 Primary production in 2006

The studies carried out in 2006 confirm that there is large spatial and temporal variability in the chlorophyll levels and there are high chlorophyll levels (spring bloom) distributed over large areas in the region. This means that the areas of highest importance for the primary production in the region will vary within season and between seasons, depending for example on ice conditions.

The overall distribution of surface chlorophyll (1 m) as well as integrated chlorophyll (from surface to max. sampling depth) from the stations shows relatively high concentrations in central and southern Disko Bay as well as west of southern Disko (west of Disko Fjord) (Figures 13 and 14). On the northern part of Store Hellefiskebanke chlorophyll levels were also high. In the deepwater 'wedge', with high turbulence between the bank and the coast east and northeast of Store Hellefiskebanke (Figure 15), there was a tendency to higher levels in the deepwater layers (integrated chlorophyll) compared with the surface chlorophyll. Chlorophyll levels were relatively low at the Disko Bay entrance (Aaasiaat-Qeqertarsuaq) and west of the entrance.

Surface chlorophyll measured from satellite (MODIS and SeaWiFS data) shows a clear increase in surface chlorophyll levels from the first week of the survey (15-22 April 2006) to the last week (9-16 May 2006) (Figures 16 and 17). In approx. half of the area a ten-time increase in chlorophyll levels was apparent. Maximum levels were in the central Disko Bay, at the northern Store Hellefiskebanke and west of southern Disko, corresponding to the vessel data, but the satellite data also showed high levels west of the Disko Bay entrance in the final week. In nearly all areas the highest chlorophyll levels were found close to an ice edge. (The red squares next to the white areas on the map. White areas on the map are caused by lack of satellite data generally due to dense ice or clouds). The resolution (in time and space) of the satellite data does not allow detailed resolution of the chlorophyll a, so small bloom areas in connection with oceanographic discontinuities, e.g. the meltwater from the glacier or in connection with upwelling along the banks, cannot be identified and followed over time.

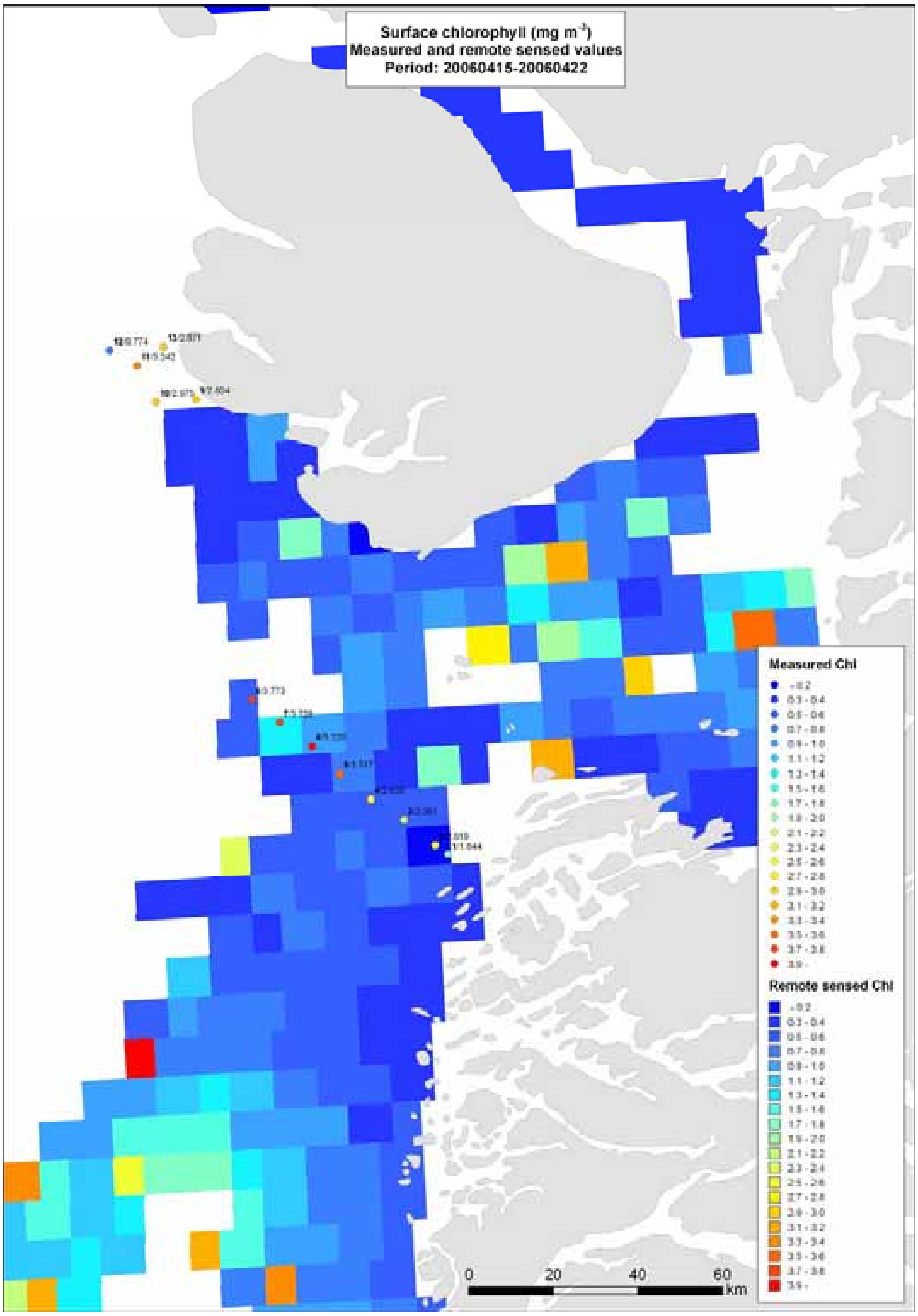


Figure 16. Surface concentration of chlorophyll (mg m-3) for the time period April 15 to April 22 2006. The colours show the concentrations when using sensing data together with a standard algorithm. The coloured dots give the in situ concentration at 1 m. depth. The numbers right next to the coloured dot indicate the station number and the absolute value of the concentration. Note that the colours corresponding to the remote sense data and in situ observation have the same scale. Along the transect located southwest of Disko Bay entrance (stations 1-8) the concentration at the first station near the coast is just below 2 mg m-3 (sampled April 18), and between 2 and 5.2 mg m-3 at stations 2-9 (sampled April 19). It seems thus that the primary production is in the early stage of a plankton bloom in this region. Note that the in situ values are much higher than the remote sense data. The algorithm to compute the chlorophyll concentration from remote sense data underestimate the surface concentration, and one should be careful when interpreting the remote sense data. Here we use the relative distribution of chlorophyll to identify high productive regions, but more analysis is needed to make any conclusions when interpreting the satellite observations. However, the preliminary results suggests that the 8 day mean value of the remote sensing data for surface chlorophyll (mg m-3) for the period April 15-April 22 shows relatively high values of chlorophyll at Store Hellefiskebanke, and lower concentration in Disko Bay and westwards towards the ice edge. Some local areas with high chlorophyll concentration are also observed at the entrance to Disko Bay and the central parts of Disko Bay. The areas with relative large concentration of chlorophyll indicate that the plankton bloom have already started before April 15, or is just about to start.

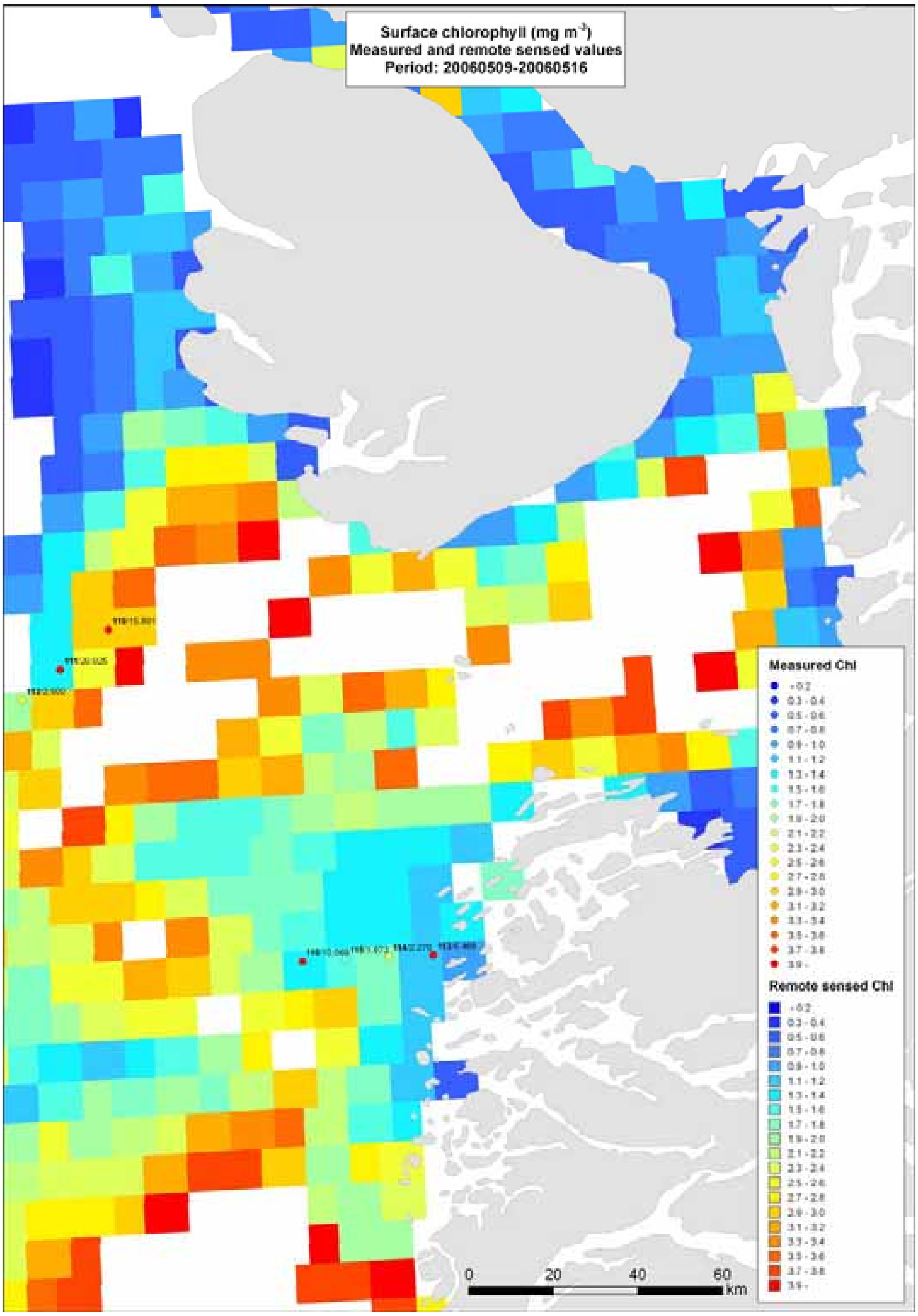


Figure 17. Surface concentration of chlorophyll (mg m-3) for the time period May 9 to May 16 2006. The colour map shows the concentrations when using sensing data together with a standard algorithm. The coloured dots give the in situ concentration at 1 m. depth. The numbers right next to the coloured dot indicate the station number and the absolute value of the concentration. Note that the colours corresponding to the remote sense data and in situ observation have the same scale. During the period 20060509-20060516 the in situ observations at the ice edge located west of Disko Bay was typically 15-20 mg m-3, and around 2 mg m-3 somewhat more to the west, which is a region where the ice concentration was higher (not shown). The observed concentration of chlorophyll North West of Store Hellefiskebanke varied between 1.6 and 10 mg m-3. The algorithm to compute the chlorophyll concentration from remote sense data underestimate the surface concentration, and one should be careful when interpreting the remote sense data. Here we use the relative distribution of chlorophyll to identify high productive regions, but more analysis is needed to make any conclusions when interpreting the satellite observations. However, the preliminary results suggests that the chlorophyll concentrations using remote sensing data were high at the Store Hellefiskebanke, central part of Disko Bay and outside Disko Bay. Low values were observed south west of Disko Bay, west of Disko Island, and in the northern channel connecting the eastern part of Disko Bay with Baffin Bay (the Vaigat).

The chlorophyll distribution measured from the vessel compared with the surface chlorophyll obtained from remote-sensing data shows that the in situ measurements from the vessel generally have higher values and with less temporal progression. This could be because the satellite sampling is more sensitive to the vertical distribution of the phytoplankton. And moreover, there seems to be a lack of proper calibration of the values derived from the satellite (with the widely used standard data processing we have used so far) and measurement of the water samples.

In Figure 18 satellite chlorophyll measurements from the Disko Bay area are shown for spring in 2001 to 2004. These maps show great variability in location and extent in the productive areas between years.

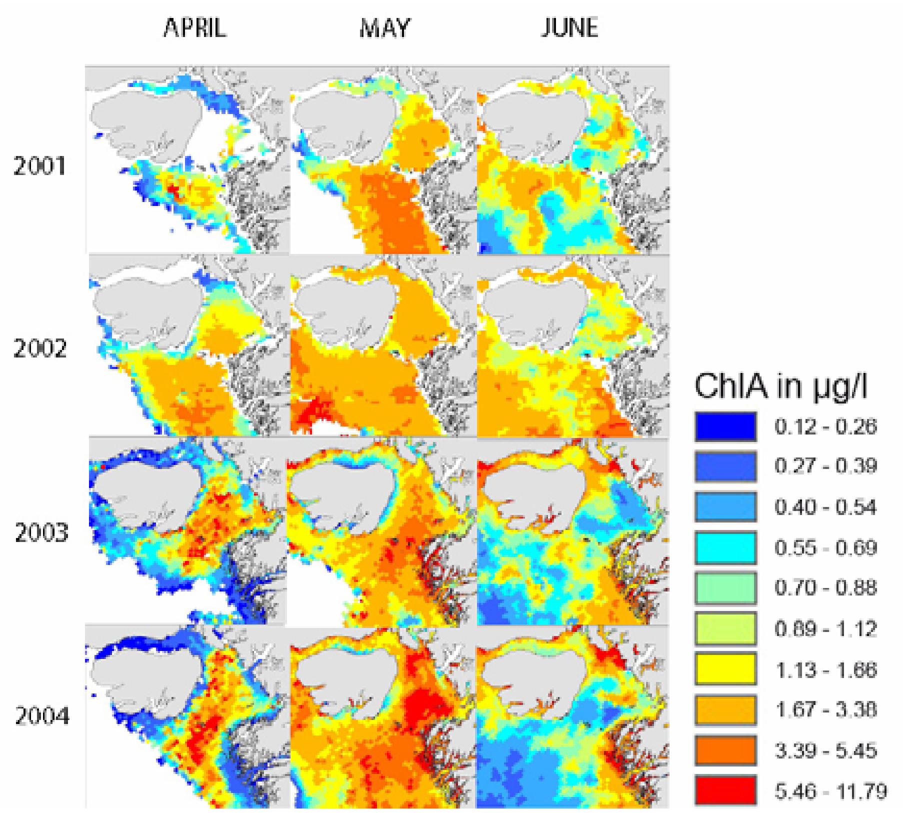


Figure 18. Monthly progression of chlorophyll a production in Disko Bay, West Greenland between 2001 and 2004. Data are presented as monthly averages from MODIS level 3 Terra (2001 and 2002) and level 3 Aqua (2003 and 2004) with adjustment of the Terra data to ensure compatibility. White areas are ice covered and grey is land. Blue is very low chlorophyll a concentrations and red is high (Figure from Heide-Jørgensen & Laidre 2006).

The marginal ice zone is an important feature in the assessment area. From other Arctic areas it is known that this zone can have high productivity in spring because meltwater stabilises the water column, and there is also a specialised (epontic) community including algae and grazers on the underside of the ice. In the assessment area there is only first-year ice which is known to have less developed epontic communities compared with multi-year ice. However, very little is known of the relative importance of the marginal ice zone in the assessment area, and further studies of the biology and oceanography have been conducted in 2006 as part of the background study programme.

4.2 Zooplankton

The mesoplankton communities in the waters off West Greenland are dominated by the large copepods of the genus *Calanus* (incl. their larval stages) (Pedersen et al. 2005). They are significant grazers on the primary production and constitute an important prey for fish and their larvae, whales (primarily bowhead whales) and seabirds (the little auk is a specialised *Calanus* feeder). Most of the higher trophic levels in the Arctic marine ecosystem rely on the lipid that is accumulated in *Calanus*. Consequently, a great deal of the biological activity e.g. spawning and growth of fish is synchronised with the life cycle of *Calanus*. The *Calanus* copepods also play an ecological key role in supplying the benthic communities with high quality food by their large and fast sinking faecal pellets (Söderkvist et al. 2006).

The investigation in the Disko Bay clearly corroborates the hypothesis that most of the biological activity in the surface layer is present in the spring and early summer in association with the spring bloom and the appearance of the *Calanus* populations. The peak abundance of shrimp and fish larvae is also observed in the early summer in association with the peak abundance of their plankton prey. *Calanus* occur widespread in the West Greenland waters where high numbers have been recorded in Disko Bay and both on the banks and west of the banks in deep waters (Figure 19).

The only locality along western Greenland where the annual dynamics of the plankton community have been investigated at high temporal resolution is in Disko Bay off Qeqertarsuaq.

Larvae of fish and shrimp are important components of the plankton, and movements and behaviour have been studied for some of the commercially utilised species. Pedersen & Smidt (2000) analysed shrimp and fish larvae data sampled along three transects during summer in West Greenland waters over 34 years. Recently, several surveys have investigated the horizontal distribution of shrimp larvae (Pedersen et al. 2002, Storm & Pedersen 2003) and fish larvae (Munk 2002, Simonsen et al. 2006) in relation to oceanography and their potential prey along West Greenland. An integrated part of these investigations was the development of a particle-tracking model. To simulate larval drift, particles (larvae) were released in four areas along the southwest Greenland coast assuming a pelagic life of 100 day's duration (Ribergaard et al. 2004). The model illustrates how the fish larvae are concentrated over the fishing banks. The residence times were significantly longer on the banks indicating that they act as retention areas. Despite pronounced difference in the year class strength, the simulations of shrimp larval drift for 1999 and 2000 were almost identical. The model results are corroborated by results of sampling programmes conducted along the coast. The cruises cover the main part of the productive season (May to July). They document that the important sites for the development of shrimp and fish larvae are the slopes of the banks and the shelf break, and in Disko Bay where the highest biomass of their copepod prey is also located (Simonsen et al. 2006).

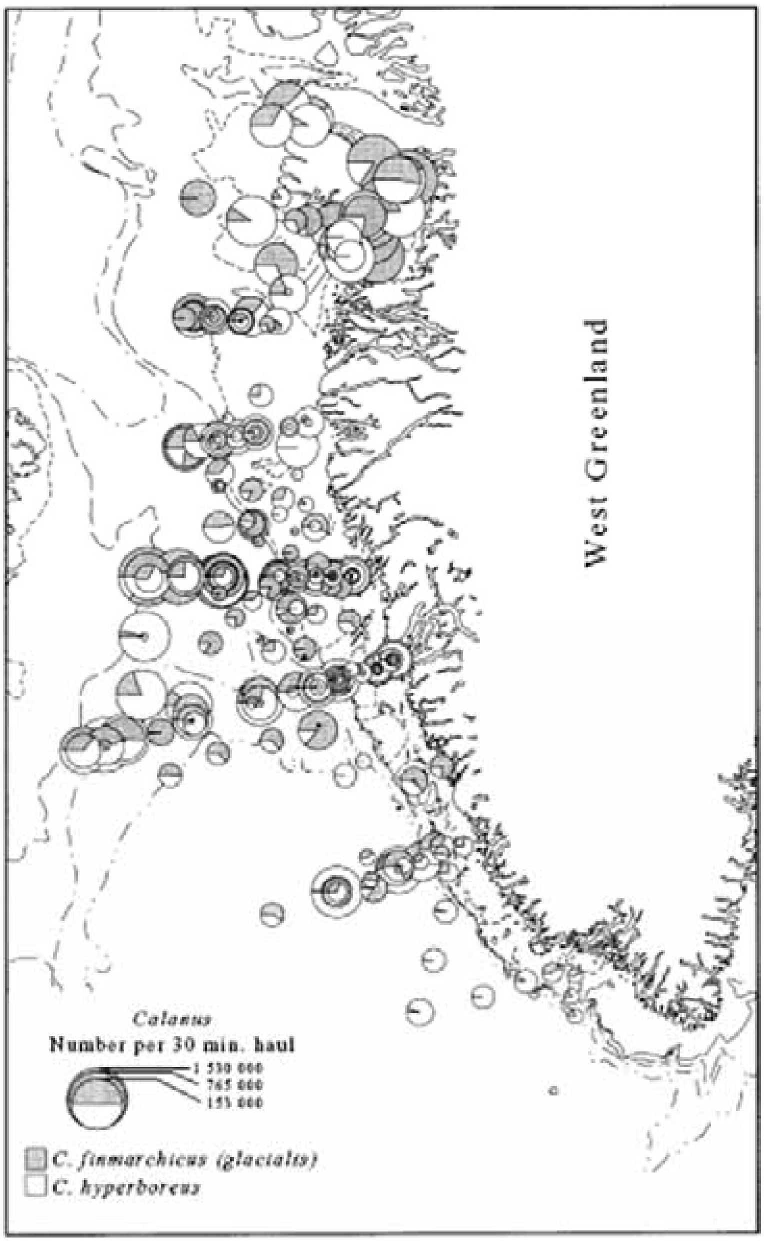
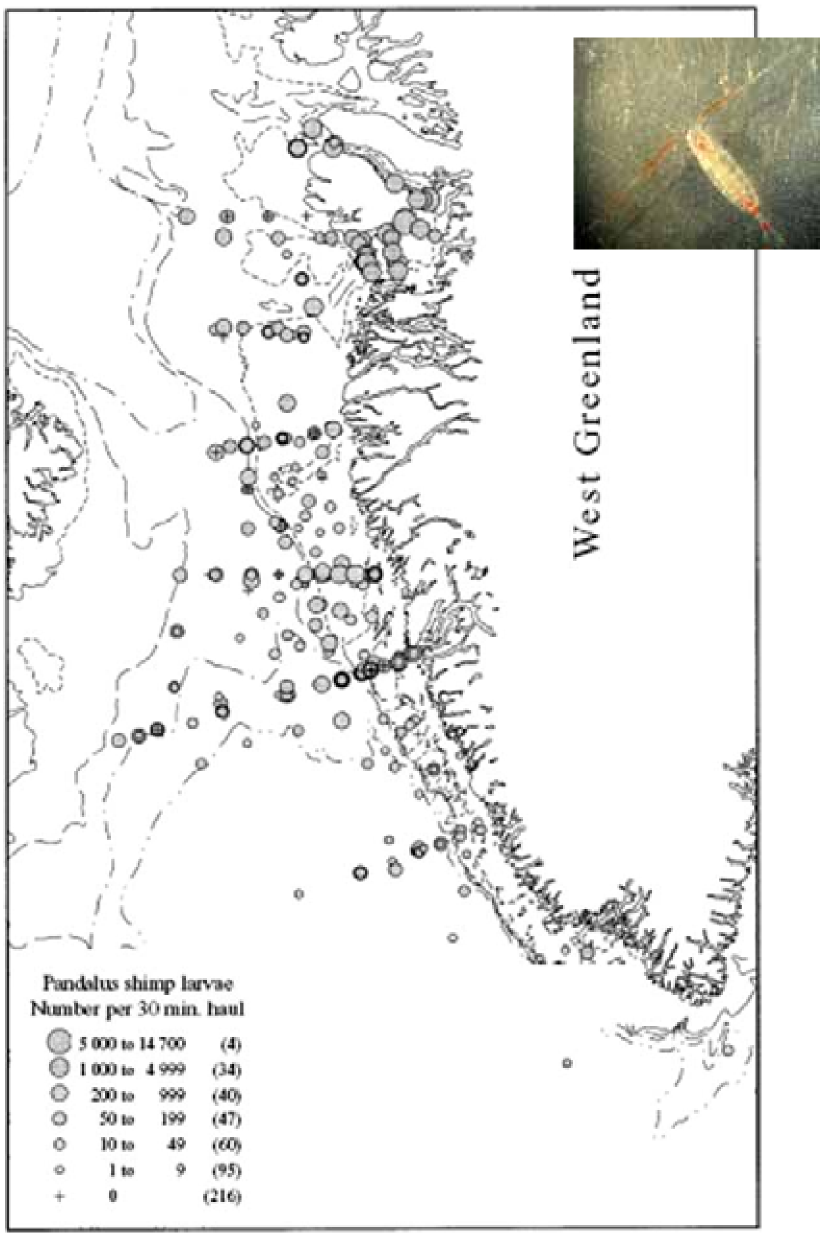


Figure 19. Distribution of two species of Calanus. Numbers per 30 min hauls summarised over all sampling in June-July 1956-1983, with frequency of occurrence in parentheses (From Pedersen & Smidt 2000).

Shrimp larvae are widely distributed with high numbers both on the banks, west of the banks and in the assessment area (Figure 20). Shrimp larvae are estimated to travel up to 500 km from their release site before they settle, and simulations indicate that there are several such release sites on the banks south of Disko Bay. An analysis of many years' sampling in the West Greenland waters showed that shrimp larvae were generally more abundant in waters less than 200 m deep and showed high abundance mainly over the West Greenland shelf and in the Disko Bay area, and also that shrimp larvae abundance correlated most highly with copepods and Greenland halibut larvae (Pedersen & Smidt 2000). Shrimp larvae are usually released from the females at rather shallow water depths (< 150 m), shallower than where the fishery usually occurs (100-600 m). Larvae are released in May off Nuuk and Maniitsoq and possibly later in August in Disko Bay (S.A. Pedersen ICES pers. comm.). Larvae in some areas may be more important for recruitment than others because of a good match with food resources resulting in rapid growth and high survival. This may occur in the retention areas created by currents on some of the banks areas.

Figure 20. Distribution of shrimp larvae. Numbers of larvae per 30 min hauls, summarised over all sampling in June-July 1956-1982, with frequency of occurrence in parentheses (From Pedersen & Smidt 2000).



It is not clear whether shrimp stocks in Disko Bay are self recruiting or to what degree influx of larvae from the southern shrimp areas contributes to the stock (S.A. Pedersen ICES pers. comm.). Shrimps in waters north of Disko Bay are probably recruited from Disko Bay (S.A. Pedersen ICES pers. comm.). Within the assessment area high numbers of shrimp larvae were found on the northern edge of Store Hellefiskebanke, in Disko Bay and in the waters around Hareø (Figure 20).

Greenland halibut larvae concentrations in the upper water column are relatively high south of 68° N, while within the major part of the assessment area they are low in June-July, based on Figure 21.

Other fish larvae which have been studied include sandeel (*Ammodytes spp*.), which were very numerous particularly in Disko Bay and on some of the banks (Figure 22), and redfish (*Sebastes spp*.), which were very numerous south of 62° N and almost absent from the waters of the assessment area (Pedersen & Smidt 2000).

Figure 21. Number of Greenland halibut larvae per 30 min haul. All samples in June-July 1950-1984, frequency of occurrence in parentheses. From Pedersen & Smidt 2000.

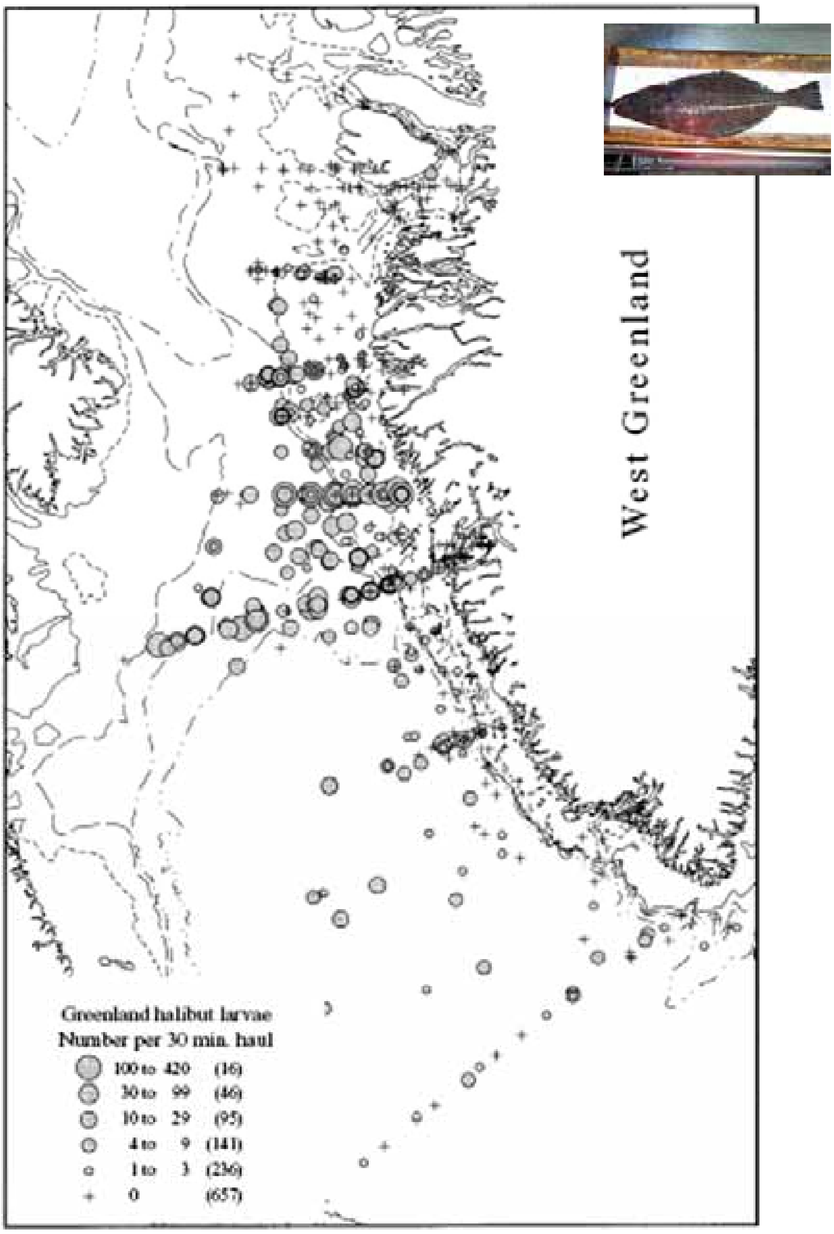
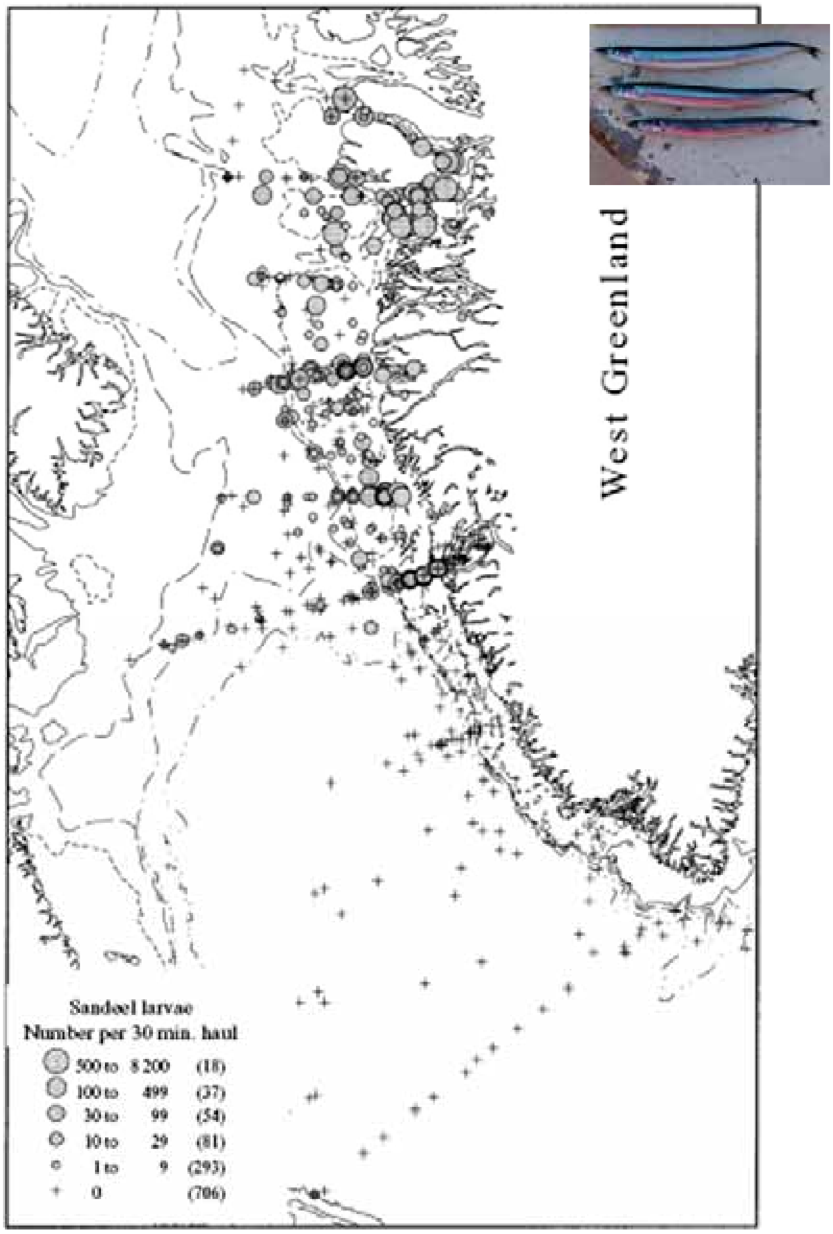


Figure 22. Number of sandeel larvae per 30 min haul. All samples in June-July 1950-1984, frequency of occurrence in parentheses. From Pedersen & Smidt 2000.



New studies of fish larvae in the West Greenland waters have been carried out in the years 1996-2000 (Munk et al. 2000, 2003, Munk pers. comm., and REKPRO-data from C. Simonsen and S.A. Pedersen pers. comm.). These studies did not find the sand eel larvae concentrations as reported by Pedersen & Smidt (2000) (Figure 23). They found a large interannual variation in abundance of polar cod larvae in Disko Bay (Figure 24) and confirmed the distribution of Greenland halibut larvae as reported by Pedersen & Smidt (2000) (Figure 25). Recurrent concentrations areas of fish larva were not located, and generally there seems to be large variation in distribution and abundance of fish larvae between years.

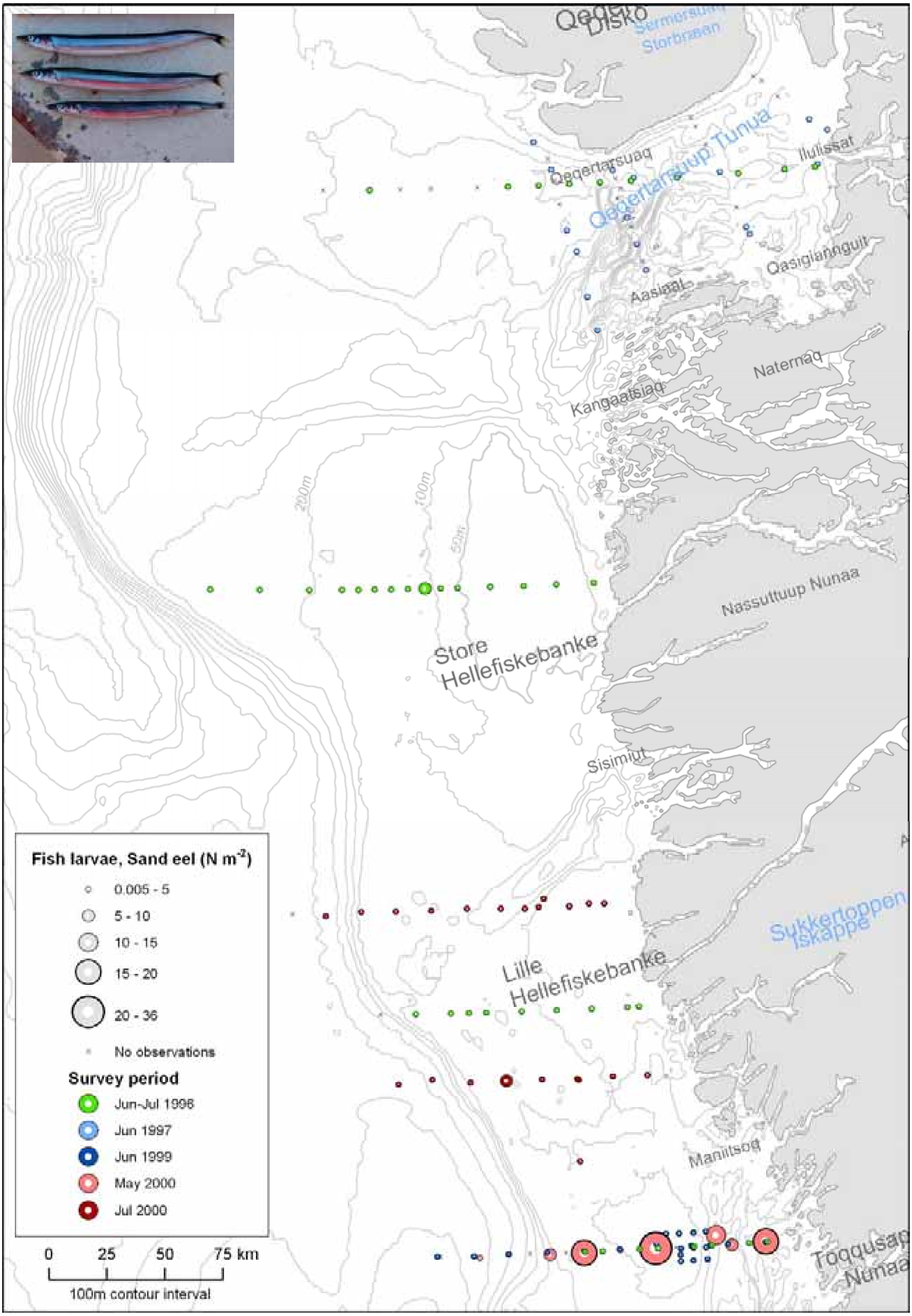


Figure 23. Distribution of sand eel larvae recorded during surveys in May-July 1996-2000. (Munk et al. 2000, 2003, Munk pers. comm. and REKPRO-data from C. Simonsen and S.A. Pedersen pers. comm.).

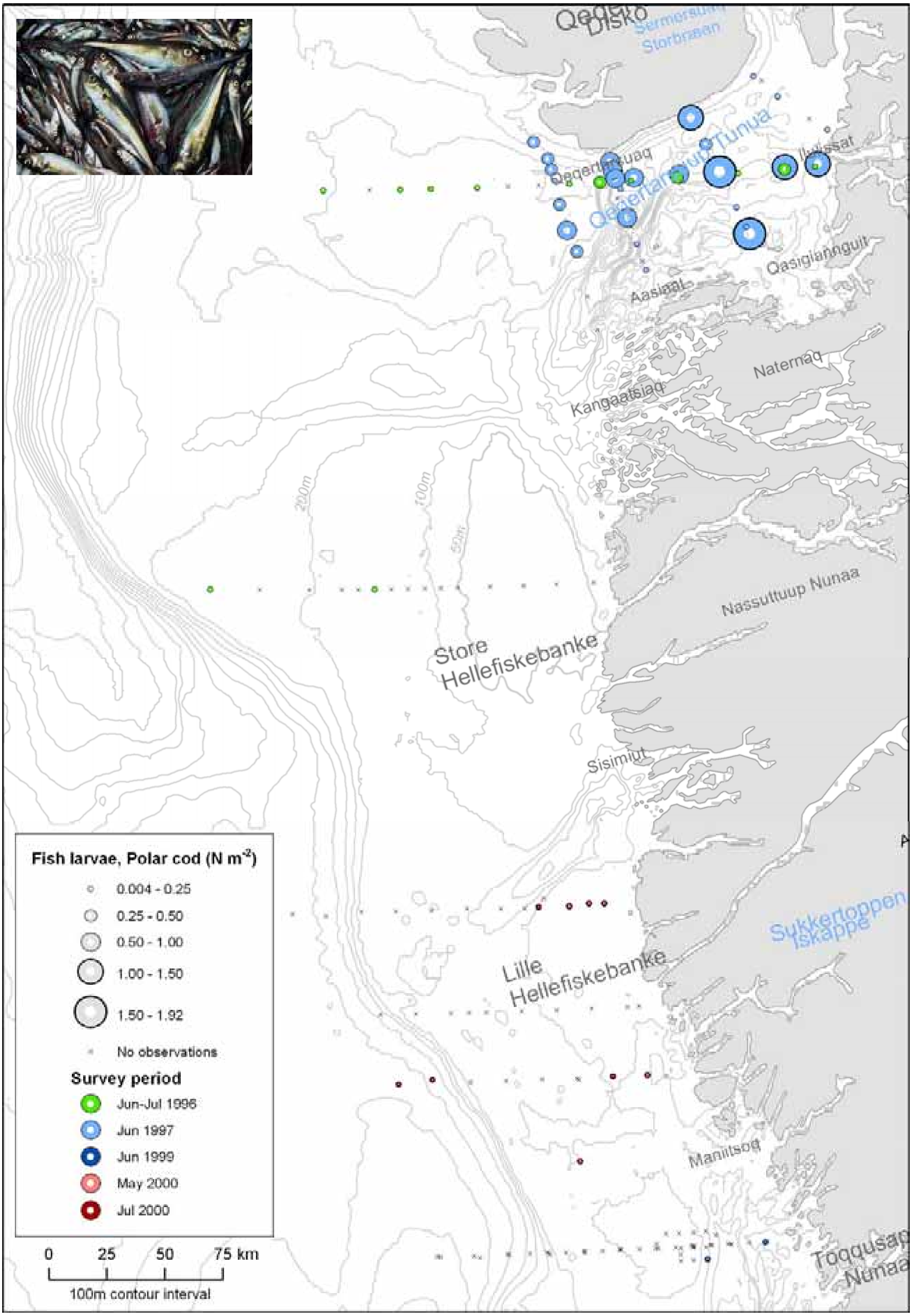


Figure 24. Distribution of polar cod larvae recorded during surveys in May-July 1996-2000. (Munk et al. 2000, 2003, Munk pers. comm. and REKPRO-data from C. Simonsen and S.A. Pedersen pers. comm.).

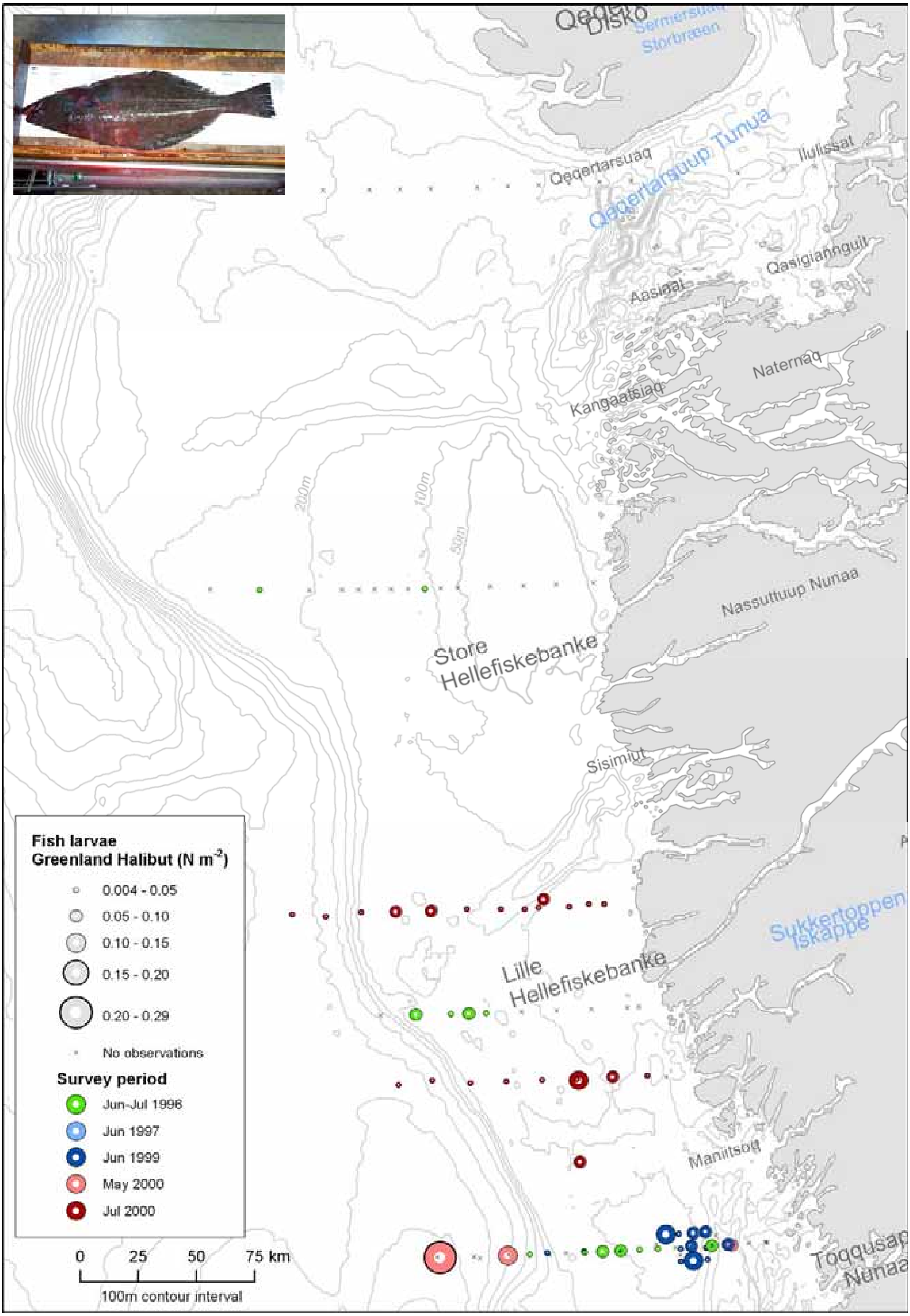


Figure 25. Distribution of Greenland halibut larvae recorded during surveys in May-July 1996-2000. (Munk et al. 2000, 2003, Munk pers. comm. and REKPRO-data from C. Simonsen and S.A. Pedersen pers. comm.).

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

The zooplankton sampled in April and May 2006 is still under analysis, and the assessment will be updated when results are available.

4.3 Benthic flora and fauna

The shallow coastal areas of the arctic seas can be highly productive and very important to the marine food web. The benthos in general and bivalves in particular constitute an important food source for fish, birds and marine mammals (Born et al. 2003, Merkel et al. 2007). Here often a high biomass of benthic algae, particularly brown algae, is found in the intertidal and subtidal zone down to about 50 metres of water depth. Common species in the assessment area include *Fucus vesiculosus*, *Fucus distichus*, *Ascophyllum nodusum*, *Agarum cibrosum* and several *Laminaria* species (Christensen 1981).

In coastal areas, species composition and diversity differ a great deal according to coastal type and exposure to wave action and ice (Anonymous 1979). In some coastal areas the benthic fauna can be characterised by high diversity and biomass combined with an abundance of very old individuals (Sejr & Christensen in press). In the assessment area important species include the bivalves *Mytilus edulis*, *Hiatella bysifera*, *Serripes groenlandicus* and *Mya truncata* (Theisen 1973, Anonymous 1979, Petersen & Smidt 1981, Mosbech et al. 1998). But also many species of polychaetes, echinoderms, amphipods and gastropods are found. The long lifetime of several arctic species and their slow growth makes the benthic community particularly vulnerable to disturbance. The benthic communities in intertidal and shallow areas are more exposed to effects from oil spills, both short- and long-term effects, than communities in deeper water.

On the banks (50-100 metres of water depth) polychaetes are the most numerous infaunal species, whereas the epifauna also hosts crustacea (e.g. *Hyas*, *Caprella* and shrimp species), important as fish food, and many other taxae, including bryozoa and echinoderms (Petersen & Smidt 1981, Anonymous 1978). At the slopes of the Store Hellefiskebanke the benthic fauna is richer than on the top of the banks (Anonymous 1978).

In deeper waters the bottom is often soft and silty. Here a diverse in- and epifauna is found, including crustacea, bivalves, ehcinoderms and polychates (Petersen and Smidt 1981, Anonymous 1978). This habitat is important to the fishery for deep-sea shrimp (*Pandalus borealis*) and also for snow crab (*Chionoecetes opilio*). Deep-sea shrimp occur in waters 100-600 m deep, mainly on the outer slope of the fishing banks and in Disko Bay. During the dark hours of the day shrimps can forage widely distributed in the water column and can even occur near the surface during night. They carry their eggs until they hatch and the larvae are released during spring and summer (Horsted & Smidt 1956, Carlsson & Smidt 1978). In Disko Bay the release probably occurs as late as August (S.A. Pedersen pers. comm.). The larvae then move passively with the water currents (see plankton section). Snow crab and Iceland scallop also have planktonic larvae which move passively with the water currents (Pedersen 1988, Andersen 1993). Few other species of the benthos have larvae with a planktonic life stage (Anonymous 1978).

In other oil exploration areas in the north Atlantic, consideration has been given to deep-sea coral reefs as especially vulnerable ecological components, e.g. in Norway and the Faroe Islands. Such reefs have not been reported from survey trawling in the assessment area (Ole Jørgensen pers. comm.) and apparently do not occur within the assessment area (O. Tendal pers. comm.)

4.4 Fish

Many different fish species occur in the waters of the assessment area. Most are demersal i.e. living near the seabed. Knowledge on the non-utilised species is generally poor (Pedersen & Kanneworf 1995). Only very few species are caught in the commercial fishery in Greenland: Greenland halibut (*Reinhardtius hippolglossoides*) and lumpsucker (*Cyclopterus lumpus*) are the most important seen from an economic point of view. Several other species are caught in local subsistence fishery including capelin (*Mallotus villosus*), arctic char (*Salvelinus alpinus*) redfish (*Sebastes spp.*), spotted wolffish (*Anarchchias minor*) and Atlantic halibut (*Hippoglossus hippoglossus*) (Mosbech et al. 1998). See also Table 1.

Previously, until the late 1980s, Atlantic cod (*Gadus morhua*) was numerous on the banks (in the assessment area mainly in the southern part) and it was fished intensively. But the offshore stock crashed and Atlantic cod only occur today in low numbers in inshore waters (local stocks) (Hovgaard & Christensen 1990, Horsted 2000). A recovery of the offshore Atlantic cod stocks is expected due to the increasing water temperatures recorded in recent years. Another cod species is common – the Greenland cod (*Gadus oqac*) – but it is considered as inferior in the commercial fisheries compared with the Atlantic cod, though it has some subsistence importance (Mosbech et al. 1998).

Greenland halibut (*Reinhardtius hippoglossoides*) live in deep waters at the seafloor, usually at depths below 200 m. Spawning takes place at depths >1000 m and south of 67° N. Eggs and larvae drift northwards with the current, later to settle in the shallower waters of the banks. Particularly the northern part of Store Hellefiskebanke and Disko Bay are important nursery areas for 1-2-year old Greenland halibut (O. Jørgensen GINR pers. comm.). Young fish subsequently, as they grow larger, seek towards deeper waters. This means that the Greenland halibut fished within the assessment area are recruited from spawning areas further south (Riget & Boye 1989, Pedersen & Riget 1993).

Lumpsucker spend most of the year in deep offshore waters, but in spring and early summer they seek shallow coastal waters to spawn. Here they are fished for their roe in an increasingly important gill net fishery from small boats (Mosbech et al. 1998, Olsvig & Mosbech 2003).

Table 1. Overview of selected species of invertebrates and fish from the assessment area.

Species	Main habitat	Spawning area	Spawning period	Exploitation	Importance of assessment area to population
Blue mussel	subtidal, rocky coast	subtidal, rocky coast		local	low
Iceland scallop	inshore and on the banks with high current velocity, at 20 -60 m depth	same as main habitat		commercial and local	medium
Deep sea shrimp	mainly offshore, at 100-600 m depth	larvae released at relatively shallow depth (100-200 m)	March-May in southern part, August in northern	commercial and very important	high
Snow crab	coastal and fjords, at 180-400 depth	same as main habitat	April-May	commercial	medium
Atlantic cod	banks south of 64 ° N	pelagic eggs and larvae in upper water column	March-April	local	low*
Greenland cod	inshore/fjords	inshore/fjords, demersal eggs, pelagic larvae	February-March	commercial and local	medium
Arctic cod	Pelagic	mainly N of 68° N	-	-	medium
Sand eel	on the banks at depths between 10 and 80 m	on the banks, demersal eggs, pelagic larvae	July-August	important prey item	medium
Spotted wolffish	inshore and offshore	hard bottom, demersal eggs	peaks in September	local	medium
Arctic char	coastal waters, fjords	Freshwater rivers	in autumn	local	medium
Capelin	Coastal	beach, demersal eggs	April-June	local, important prey item	medium
Atlantic halibut	offshore and inshore, deep water,	pelagic eggs and larvae, deep water	spring	and local	low
Greenland halibut	deep water, in fjords and offshore	deep water, pelagic eggs and larvae	winter	important, both local and commercial	high
Redfish	offshore and in fjords, 150-600 m depth	spawn outside area	-	local	medium
Lumpsucker	Pelagic	coastal, demersal eggs	May-June	commercial and local	medium

*may change if offshore stock is re-established. Importance of study area to population (conservation value) indicates the significance of the population occurring within the assessment area in a national and international context as defined by Anker-Nilssen (1987).

The schooling capelin (*Mallotus villosus*) spawns in huge numbers in spring in the subtidal zone along beaches and low rocky coasts (Kanneworf 1968, Sørensen 1985, Sørensen & Simonsen 1988). The capelin is an ecological key species because it is an important food resource for larger fish, seabirds and marine mammals. Capelin and lumpsucker spawning areas have been mapped in the assessment area using local knowledge from fishermen and others (see Figure 45). They spawn along extensive coastlines in the assessment area. In 2005 GINR surveyed offshore capelin in the assessment area, and found only significant occurrences in the mouth of Vaigat and in southeastern Disko Bay (GINR unpubl.).

Two other fish species are also potential key species in the marine food web, sandeel (*Ammodytes spp.*) and polar cod (*Boreogadus saida*). Both are often important food sources for seabirds and marine mammals. Sandeel live on the banks, where they often are buried in the sand, and they are one of the few fish species which spawn during the summer (Kapel 1979, Larsen & Kapel 1982, Andersen 1985). Polar cod is pelagic and often closely associated with ice, and play an important role in the food web

(Angantyr & Kapel 1990, Mosbech et al. 2003). Polar cod spawns in late winter and the eggs float and assemble under the ice. The larvae hatch in spring when the ice melts. However, knowledge on the ecology and abundance of polar cod in the assessment area is poor.

Arctic char spend the winter in rivers where they also spawn. In spring they move into the coastal waters near the river outlets, and here they feed until they move back into the river in summer and autumn. Arctic char rivers have been mapped in the assessment area using local knowledge from fishermen and others (Olsvig & Mosbech 2003, Mosbech et al. 2004).

4.5 Seabirds

Seabirds are an important component in the marine ecosystem of the assessment area. Many species are primarily fish consumers living from schooling species (capelin, sandeel, polar cod). Some species live on or supplementing their fish diet with large zooplankton (copepods, krill), and others feed primarily on benthic invertebrates (e.g. mussels) (Falk & Durinck 1993, Merkel et al. 2007). The species utilise the common resources by means of different feeding methods, for example, some species are deep-diving foragers while others take their food on the surface. Many seabird species tend to aggregate at breeding or foraging sites, and extremely high concentrations may occur. A single flock of king eiders was estimated to hold up to 30,000 birds, which may constitute as many as 6% of the total population, and some breeding colonies hold between 50,000 and 100,000 individuals. An overview of the species is given in Table 2.

Most seabirds are colonial breeders and numerous seabird breeding colonies are found dispersed along the coast of the assessment area (Figure 26). Colonies vary in size (from a few pairs to more than 50,000 individuals) and in species composition, from holding only a single species up to 10 different species. The breeding seabirds utilise the waters near the breeding site; thick-billed murres (*Uria lomvia*) may fly more than 100 km to find their food, but most feed within a much smaller range (Falk et al. 2000, NERI unpublished). However, numerous seabirds also utilise the waters much further away from the coasts and these comprise non-breeding individuals from breeding populations all over the North Atlantic – mainly black-legged kittiwakes (*Rissa tridactyla*) and northern fulmars (*Fulmarus glacialis*), which spend the summer in the food rich waters off West Greenland (Mosbech et al. 1998). Great shearwaters (*Puffinus gravis*), breeding in the southern hemisphere, also summer in the offshore seas of the region. Another non-breeding seabird segment utilises the region in summer: seaducks arrive form breeding sites in Canada and inland Greenland and assemble to moult in remote and peaceful bays and fjords (Figure 27). King eiders (*Somateria spectabilis*) are numerous in the fjords of Disko Island, harlequin ducks (*Histrionicus histrionicus*) stay at remote rocky islands, and long-tailed ducks (*Clangula hyemalis*), and red-breasted mergansers (*Mergus serrator*) in shallow fjords and bays (Frimer 1993, (Mosbech & Boertmann 1999, Boertmann & Mosbech 2002). A few species occur only as migrant visitors during spring and autumn, e.g. two species of phalaropes, Sabines gull (*Larus* *sabini*) and the rare and threatened ivory gull (*Pagophila eburnea*) (Boertmann 1994).

Table 2. Overview of selected species of birds from the assessment area. Red-list status is provisional, as the list has not yet been published. b = breeding, s = summering, w = wintering, mi = migrant visitor, c = coastal, o = offshore. Importance of study area to population (conservation value) indicates the significance of the population occurring within the assessment area in a national and international context as defined by Anker-Nilssen (1987).

Species	**Occurrence**		**Distribution**	**Red-list status in Greenland**	**Importance of study area to population**
Fulmar	b/s/w	year-round	c & o	least concern (LC)	high
Great shearwater	S	July-October	o	least concern (LC)	low
Great cormorant	b/s/w	year-round	c	least concern (LC)	high
White-fronted goose	B	May-September	c	endangered (EN)	high
Brent goose	Mi	spring and autumn	c	least concern (LC)	medium
Common eider	b/s/m/w	year-round	c	vulnerable (VU)	high
King eider	m w	Aug.-Sept. Oct.-May	c c & banks	not evaluated	high
Long-tailed duck	b/m/w	year-round	c	least concern (LC)	medium
Red-breasted merganser	b/m/w	year-round	c	least concern (LC)	medium
Harlequin duck	M	July-August	c (rocky shores)	near threatened (NT)	medium
Red-necked phalarope	mi, (b)	spring and autumn	o	least concern (LC)	low
Grey phalarope	mi, (b)	spring and autumn	o	least concern (LC)	low
Arctic skua	B	summer	c	least concern (LC)	low
Black-legged kittiwake	b/s	year-round	c & o	endangered (EN)	high
Glaucous gull	b/s/w	year-round	c & o	least concern (LC)	medium
Iceland gull	b/s/w	year-round	c & o	least concern (LC)	medium
Great black-backed gull	b/s/w	year-round	c & o	least concern (LC)	medium
Sabines gull	Mi	August and May/June	o	near threatened (NT)	low
Ross' gull	B	summer, very localised	c	vulnerable (VU)	low
Ivory gull	w, mi	November - May	o	vulnerable (VU)	medium
Arctic tern	B	May - September	c	near threatened (NT)	high
Thick-billed. murre	b/s/w	year-round	c & o	vulnerable (VU)	high
Razorbill	b/w	year-round	c & o	least concern (LC)	high
Atlantic puffin	b/w	year-round	c & o	neat threatened (NT)	high
Black guillemot	b/w	summer winter	c c & o	least concern (LC)	high
Little auk	b w	May - August September - May	c & o o	least concern (LC)	high
White-tailed eagle	b/w	year-round	c, rare in southern part	vulnerable (VU)	low

Figure 26. Distribution of seabird breeding colonies in the study area. Colonies with less than 200 individuals not shown (NERI, Map based on data from NERI and GINR, Greenland Seabird Colony Database).

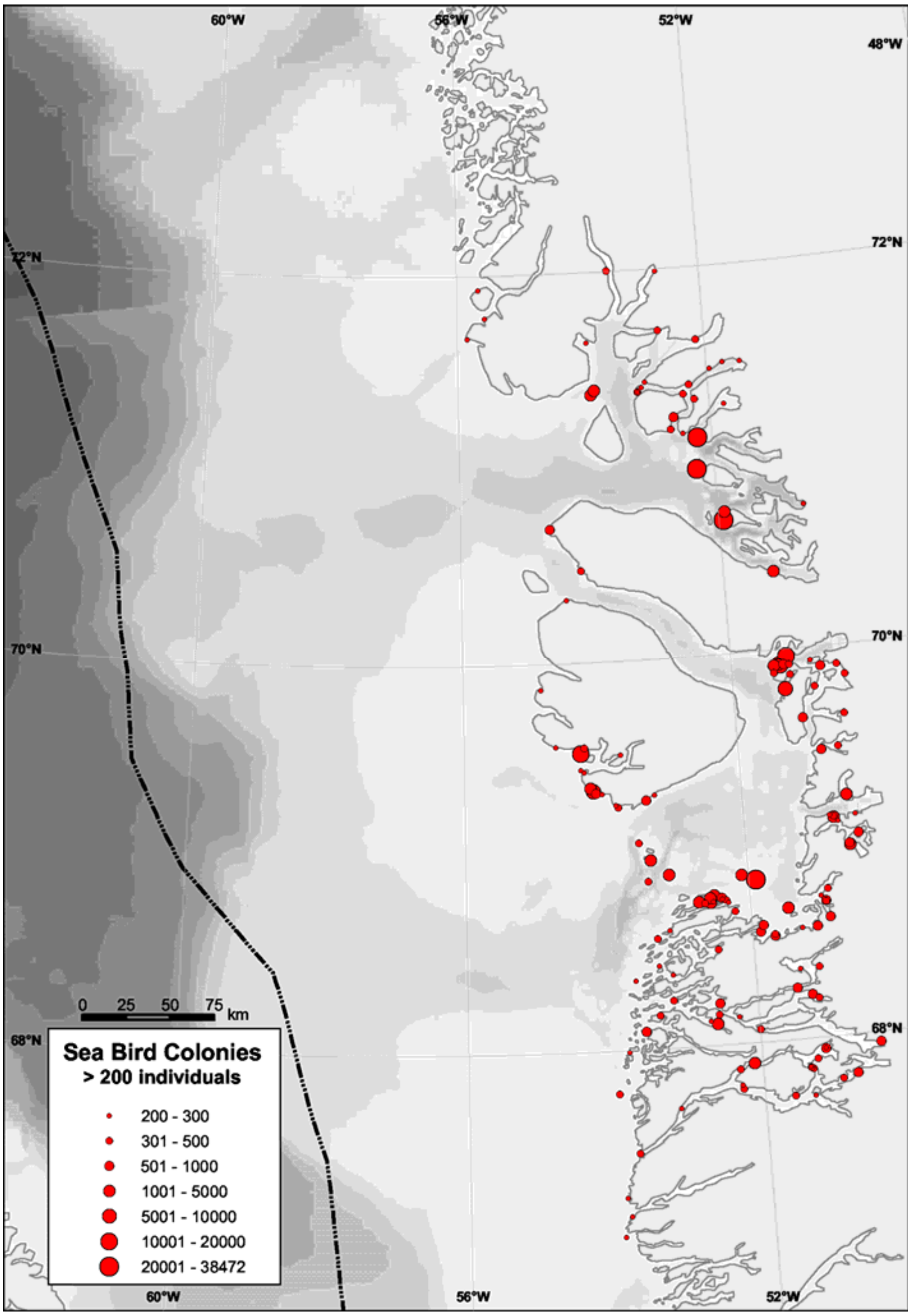
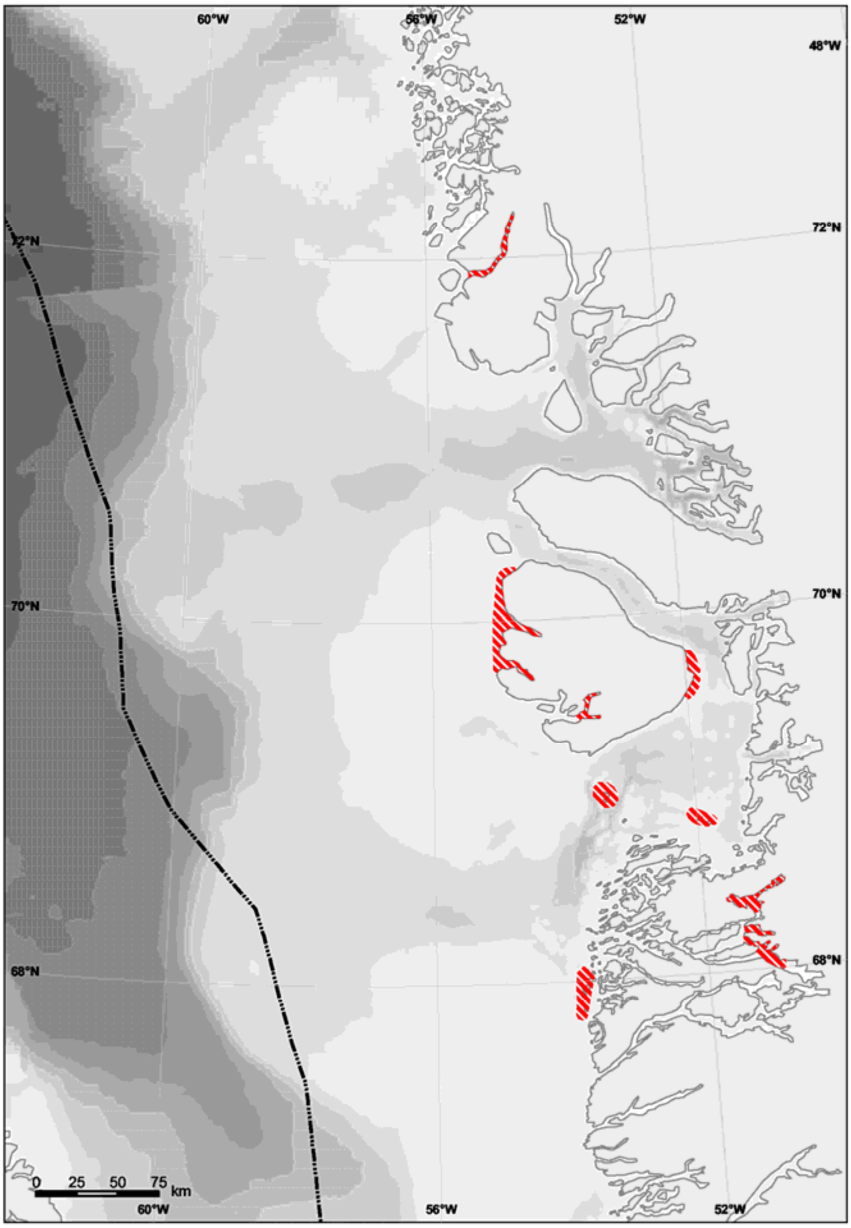


Figure 27. Important areas for moulting seaducks. These are mainly king eiders, but also common eiders, harlequin ducks and red-breasted merganser are among the moulting ducks. The moulting period is July to September. (NERI, Map based on Mosbech & Boertmann (1999) and Bortmann & Mosbech 2001, 2002).



There are 14 breeding seabird species in the assessment area (Boertmann et al. 1996). The most widespread is the black guillemot (*Cepphus grylle*), breeding along almost all rocky coasts. Northern fulmar is found in immense numbers in a few breeding colonies in Disko Bay and Uummannaq Fjord. Several of the breeding seabird species are decreasing in numbers, mainly caused by unsustainable exploitation, an issue recently addressed by the Greenland Homerule by reducing the hunting season for seabirds. The most prominent of these are thick-billed murre (one colony in the region), black-legged kittiwake (several colonies), common eider (*Somateria mollissima*) (several colonies) and Arctic tern (*Sterna paradisaea*) (several colonies). Scarcer breeding species include Atlantic puffin (*Fratercula arctica*) and little auk (*Alle alle*), and a very rare species occurring in the region is Ross's gull (*Rhodostethia rosea*) (Boertmann 1994).

During autumn large numbers of seabirds begin to assemble in the waters off the West Greenland coast. Some are under way to wintering sites outside Greenland waters, but many and probably the major part will stay throughout the winter (Boertmann et al. 2006). However, the winter ice will exclude seabirds from large parts of the assessment area, except in the southern part where open waters occur along the coast and the drift ice often is rather loose. Here, extremely high numbers of wintering seabirds often are found. These are not only of local origin, but arrive from breeding sites in Canada, Iceland and Svalbard, making the Greenland wintering sites of high international concern as regards nature conservation. The most numerous species in winter are common eider, king eider, thick-billed murre and the large gull species. The distribution of the wintering seabirds has been surveyed in the coastal area of West Greenland (Merkel et al. 2002, Boertmann et al. 2004). It is estimated that more than 3.5 million birds winter along the entire coast of Southwest Greenland. To this figure an unknown but probably very high number (several million) of little auks should be added (Boertmann et al. 2006). They occur mainly in offshore waters, where they are difficult to survey. Also large numbers of thick-billed murres occur in the offshore area in spring and autumn. The knowledge of the habitat use of the wintering seabirds and the factors governing their distribution is generally poor. Despite the unknowns it is evident that, seen in a North Atlantic perspective, the waters of West Greenland are very important for seabirds (Barret et al. 2006).

The assessment area is very important for the king eider population breeding in eastern Arctic Canada and a number of studies have been conducted in recent years (Figures 28, 29 and 30). Thirty-six king eiders were tracked from the breeding and moulting sites by means of satellite transmitters on their migration to the wintering grounds on the fishing banks off West Greenland (Mosbech et al. 2004, Mosbech et al. 2006). A single bird was followed for two years (Figure 29). Regardless of the locality where the birds were caught and implanted with a transmitter (Canada and West Greenland), almost half of the tracked birds wintered at Store Hellefiskebanke and the adjacent coast.

On Store Hellefiskebanke most birds were found in an area with water depths less than 50 m and up to 70 km from the coast (Figure 29). Surveys have shown that there can be up to in the region of 300,000 king eiders wintering in the ice in the area in March (Mosbech & Johnson 1999) and, based on the aerial survey conducted as part of the marginal ice zone project in late April 2006, it is estimated that there were about 400,000 king eiders (75% confidence intervals: 227,000 – 709,000) staging at Store Hellefiskebanke at depths less than 50 m, while outside this area king eiders were only observed sporadically.

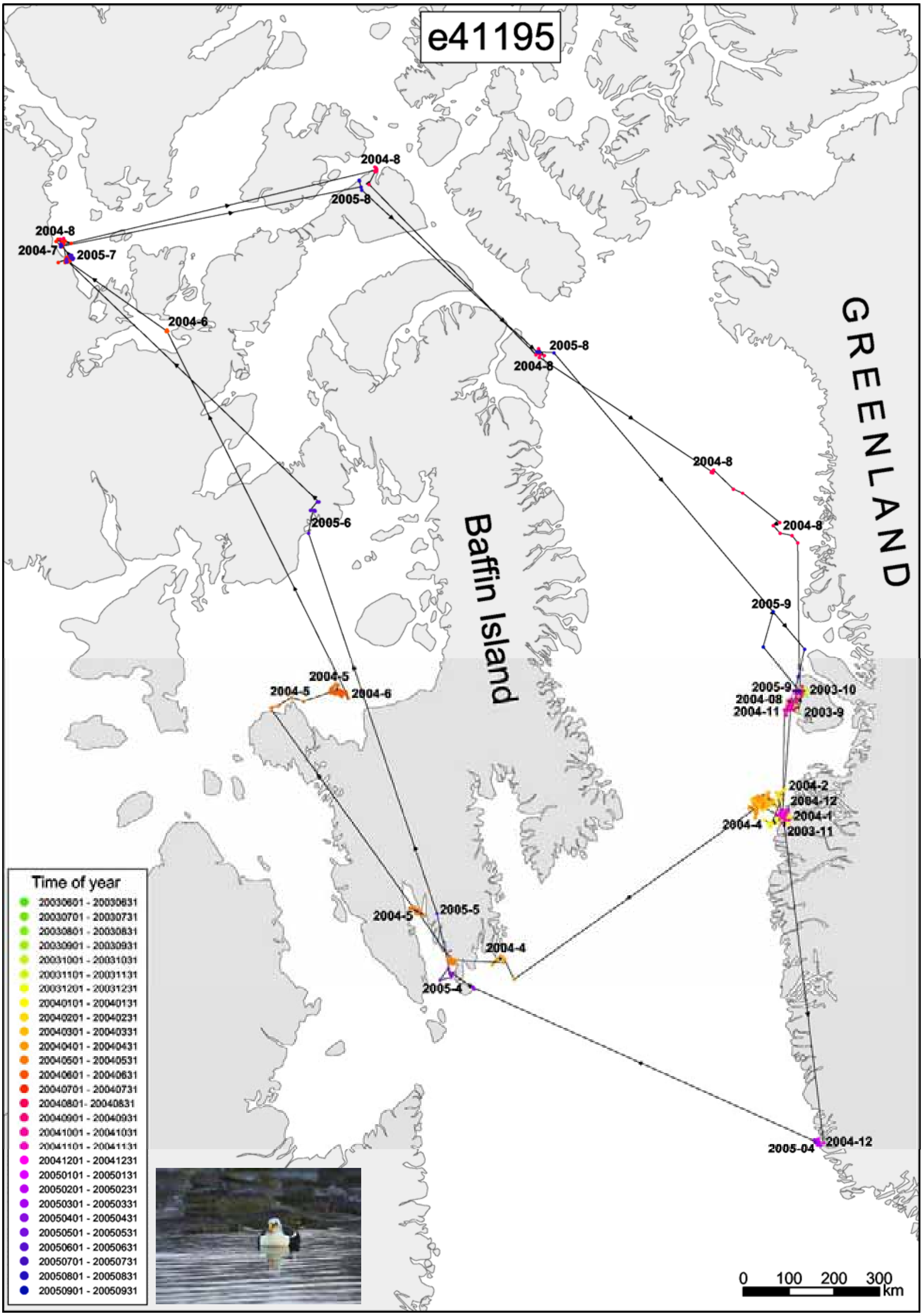


Figure 28. A King eider (No. e41195) tracked with satellite transmitter from the moulting area at Disko Island in September 2003 and the following two years through two full migration cycles to the breeding grounds in Arctic Canada. Two sites in the assessment areas were of particular importance to this bird: The waters west of Disko Island and the shallow part of Store Hellefiskebanke. Based on NERI/GINR data, Mosbech et al. (in prep.).

Figure 29. King eider satellite tracking locations from year round tracking of birds implanted at moulting localities in Umiarfik and the fjords at the west coast of Disko and at a breeding locality in Arctic Canada outside the map. The scattered dots in the central Baffin Bay and on Baffin Island are from bird migrating to and from breeding localities in Arctic Canada west of the map border. See fig 5.5.3 for an example of a full migration route. Observations from two ship based surveys are also indicated on the map. The importance of the waters west of Disko Island and on Store Hellefiskebanke (at c. 68° N) is apparent. Based on NERI/GINR data, Mosbech et al. (2006).

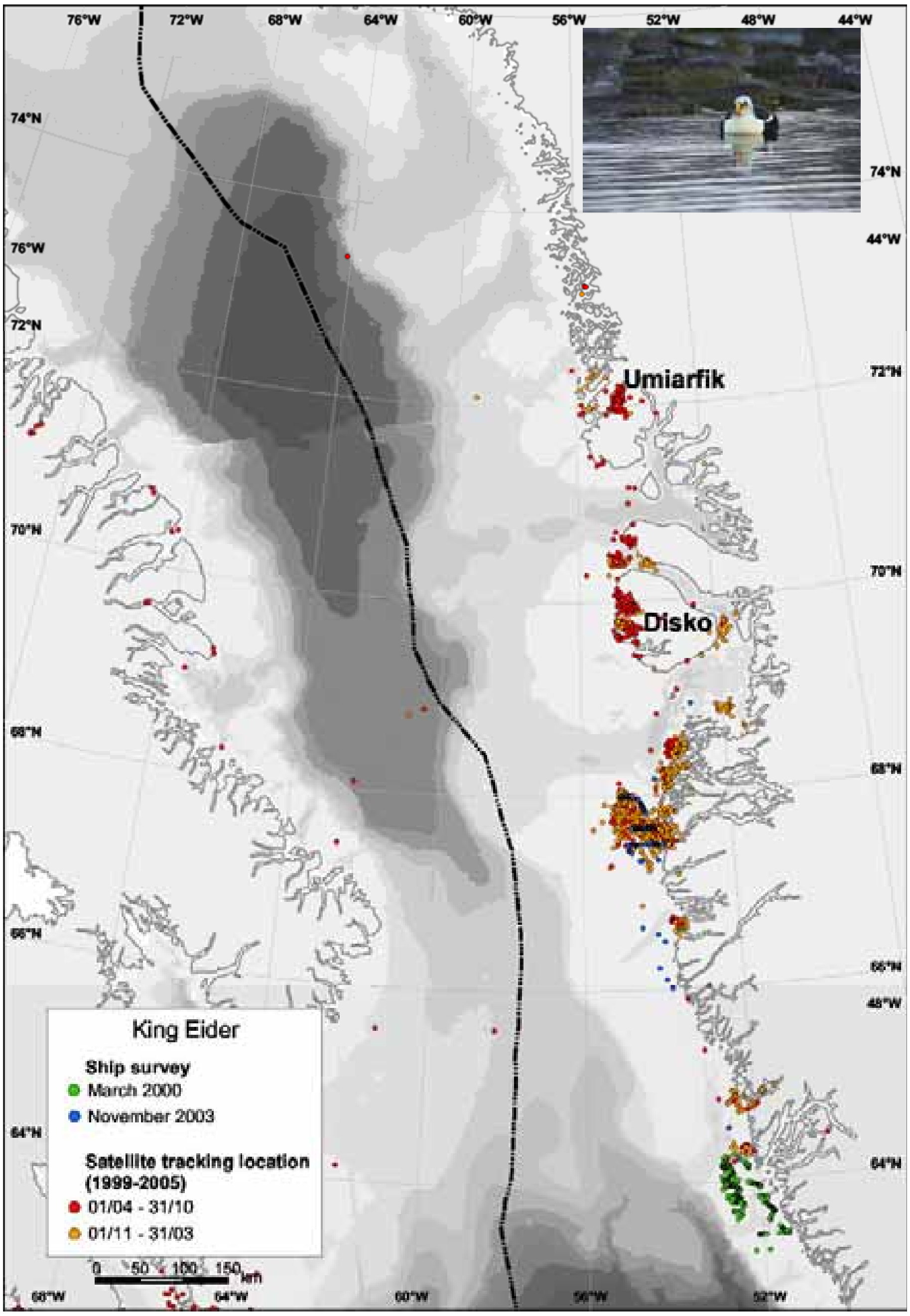
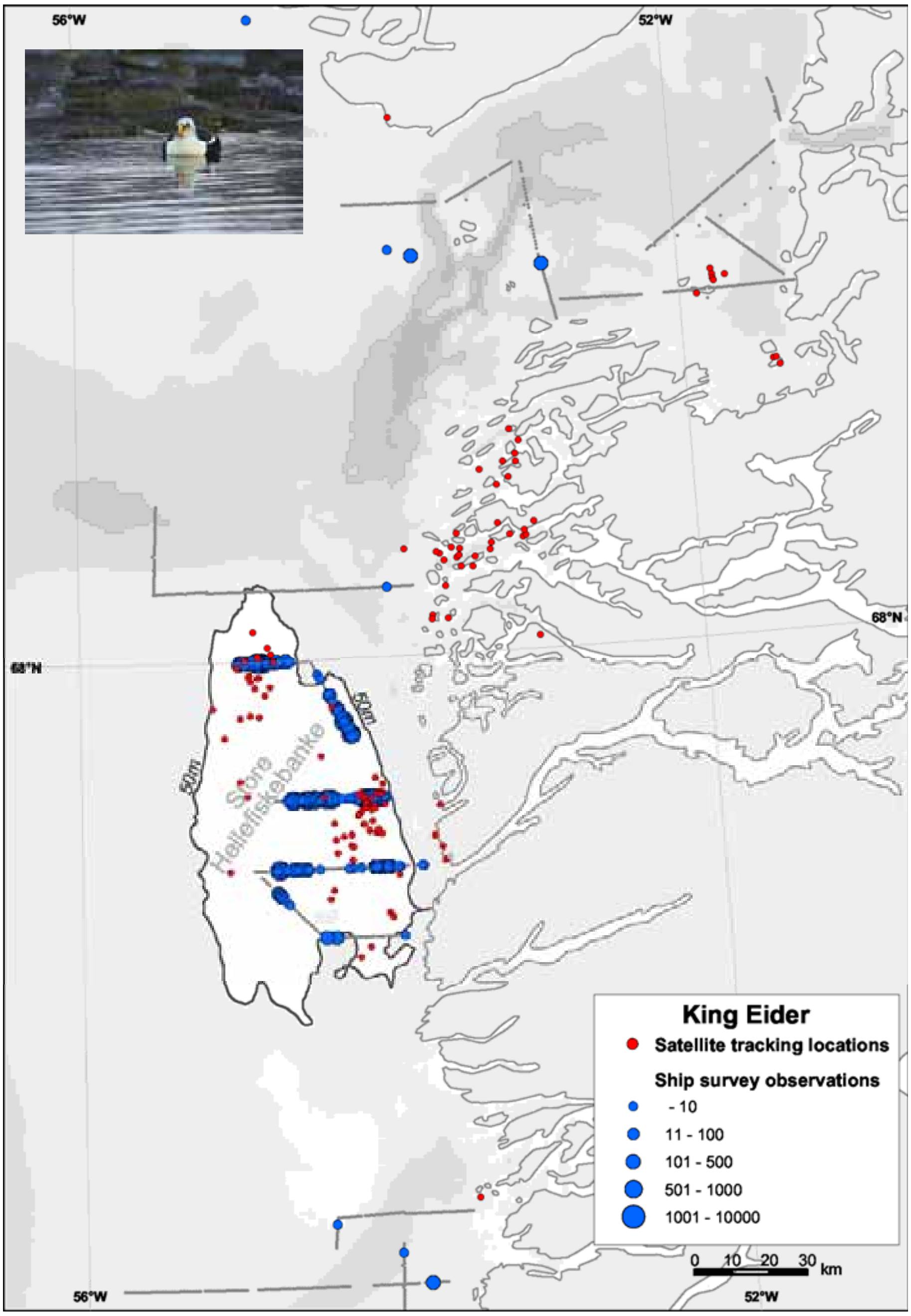


Figure 30. Locations of satellite tracked king eiders in November 2003 and observations of king eiders from a ship based survey in November 2003 (grey lines). Based on the limited number of transect lines an estimated 500,000 king eiders (75% confidence interval: 529,000-1,083,000) where present within the 50 m depth contour at Store Hellefiskebanke (excluding the not surveyed southwestern part). Based on NERI data, Mosbech et al. (2006).



Based on a ship survey in 2003 it was estimated that there were more than 500,000 king eiders (75% confidence intervals: 529,000 – 1,083,000) on Store Hellefiskebanke in November (Figure 30) (Mosbech et al. 2006). This probably approaches the entire population of king eiders wintering in West Greenland, which makes this shallow part of Store Hellefiskebanke extremely sensitive to oil spills. A tracked king eider equipped with a depth transducer recorded 43 m as maximum dive depth and it showed a diurnal diving pattern of diving preferentially during daylight, even in midwinter when there are only a few hours of twilight (Mosbech et al. in 2006). So, these few hours of foraging appears to be very important. It also indicates that there are plenty of benthic mussels at the site, since the birds are able to find sufficient food during these few hours.

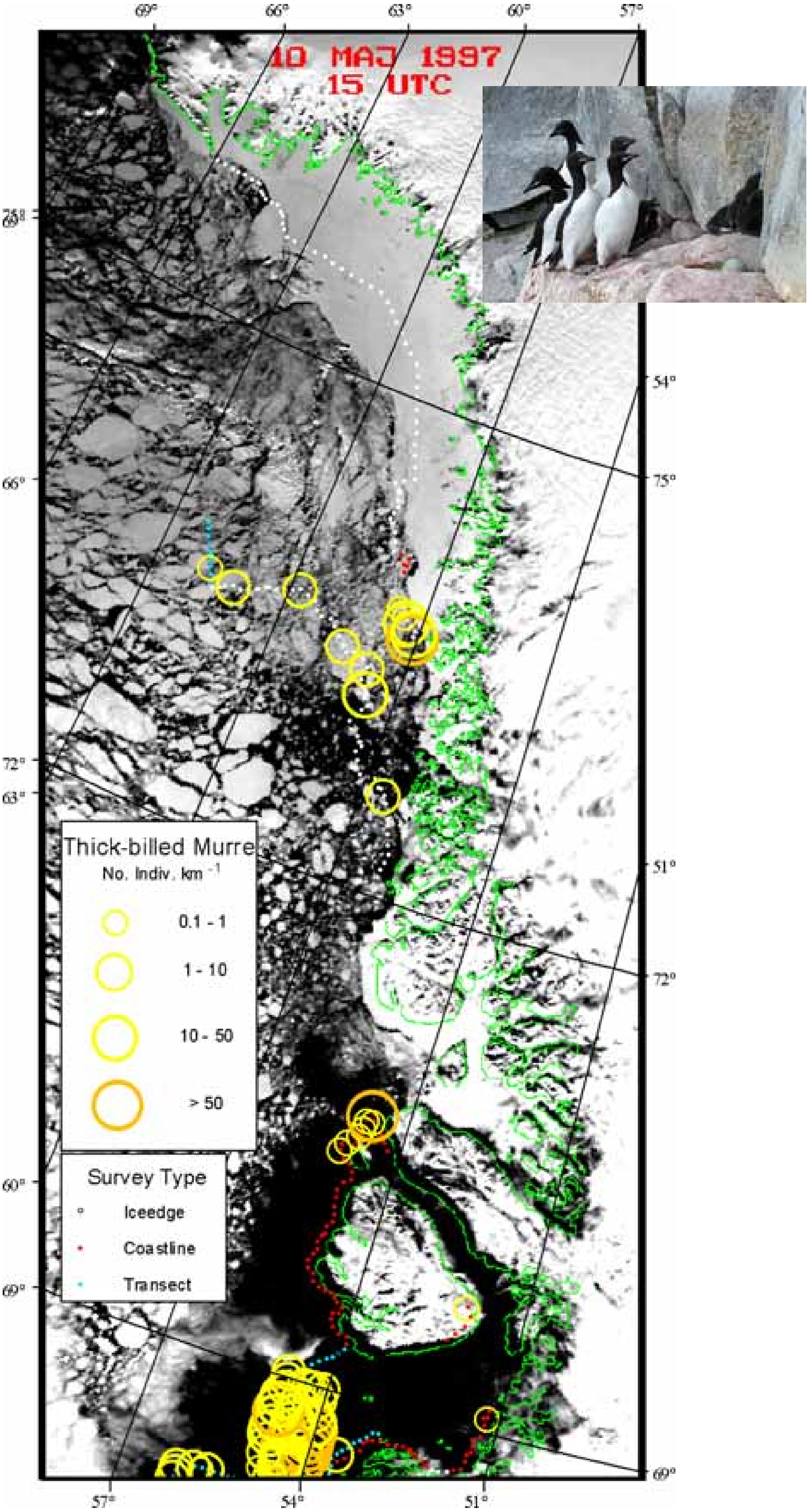
Thick-billed murre abundance and distribution have been surveyed from aircraft in spring, and some significant concentrations were observed in the assessment area (Figure 31) (Merkel et al. 2002). Another study initiated in 2005 focused on the post-breeding migration of the thick-billed murres from the breeding colony in Disko Bay. The three-week old chicks leave the colony and initiate a swimming migration together with one of the parent birds which then moult flight feathers and become unable to fly for a three-week period. The temporal and spatial distribution of this swimming migration was unknown until 2005, when ten birds were satellite tracked. This study was followed up in 2006 by tracking an additional 17 birds (NERI unpublished). The birds moved both to the south of Disko island and to the north through Vaigat, and dispersed in the waters west of Disko (Figure 33).

The marginal ice zone project in April and May 2006 revealed large concentrations of thick-billed murres present in the assessment area and confirmed earlier studies (Figure 31), although the murres were much more widespread in the area and many were found even in dense drift ice near the Canadian border (Figure 32). In total about 400,000 thick-billed murres were estimated to be present in the assessment area during the survey, and significant concentration areas were located (Figure 32).

Although not seabirds, geese should also be mentioned in this context, because they often utilise saltmarshes within the assessment area. These saltmarshes are very low and become inundated at high water levels. Particularly the Greenland white-fronted goose (*Anser albifrons flavirostris*) is vulnerable, because the population is seriously decreasing. Brent geese (*Branta bernicla*) on migration between breeding sites in Arctic Canada and wintering grounds in northwest Europe also utilise these salt marshes during stopovers (Boertmann et al. 1997, Boertmann & Egevang 2001).

The overall and general knowledge of seabirds in the assessment area is fairly good. However, many specific questions remain to be solved in order to conduct specific EIAs.

Figure 31. Distribution of thick-billed murres in May 1997 transposed on a synoptic image of the ice distribution. A large concentration is seen in the mouth of Disko Bay (NERI).



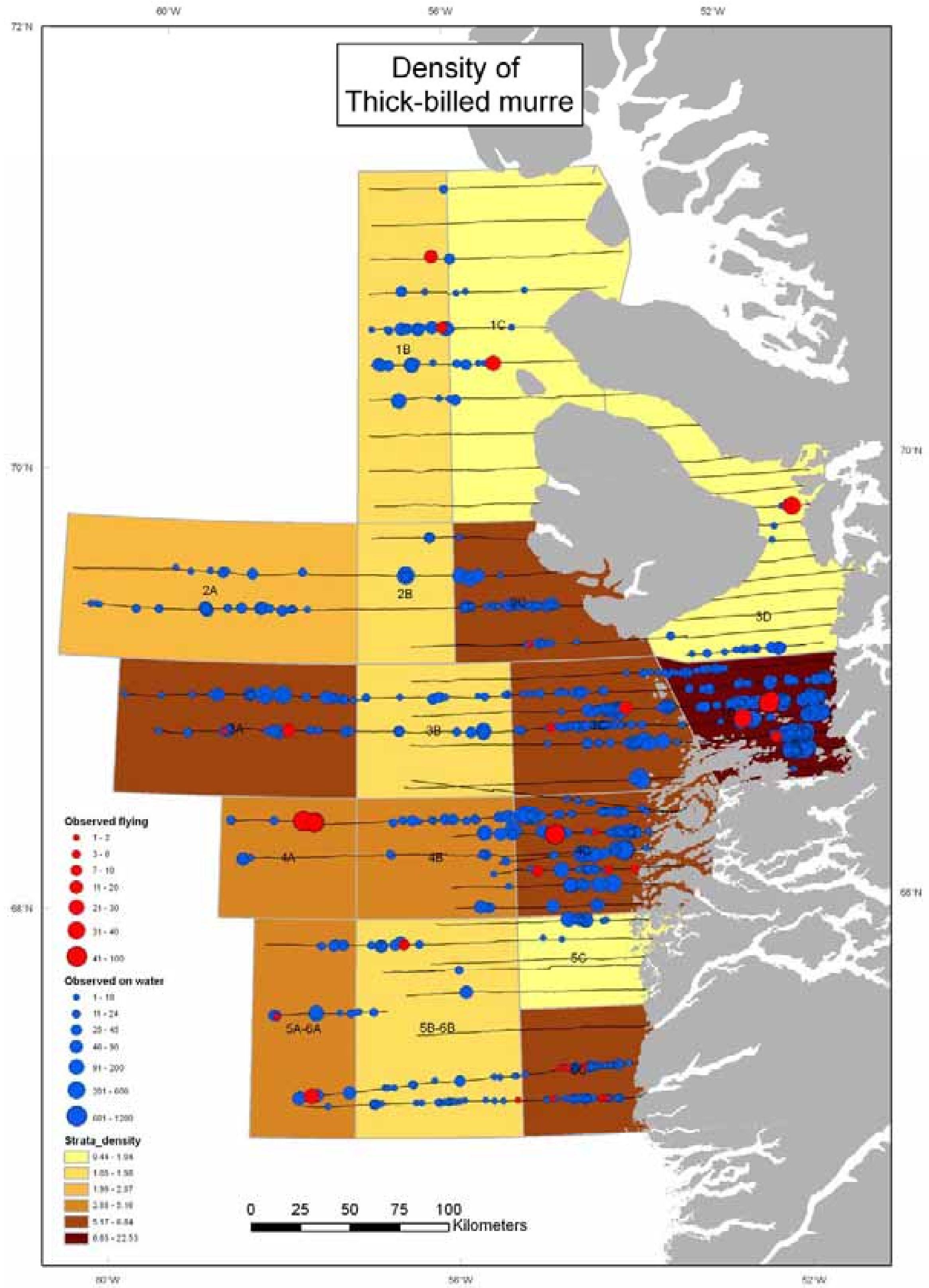


Figure 32. Densities of thick-billed murres in the spring 2006 survey area. Based on a preliminary estimate of the number observed from aircraft during the marginal ice zone project in April and May 2006. In total about 430,000 (CV 11%) thick-billed murres were estimated to reside in the area and especially high concentrations were found in southern Disko Bay (ice free) and relatively high concentrations were found northwest, west and southwest of the entrance to the bay in areas with both open water and quite dense ice cover. Surprisingly high concentrations were found far offshore near the Canadian border in areas with dense ice cover. This is presumably birds crossing directly over the central Davis Strait and Baffin Bay on their way to the large breeding colonies in Arctic Canada.

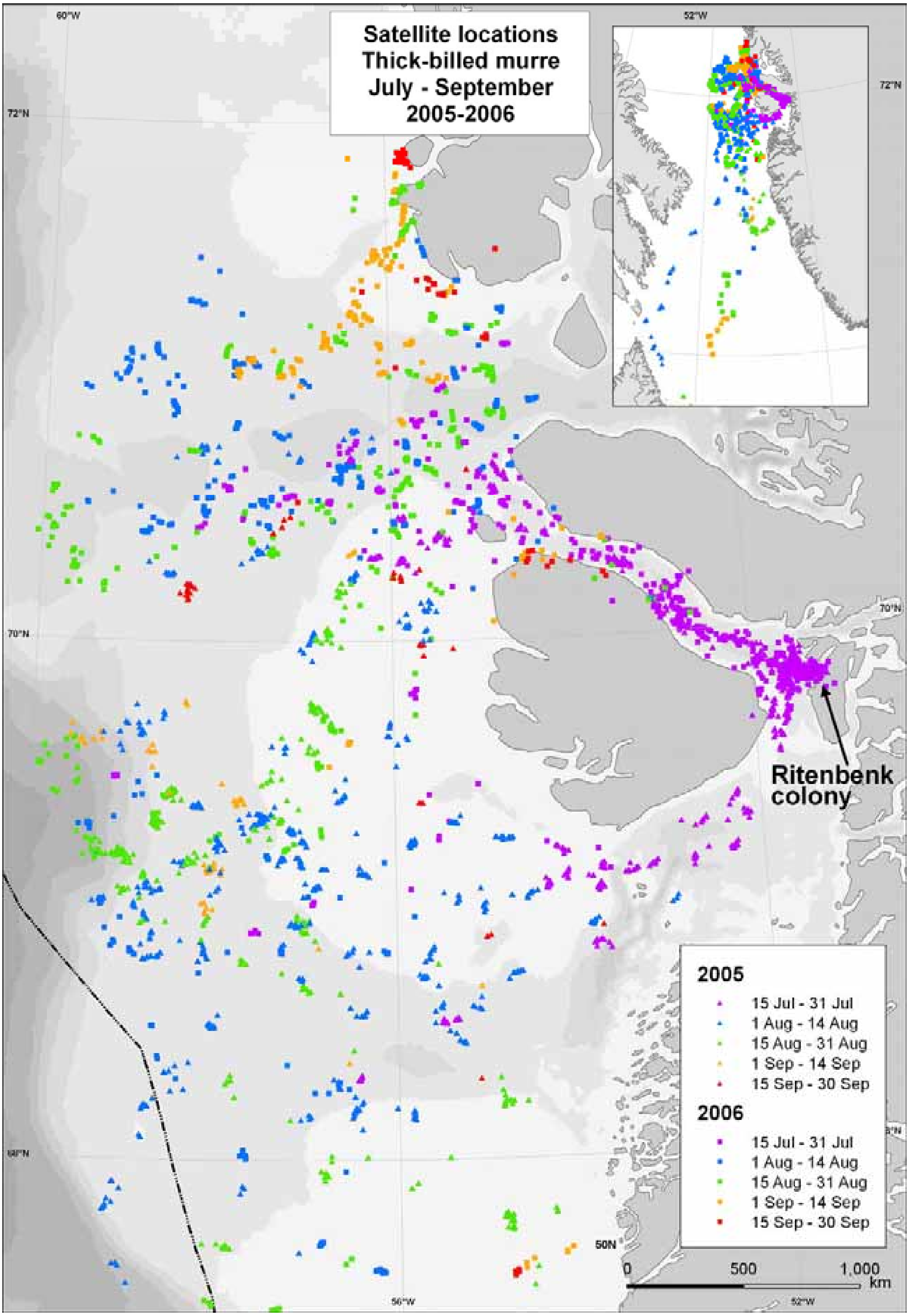


Figure 33. Locations of thick-billed murres equipped with satellite transmitters in July 2005 (n = 10) and 2006 (n = 17) on the breeding site (Ritenbenk colony).

4.6 Marine mammals

The marine mammals of the assessment area comprise 5 species of seals, walrus, 13 species of whales and polar bear (*Ursus maritimus*) (Table 3).

Table 3. Overview of selected marine mammals occurring in the assessment area. Red-list status is provisional, as the list has not yet been published. Importance of study area to population (Conservation value) indicates the significance of the population occurring within the assessment area in a national and international context as defined by Anker-Nilssen (1987).

Species	Period of occurrence	Main habitat	Stock size or abundance	Protection/ exploitation	Greenland red-list status	Importance of assessment area to population
Bowhead whale	February-June	Pack ice/ marginal ice zone	some hundreds	Protected (since 1932)	near threatened (NT)	high
Minke whale	April-November	Coastal waters and banks	4000	Hunting regulated	least concern (LC)	medium
Humpback whale	June-November	Edge of banks, coastal waters	1000	Protected (1986)	least concern (LC)	medium
Fin whale	June-October	Edge of banks, coastal waters	2000	Hunting regulated	least concern (LC)	medium
Blue whale	July-October	Edge of banks	few	Protected (1966)	data deficient (DD)	low
Harbour porpoise	April-November	Whole area	common	Hunting unregulated	data deficient (DD)	medium
Bottlenose whale	(June-August)	Deep water	infrequent	Hunting unregulated	not applicable (NA)	low
Pilot whale	June-October	?	occasionally	Hunting unregulated	least concern (LC)	low
Killer whale	June-August	Whole area	rare but regular	Hunting unregulated	not applicable (NA)	low
White whale	November-May	Banks	8000	Hunting regulated	critical endangered (CR)	high
Narwhal	November-May	Edge of banks, deep waters	3000	Hunting regulated	critical endangered (CR)	high
Sperm whale	May-November	Deep waters	rare but regular	Protected (1985)	not applicable (NA)	low
Harp seal	June-October	Whole area	5.4 millions.	Hunting unregulated	least concern (LC)	medium
Hooded seal	March-October	Whole area	unknown, but many	Hunting unregulated	least concern (LC)	medium
Ringed seal	Whole year	Whole area, usually in ice	common	Hunting unregulated	least concern (LC)	medium
Harbour seal	Whole year	Coastal waters	very rare	Hunting regulated	critical endangered (CR)	high
Bearded seal	Mainly winter	Drift ice on the banks	common	Hunting unregulated	data deficient (DD)	medium
Walrus	Winter	Drift ice on the banks	3000	Hunting regulated	endangered (EN)	high
Polar bear	Mainly winter	Drift ice and ice edges	4000	Hunting regulated	vulnerable (VU)	medium

Seals

The most numerous seals in the assessment area are the ringed seal (*Phoca hispida*), hooded seal (*Cystophora cristata*) and harp seal (*Phoca groenlandica*). Ringed seals occur mainly in ice-covered waters and they whelp on the fast ice of the fjords. They live on fish and crustaceans (Siegstad et al. 1998). Harp and hooded seals are migrant seals occurring mainly in the summer and they whelp outside the assessment area; both are mainly fish eaters and hooded seals are known to dive to considerable depth (1000 m) (Kapel 1995, 1996, Kapel & Rosing-Asvid 1996, Folkov & Blix 1999). Bearded seals are a winter visitor, occurring in the drift ice, where they mate and whelp in the early spring (Kapel unpublished). Harbour seals are today very rare or absent from the assessment area. The nearest known site with regular occurrence is the fjord Kangerlussuaq just south of the assessment area (Teilmann & Dietz 1994, Lisborg & Teilmann 1999, NERI unpublished).

Walrus

Walruses occur in the period February to May on the relatively shallow bank areas (water less than 100 m deep) where they can dive to the seafloor and feed on bivalves (e.g. Born 2005). The population is declining due to unsustainable harvest. Based on an aerial survey conducted by GINR in March 2006 the population between the entrance to Nassuttoq and Vaigat was estimated to 3,085 individuals (90% confidence interval 1239-7681 animals). Their exact summer habitats are unknown, and a relationship with southeast Baffin Island in Canada and the Qaanaaq area has been speculated (Born et al. 1994). Not until 2005 was direct evidence for the connection to southeast Baffin Island established, when a single female was tracked (by means of satellite) across the northern Davis Strait to Baffin Island (Figure 34) (NERI & GINR unpublished data). Additionally, seven walruses were equipped with satellite transmitters in March 2005 and 2006 to follow their movements on and away from the West Greenland wintering grounds (NERI & GINR unpublished data). The tagging also showed that an animal moved northwards indicating a link between Store Hellefiskebanke and the banks west of Disko Island (Dietz et al. in prep.).

Walruses were surveyed from aircraft during the NERI marginal ice zone project for the present assessment in April and May 2006. In total, 415 walruses were estimated, located in two separate areas, one off northwest Disko Island and one on Store Hellefiskebanke. In the first area, 46 individuals were estimated and in the second 370 (figures not yet corrected for submerged animals, a correction which will increase the estimate). Particularly on Store Hellefiskebanke the walruses were confined to a very distinct area similar to the home range calculated from the satellite tacked animals in 2005 and 2006 (Figure 35).

The walruses occurring in West Greenland are confined to a restricted habitat, where they concentrate for feeding and mating. This habitat is found entirely within the assessment area, and no alternative habitats are known in West Greenland.

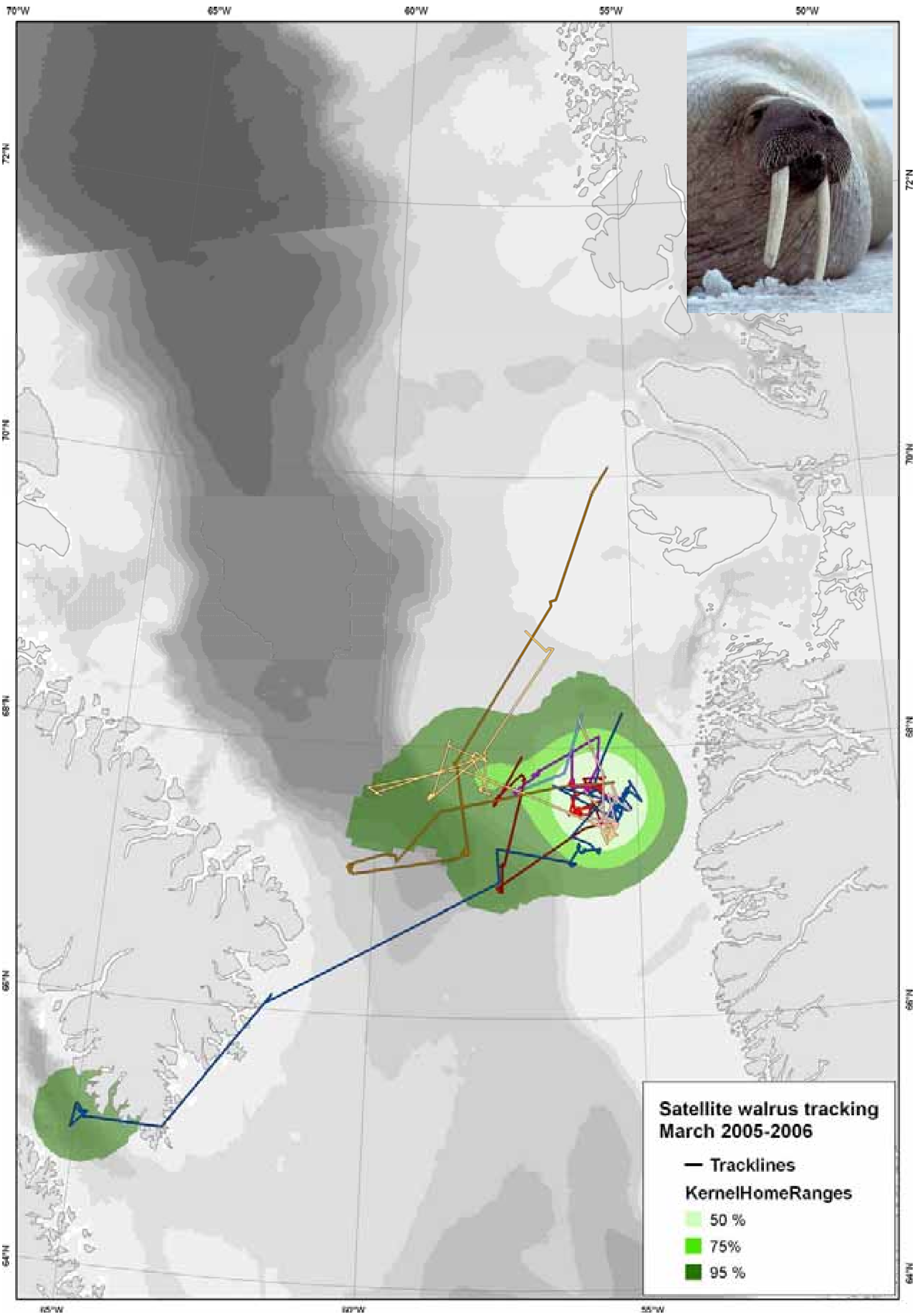


Figure 34. Track lines from eight walruses tagged with satellite transmitters during March 2005 and 2006 off West Greenland. One transmitter (in 2005) lasted long enough to show the migration route across the northern Davis Strait to the Canadian summering grounds of South East Baffin Island and additional two (in 2006) entered Canadian waters during dense ice conditions trying to access the Canadian coast. Pale green colour indicates the home range with 50%, bright green with 75% and dark green with 95% probability.

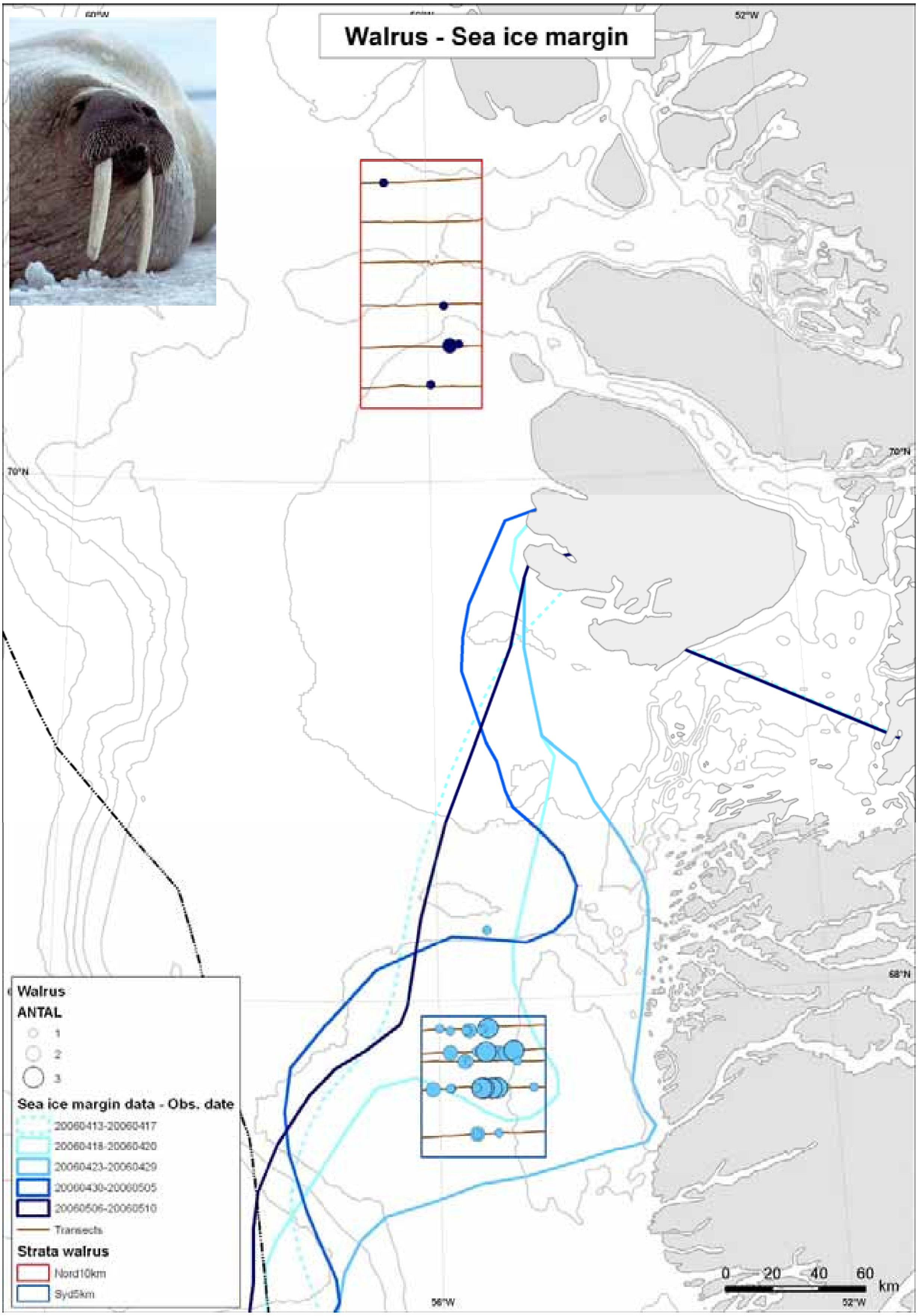


Figure 35. Walrus observations during the NERI-survey in April and May 2006. The ice edge at different dates is indicated by coloured lines. Dots represent individual observations of walruses. In the southern block (stratum) 370 walruses were estimated and in the northern block 46.

Whales

Bowhead whale (*Balaenena mysticetus*), narwhal (*Monodon monoceros*) and white whale (*Delphinapterus laucas*) utilise the assessment area during autumn, winter and spring. They rely heavily on the production and foraging opportunities provided in the open water along West Greenland in winter. Other whale species like harbour porpoise (*Phocoena phocoena*), minke whale (*Balaenoptera acutorostrata*), fin whale (*Balaenoptera physalus*) and humpback whale (*Megaptera novaeangliae*) migrate from more southern wintering grounds to the assessment area where they are abundant visitors and predators during summer and autumn. Less common but regular visitors to the area are killer whales (*Orcinus orca*), pilot whales (*Globicephala melas*), sperm whales and blue whales (*Balaenoptera musculus*).

Narwhal

Narwhals are abundant in the deeper basins of the assessment area during November through May. Narwhals winter in the dense pack ice in Baffin Bay as well as in the coastal areas close to the southern entrance to Disko Bay and in the outer parts Uummannaq Fjord. Satellite tracking studies have shown that narwhals from Melville Bay winter in the assessment area together with narwhals from the Eclipse Sound population in Canada (Figure 36) (Dietz & Heide-Jørgensen 1995, Dietz et al. 2001, Heide-Jørgensen et al. 2002, 2003). Large numbers of narwhals visit Uummannaq in November and later, narwhals arrive in Disko Bay. Narwhals from Melville Bay also enter Disko Bay in winter but it is presumed that other narwhal stocks also contribute to the winter occurrence of narwhals in Disko Bay. This is in agreement with genetic studies that suggest that a mix of narwhals from different populations contributes to the harvest in Disko Bay (Riget et al. 2002).

White whale

White whales (*Delphinapterus leucas*) are abundant on the banks of the assessment area from November through May. They arrive from the Canadian summer grounds to the assessment area in November and stay until May. They usually occur in shallower waters and closer to the coast than narwhals and mainly in the waters between the drift ice and the coast (Figure 37). The population is decreasing seriously due to excessive hunting (Heide-Jørgensen & Reeves 1995, Alvarez-Flores & Heide-Jørgensen 2004).

Only two individual have been tracked from the Canadian summer grounds to the wintering aeas in West Greenland (Heide-Jørgensen et al. 2003b), and the knowledge on the migrations of white whales in West Greenland is limited compared with that for narwhals. Just as for narwhals, belugas are expected to acquire the major part of their annual food intake in West Greenland in winter.

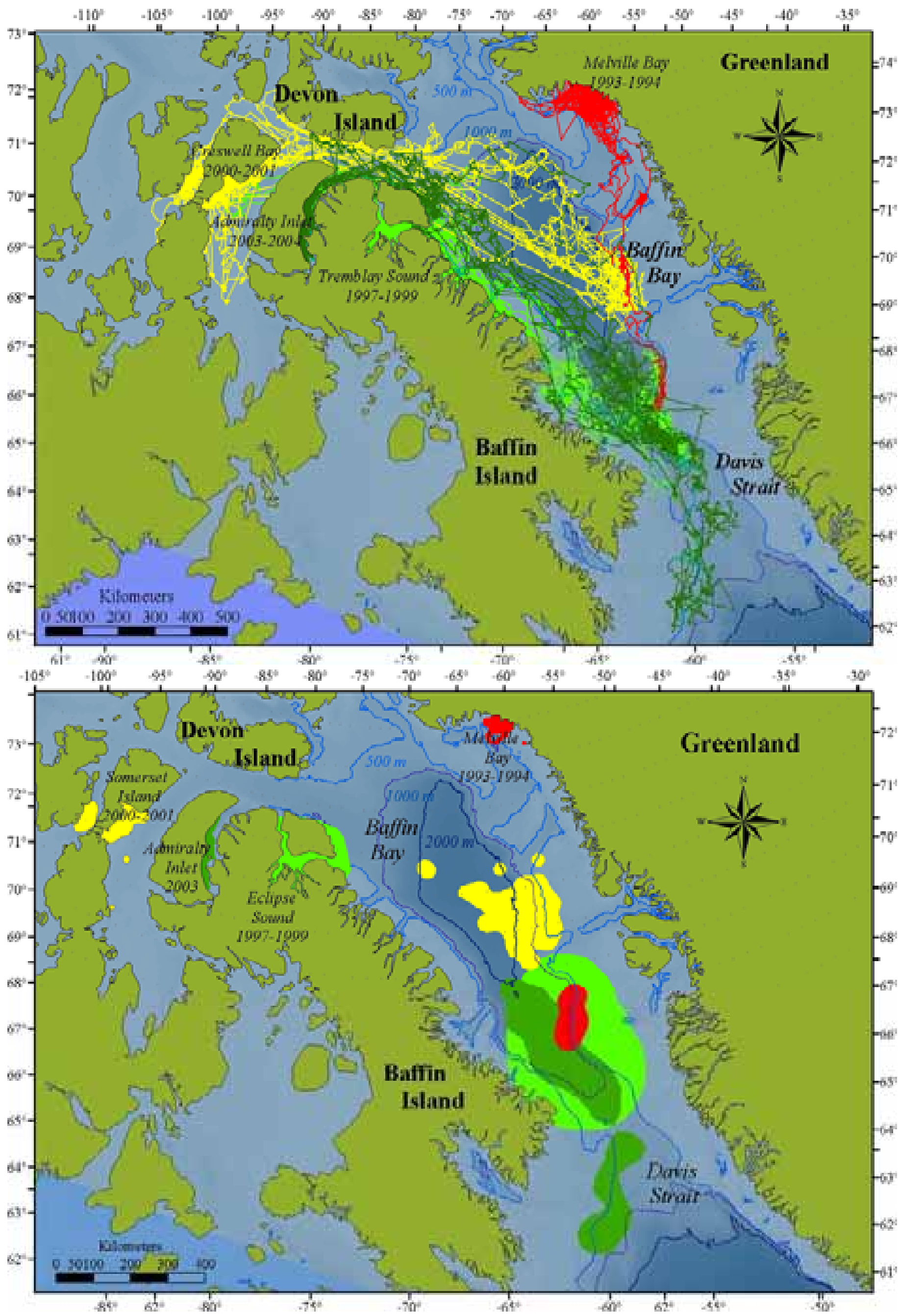


Figure 36. Track lines (upper map) and 95% kernel home range polygons (lower map) for the narwhals tagged in 2003 and 2004 in Admiralty Inlet compared with previous tagging published by Dietz & Heide-Jørgensen (1995), Dietz et al. (2001) and Heide-Jørgensen et al. (2002, 2003). Dark green = narwhals tagged in Admiralty Inlet, yellow = tagged at Somerset Island, pale green = tagged in Eclipse Sound and red = tagged in Melville Bay (Figure from Dietz et al. submitted). The winter areas are the home ranges in Baffin Bay and Davis Strait. Note particularly the restricted winter area (red) of the Melville Bay narwhals.

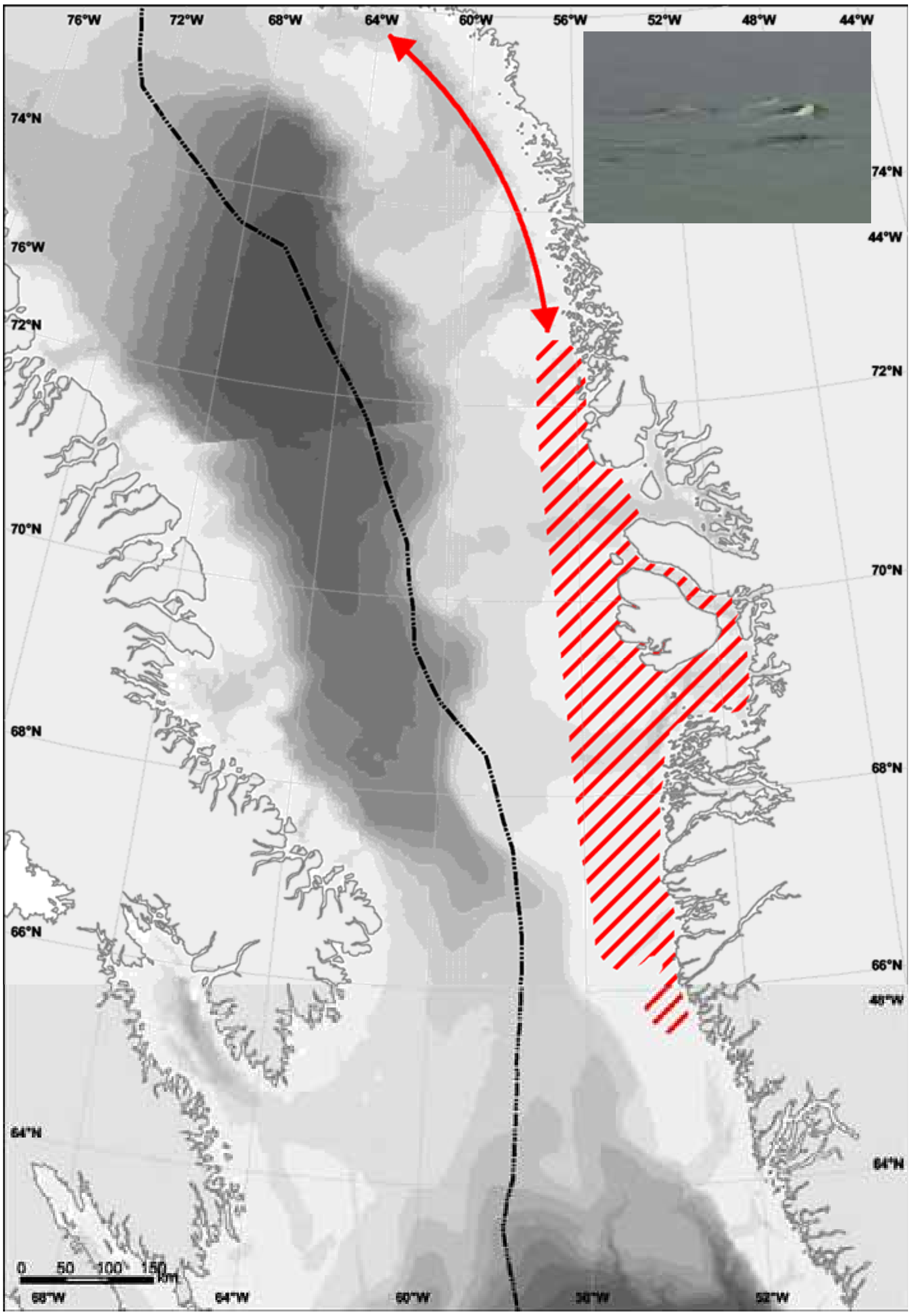


Figure 37. Distribution and migration routes of wintering white whales in West Greenland. The whales are present in October through May. During summer the white whales are in high Arctic Canada (Based on Heide-Jørgensen et al. 2003).

Bowhead whale

Bowhead whales are winter and spring migrant visitors in the assessment area, occurring from February (probably earlier in the southern parts) until late May/early June. Departure from the area initiates in mid-May. The whales stay mainly in the marginal zone of the West Ice and in the waters south of Disko Island. Recent satellite tracking has shown that they move from West Greenland across the Baffin Bay to the waters of the high Arctic Canadian archipelago, and from there along Baffin Island to winter quarters in the Hudson Strait (Heide-Jørgensen & Laidre in prep.). Bowhead whales were heavily exploited by European and North American whalers until 1932 when the whales became protected. At this time the stock was very small, and it still is, although there are now signs of a slow recovery. The bowhead whale is globally red-listed as conservation dependent and regionally listed as 'endangered' in Canada and as 'near threatened (NT)' in Greenland. The total Baffin Bay/Davis Strait population numbers probably a few thousands individuals, of which perhaps a thousand occur in Greenland waters.

Bowhead whales are specialised copepod feeders and, in the assessment area, exploit dense concentrations of *Calanus* near the seabed. Tagging has shown that dive depths range from 12 m to 487 m for individual whales in the assessment area (Heide-Jørgensen & Laidre in prep.). Thirty whales have been equipped with satellite tracking instruments in the period 2001-2006, and their movements within the assessment area are shown in Figure 38. These trackings also make it possible to calculate the area usage for different periods, which reveals an area of concentration off south Disko Island (Figure 39). It is of special concern that 85% of the whales (n=93) that have been sex determined are females and all of mature length but usually without calves. It is suspected that the assessment area is a major foraging ground for pregnant or resting females from the entire Canada-Greenland population of bowhead whales.

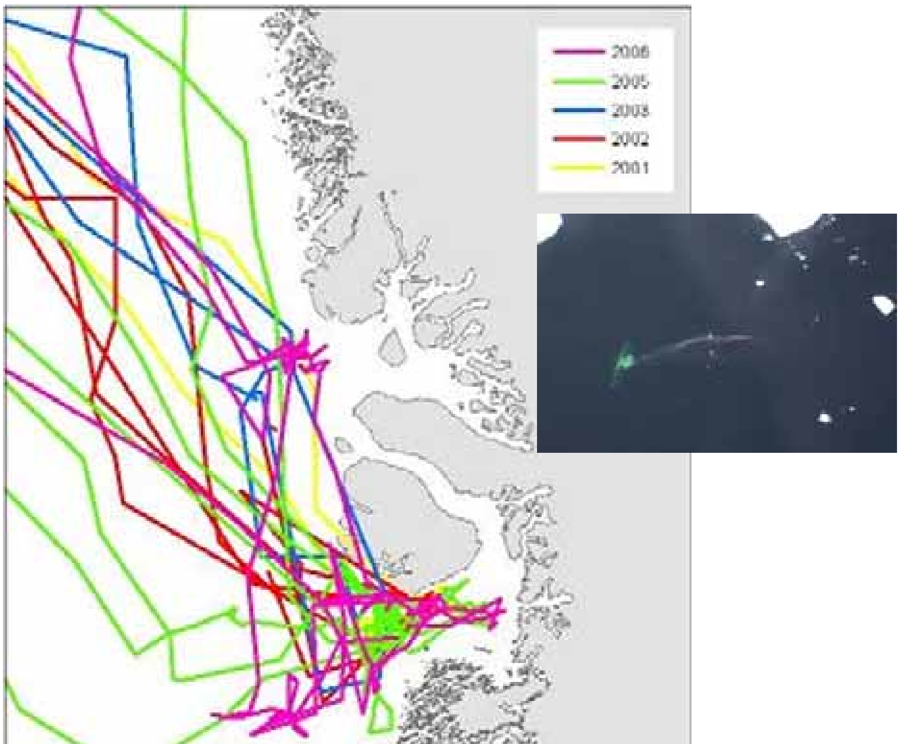
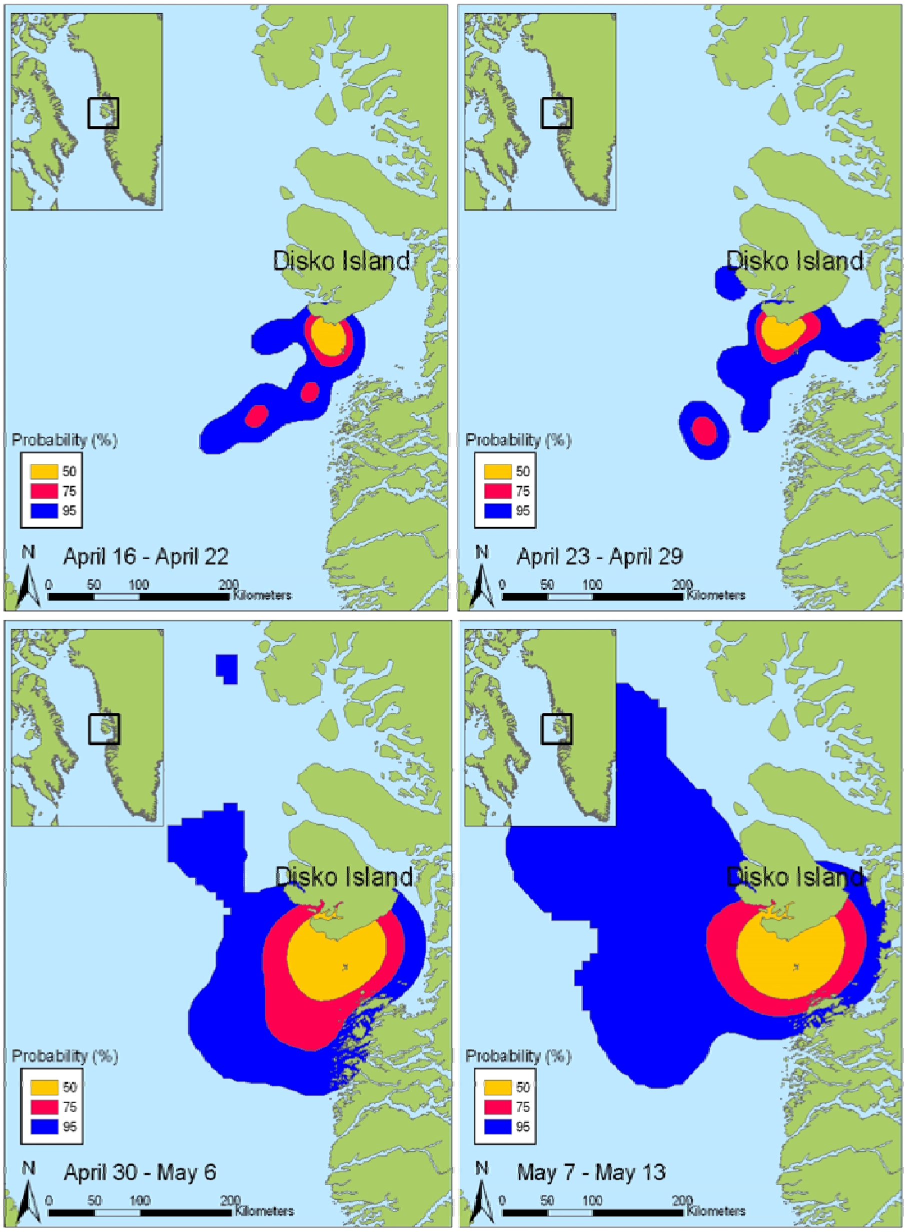


Figure 38. Tracks of bowhead whales departing Disko Bay between 2001 and 2006 in spring during their migration towards Canada in May-June (Heide-Jørgensen & Laidre 2006).

Figure 39. Area usage (kernel home ranges) mid-April to mid-May by bowhead whales tracked by satellite in 2001-2006 (n=30) (Heide-Jørgensen & Laidre in prep.). Within the yellow area there were a 50% probability of finding the whales, within the yellow and red area there were a 75% probability and within the yellow, red and blue area there were a 95% probability.



Polar bear

The polar bear (*Ursus maritimus*) occurs within the assessment area when sea ice (the West Ice) is present. These bears belong to two different populations: the Davis Strait population and the Baffin Bay population, which both are shared with Canada. Many bears follow the movements of the West Ice, bringing some into the assessment area in autumn, winter and spring (Taylor et al. 2001). The Davis Strait population was in 1996 estimated at approx. 2,000 individuals and the Baffin Bay population at 2,074 individuals (Aars et al. 2006, E.W. Born pers. comm.); it is not known how many of these bears occur on the Greenland side of the border.

Polar bears are very sensitive to oiling as they are dependant on the isolative properties of their fur and because they will ingest the toxic oil as part of their grooming behaviour (Øritsland et al 1981, Geraci & St Aubin 1990). Therefore polar bears coming into contact with oil are likely to die.

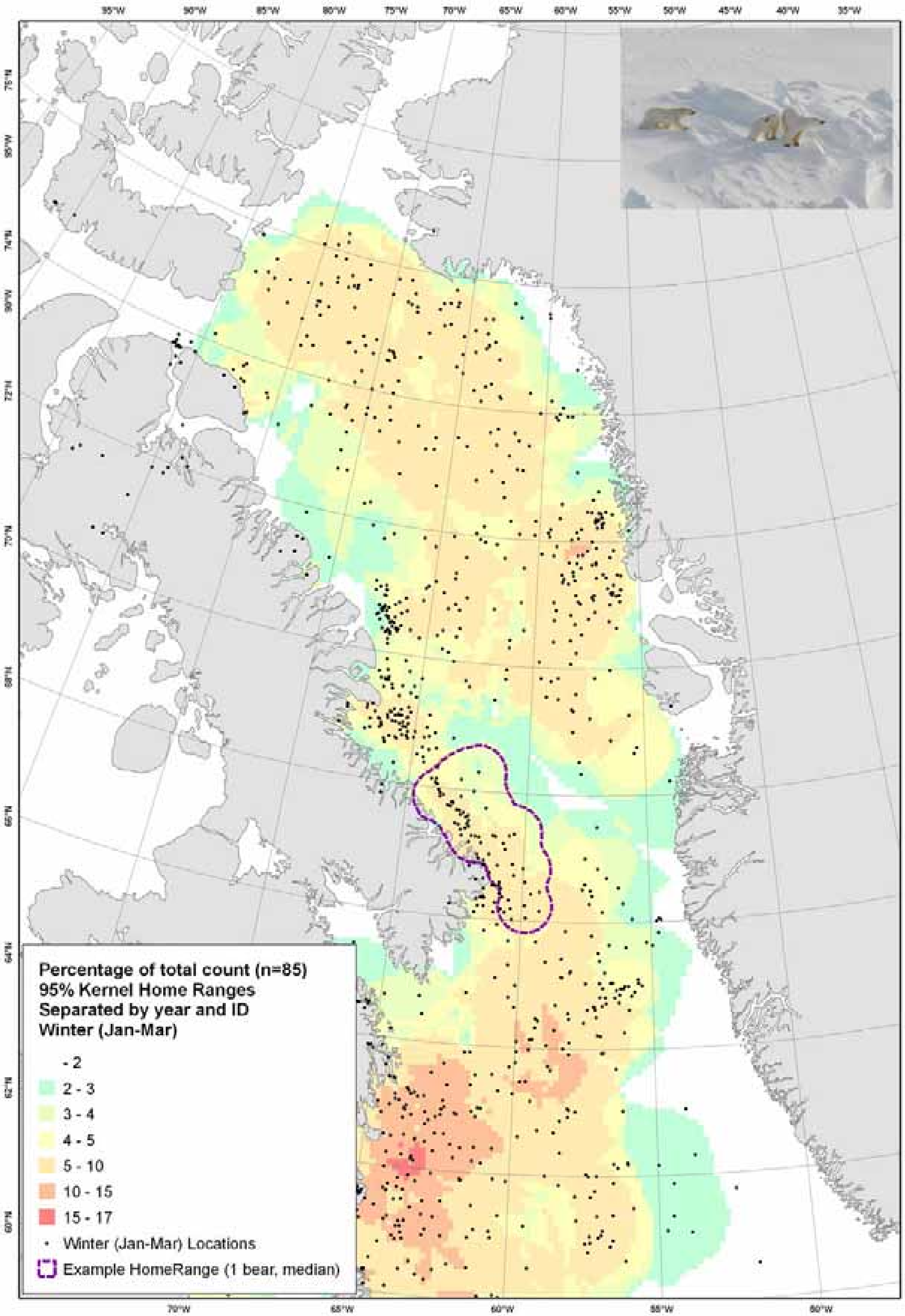


Figure 40a. Density of overlapping polar bear home ranges based on satellite tracked animals in the period 1991-2001.Colour scale indicates percentage of total number of home ranges which overlap within the single grid cells (10x10 km^2) during the season. The hatched line shows an example of a single home range. Winter situation (January– March) with 53 tracked polar bears. Black spots show locations of individual bears. Data kindly provided by Canadian Wildlife Service, Greenland Institute of Natural Resources, University of Saskatchewan, Wildlife Research Section Department of Environment (Ferguson et al. 1998, 2000; Taylor et al. 2001, 2006).

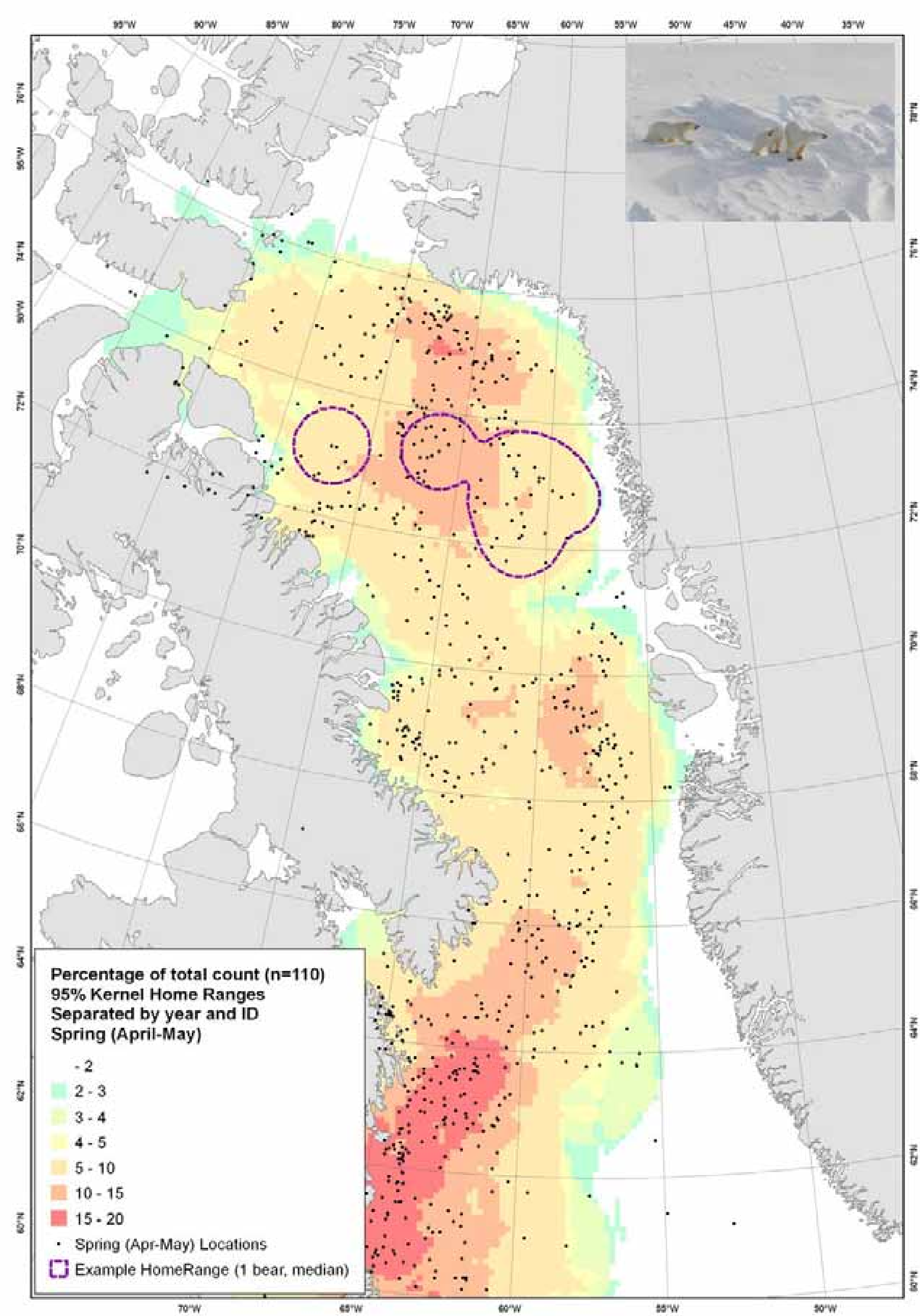


Figure 40b. Polar bear home ranges based on satellite tracked animals in the period 1991-2001. Spring (April – May) 59 tracked polar bears. See Figure 40a for explanation.

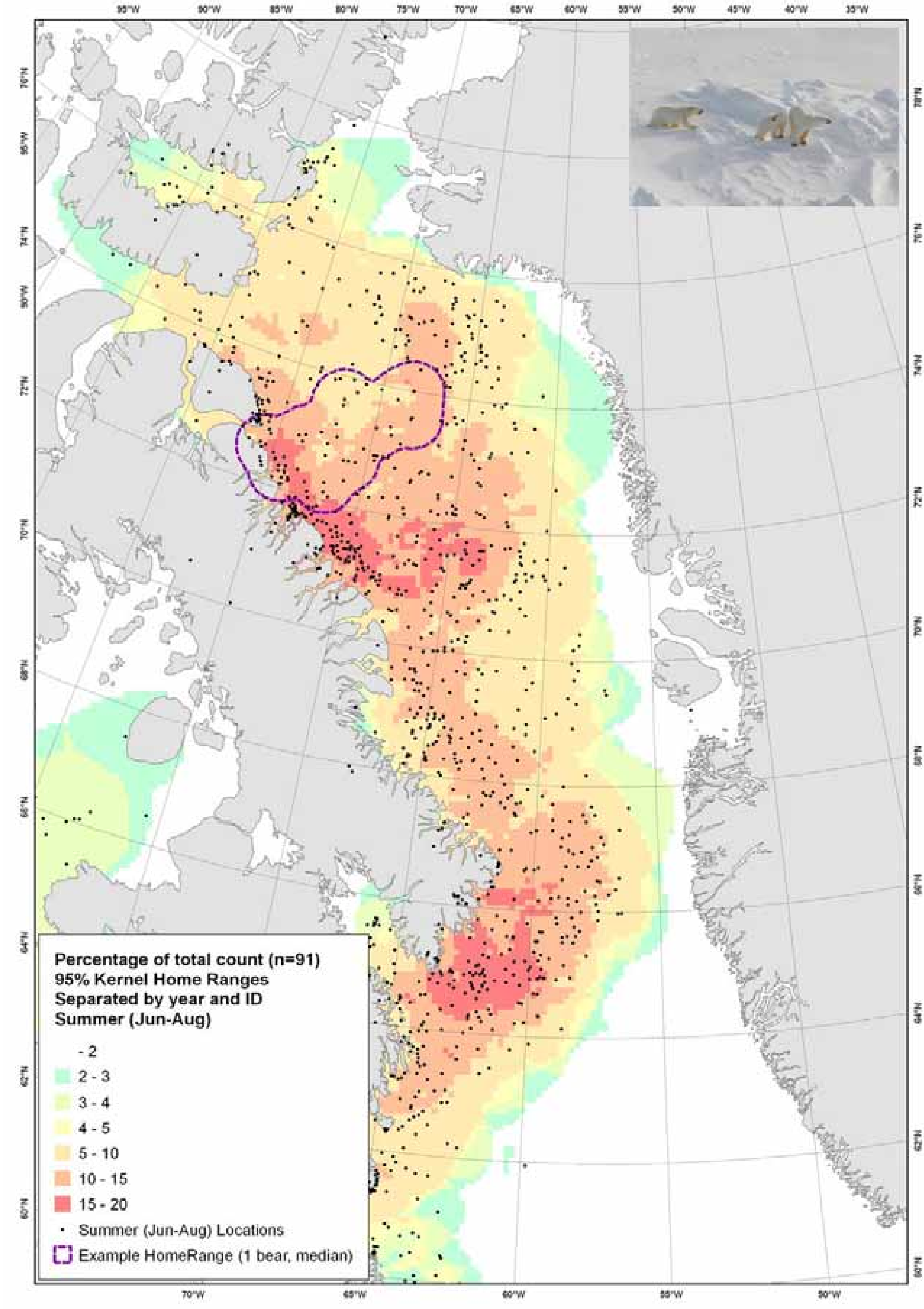


Figure 40c. Polar bear home ranges based on satellite tracked animals in the period 1991-2001. Summer (June-August) 49 tracked polar bears. See Figure 40a for explanation.

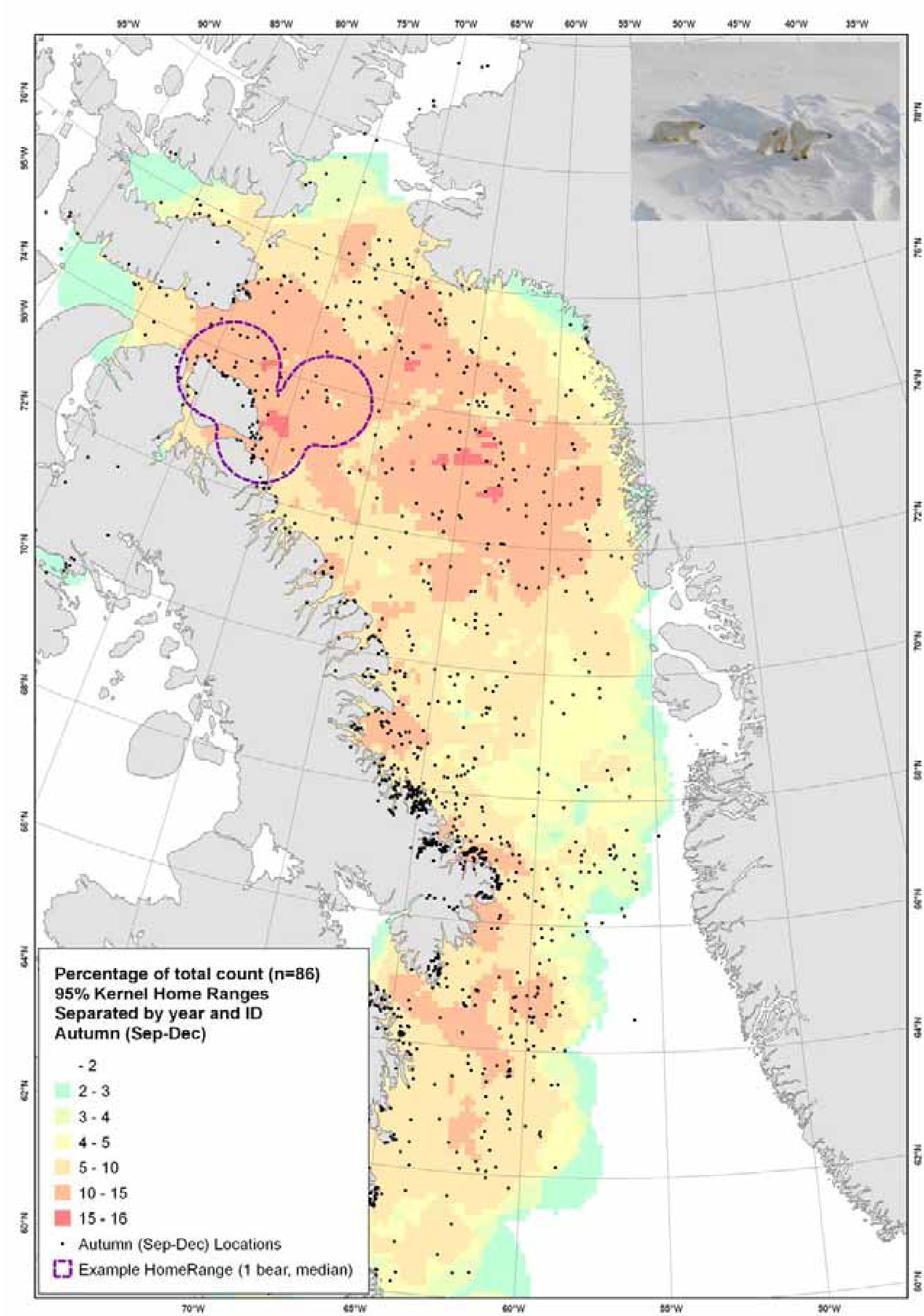


Figure 40d. Polar bear home ranges based on satellite tracked animals in the period 1991-2001. Autumn (September-December), 53 tracked polar bears. See Figure 40a for explanation.

Updated information on the occurrence and abundance of polar bears in the assessment area is not available. However, from a joint Canadian-Greenlandic population study satellite-telemetry data on polar bear movements exist for the period 1991-2001. These data allow for an estimation of the relative proportion of the Baffin Bay and Davis Strait population that may occur at various seasons inside the assessment area (Figure 40).

Recent observations and increased catches of polar bears by local hunters north of the assessment area, in Upernavik and Qaanaaq, indicate a changed distribution with higher densities near the Greenland coast (Born & Sonne 2006).

5 Natural resource use

5.1 The commercial fisheries

Commercial fisheries represent the most important export industry in Greenland, underlined by the fact that fishery products accounted for 87% of the total Greenlandic export revenue (2.4 billion DKK) in 2004 (Statistics Greenland 2006).

Very few species are exploited by the commercial fisheries in the assessment area and in Greenland as a whole. The three most important species on a national scale are deep-sea shrimp (export revenue in 2004: 1.133 billion DKK), Greenland halibut (469 million DKK) and snow crab (102 million DKK) (Statistics Greenland 2006). These three species are also the most important within the assessment area. The following information about the fishery is based on data provided by GINR unless otherwise quoted.

Deep-sea shrimp (*Pandalus borealis*) is caught on the bank slopes and in Disko Bay. In recent years 30-40% of total Greenland shrimp catches were taken within the assessment area. The map on Figure 41 displays the shrimp fishing grounds of the region. The major part of the catch is taken by large modern trawlers which process the catches onboard. In Disko Bay and other inshore waters smaller vessels are used and the catches are usually delivered to factories in the towns. The fishery takes place whenever the sea ice does not close the waters.

The fishery of Greenland halibut (*Reinhardtius hippoglossoides*) has two components in the assessment area. An inshore fishery from Disko Bay and northward takes place in fjords with deep waters and here the fish are caught on long-lines either from small vessels or from the winter ice. This activity takes place throughout the year, and in 2001 comprised around 11,000 tonnes in total. Jakobshavn Isfjord (interior Disko Bay) is by far the most important site for this fishery. The other component is an offshore fishery with large trawlers, which takes place summer and autumn on the shelf slope (Figure 42). Since 2000 the catch from this fishery has ranged between 200 and 1,500 tonnes in the assessment area, and during the recent three years (2003-2005) about 350 tonnes. In 2001, 82% of the total Greenland halibut catch was taken within the assessment area.

Snow crabs (*Chionoecetes opilio*) are caught both in inshore waters and on the banks. The fishery was initiated in 1992 and increased rapidly. However, catches in recent years have decreased in spite of increasing effort. The catches from the assessment area comprised 32-38% of the total Greenland catch (5,500-1,600 tonnes) in the years 2002-2005 (Figure 43)

Figure 41. Distribution of shrimp fishing areas. Dots show mean annual catches over the period 1995-2004 in a standard grid, where each cell is 0.25°longitude x 0.125°latitude and used for reporting catches. Based on data from GINR.

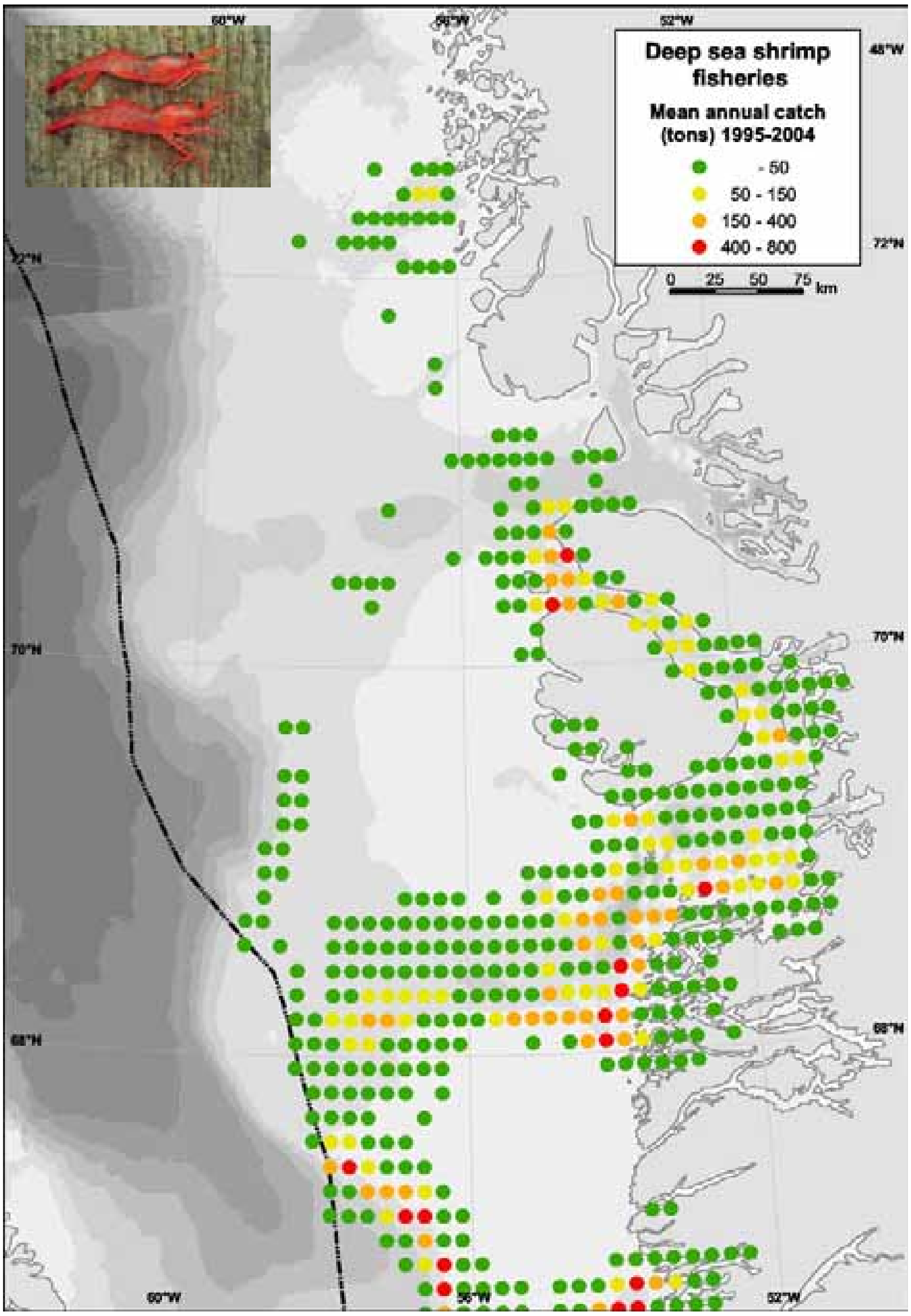


Figure 42. Distribution of Greenland halibut fisheries within the study region. The inshore fisheries are shown with squares, and only catches from 2001 have been available. The Ilulissat Isfjord is by far the most important areas for the inshore fisheries (red square). The offshore fisheries show the annual average catches over the period 2000-2005. This fishery is still in development and much smaller than the inshore fisheries (note the different scales between inshore an offshore fisheries). Cf. Figure 6.1. Data provided by GINR.

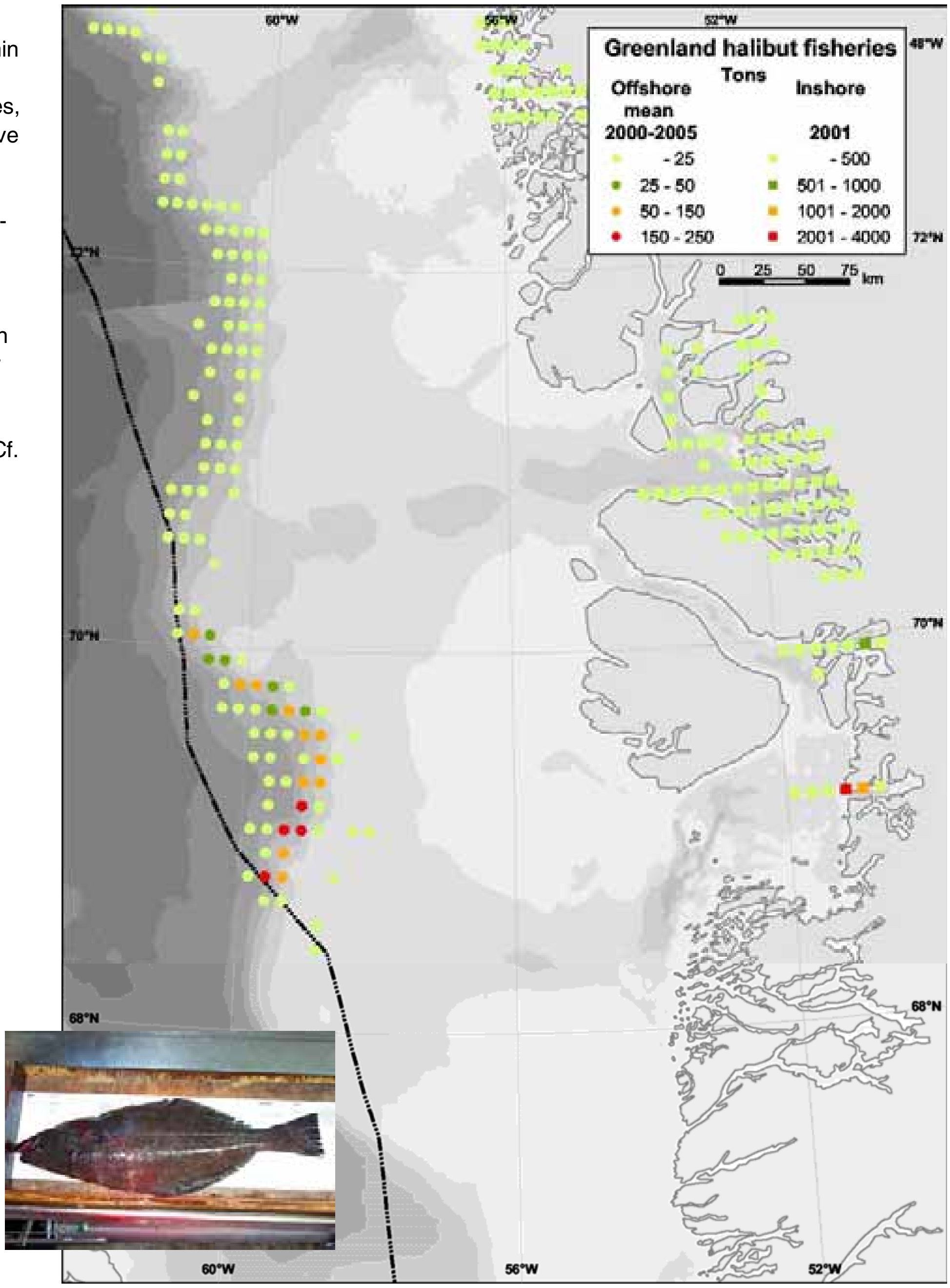
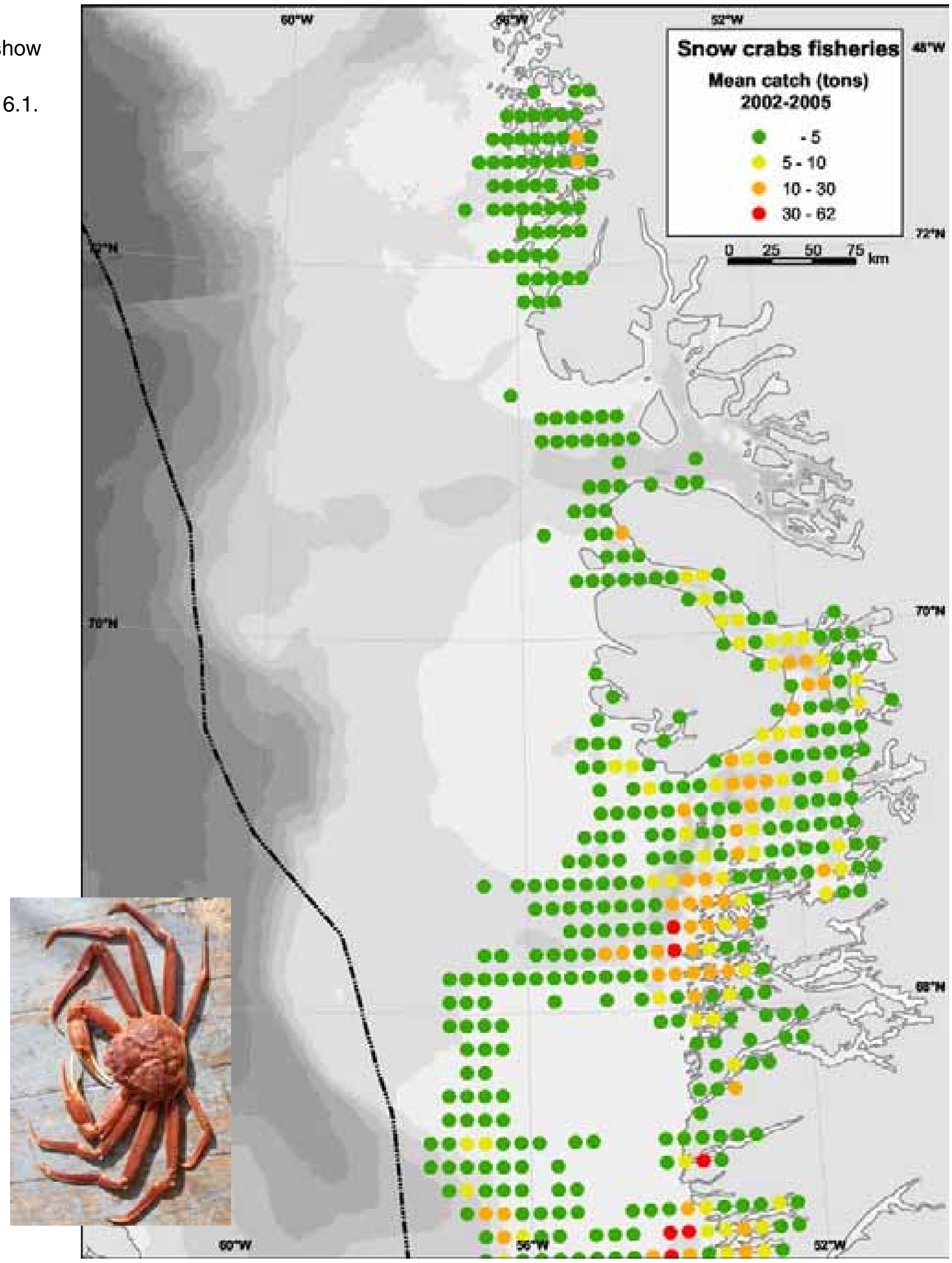


Figure 43. Distribution of the snow crab fishery. The dots show mean annual catch over the period 2002-2005. Cf. Figure 6.1. Data provided by GINR.



Iceland scallop (*Pecten islandica*) is caught in rather shallow water where currents are strong. This fishery is relatively important in the assessment area. In recent years (2003 and 2004) the fraction of the total catch in Greenland (about 2,500 tonnes) has ranged between 58 and 68% (Figure 44).

The lumpsucker (*Cyclopterus lumpus*) fishery takes place in spring and early summer when the fish move into shallow coastal waters to spawn. The fish are caught in gill nets set from small vessels. The roe is the commercial product, and the amount bought by the local factories in the assessment area varies considerably between years: 773 tonnes were landed in 1999 and 218 tonnes in 2001 in the Disko Bay region (Olsvig & Mosbech 2003).

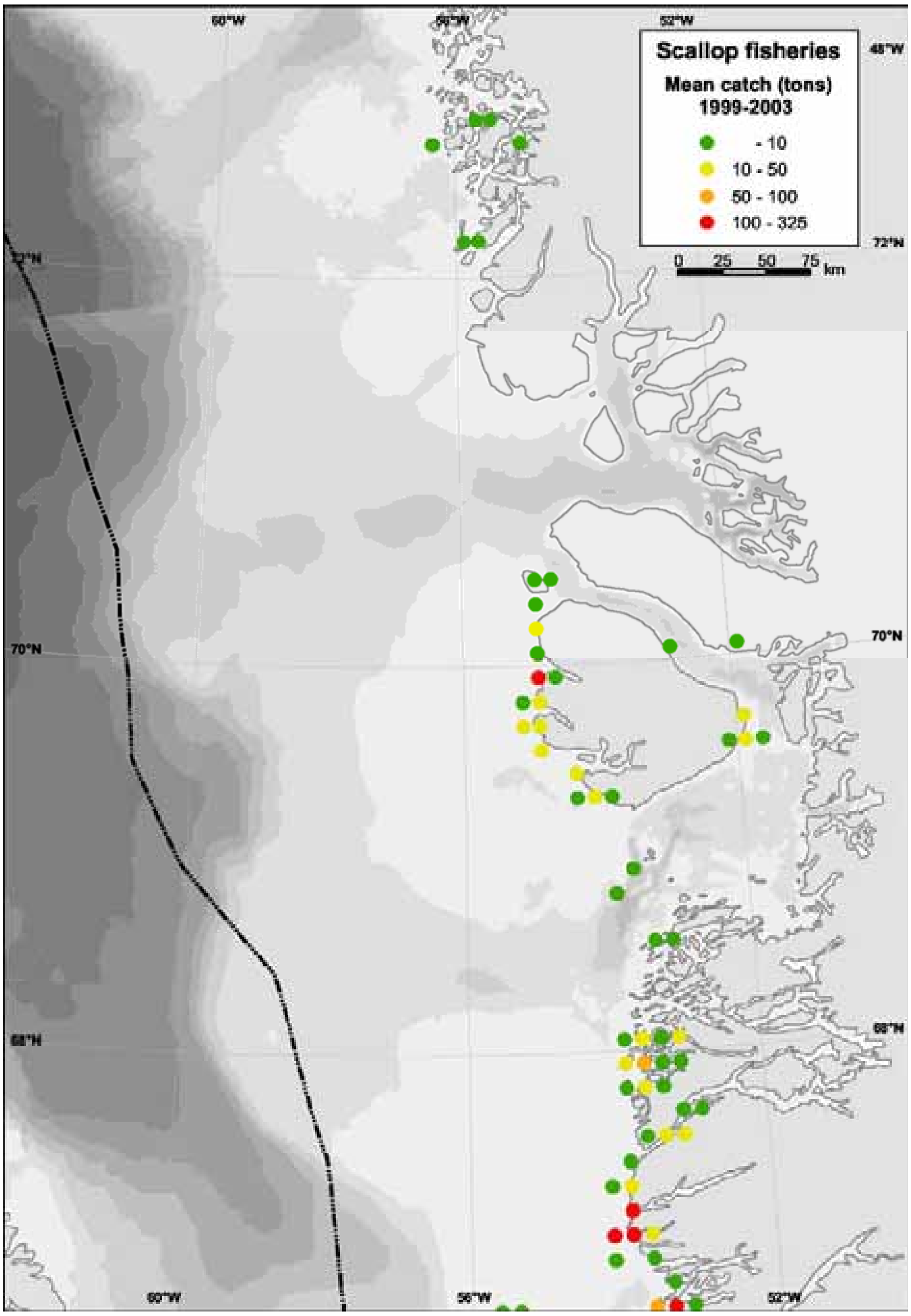


Figure 44. Fishing areas for Iceland scallop. Mean annual catch over the period 1999-2003. Cf. Figure 6.1. Based on data from GINR.

5.2 Subsistence and recreational fisheries and hunting

Besides the commercial fishery, subsistence fishery and recreational fishery supplemented by hunting take place in the region. Earlier, these activities were very important for the income of many families, but gradually this kind of fishing and hunting has become more recreational in nature. However, many people, particularly in the small settlements, are still dependent on subsistence hunting and fishing. The catches are usually sold at local outdoor markets where also hunting products are sold (Kapel & Petersen 1982, Pars et al. 2001).

Many fish species are utilised in these fisheries. The species that will be most vulnerable to an oil spill are those caught close to the shoreline: capelin (*Mallotus villosus*), lumpsucker (*Cyclopterus lumpus*) and Arctic char (*Salvelinus alpinus*). Fisheries for these species are restricted to spring and summer. Blue mussels (*Mytilus edulis*) are utilised occasionally.

Figure 45 shows some examples of the mapping of coastal areas where fisheries of capelin, lumpsucker and Arctic char occur.

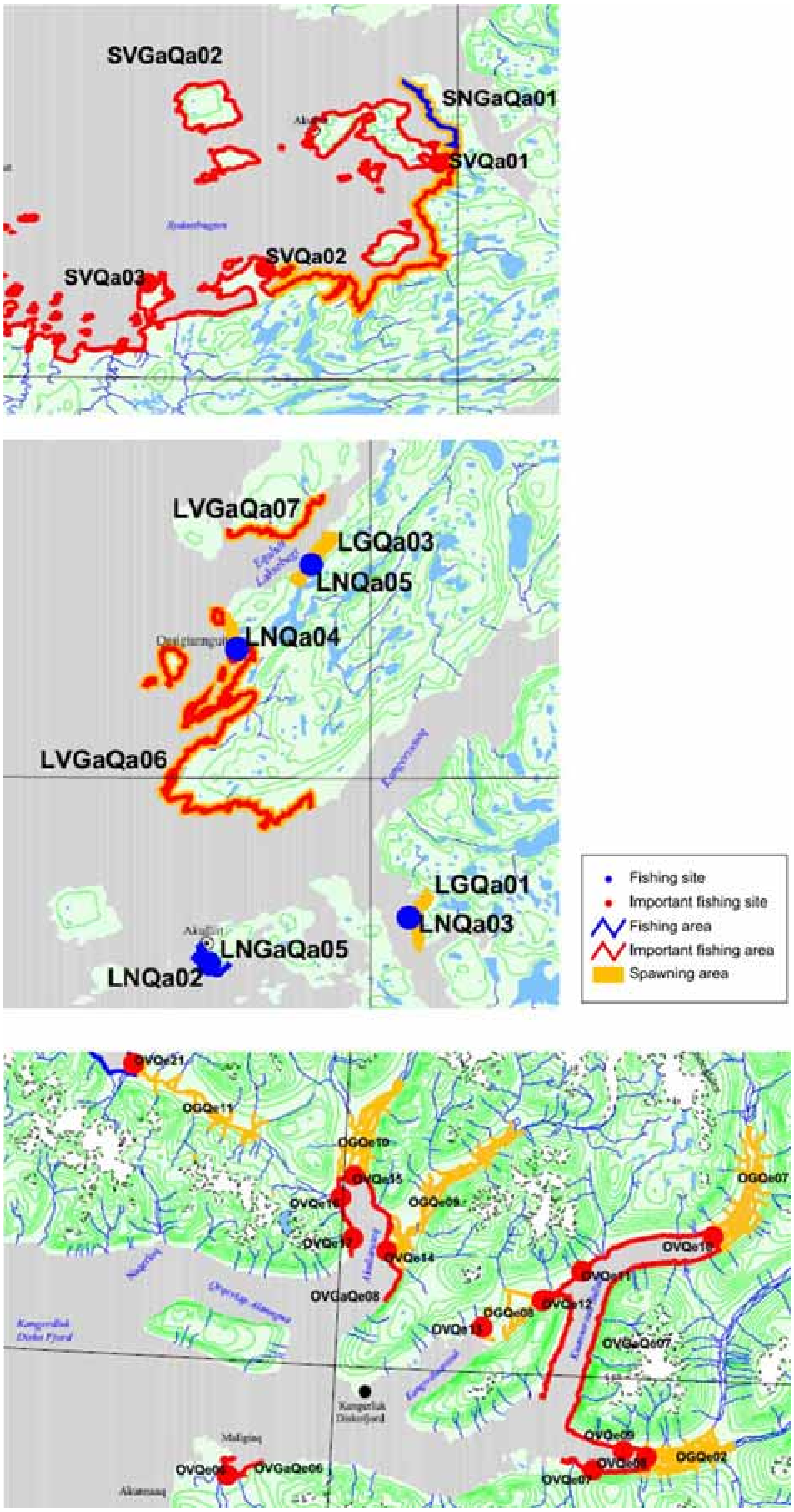
Hunted marine mammal species include all the seals, walrus, white whale, narwhal, minke whale and fin whale. In 1993, the following numbers of seals were reported to the official bag record for the Disko Bay region (Greenland Home Rule 1995): ringed seal 15,000, harp seal 15,000, hooded seal 600, bearded seal 300 and walrus 200. Of narwhals and white whale approx. 100 and 300 were taken respectively in 1993 (Greenland Home Rule 1995). The harvest of these two species from 2005 has been limited with quotas: 385 and 160 respectively for entire West Greenland in the season 2006/07, where each municipality is allocated a specific number. The harvest of minke whales and fin whales are also limited with quotas: 175 and 10 animals respectively for entire West Greenland. Seals are caught throughout the year, with ringed seals mainly when ice is present and harp seal and hooded seal in the open water season. Narwhals, white whales and walrus are caught in late autumn and winter, and in summer and autumn the two large species of whales, minke, and fin.

Seabirds are hunted mainly in autumn and winter, and the two most intensively hunted species are the thick-billed murre and common eider. In 1993 about 12,000 murres and 10,000 eiders were reported to the official bag-record system from the Disko Bay area (Greenland Home Rule 1995). Since this time the seabird harvest has been reduced due to new regulations.

5.3 Tourism

Greenland is marketed as a tourist goal, primarily for the unique and unspoiled nature. In general, tourism as an industry has developed rapidly during the recent decades, and the town of Ilulissat (in Disko Bay) is now the most important tourist site in Greenland, with three modern hotels and presence of many tour operators. The major attraction in Ilulissat is the glacier fjord Jakobshavn Isfjord, just south of the town. This was included in the United Nations list of World Heritage Sites in 2004. In the other towns of the assessment area: Aasiaat, Qeqertarsuaq and Uummannaq, tourist activities also take place but on a smaller scale compared with Ilulissat. It is not possible to give figures on the numbers of tourists in the assessment region, but the total number of tourists in Greenland were estimated at approx. 33,000 in 2005 (Greenland Statistics 2006). In addition to this figure approx. 16,500 tourists visit Greenland from international cruise ships (Greenland Statistics 2006).

Figure 45. Sections of maps showing coastal fishing sites and occurrence of three fish species important in the subsistence fishery. Based on an interview survey with local fishermen (Olsvig & Mosbech 2003.). Full map coverage in Oil Spill sensitivity maps issued by NERI (http://www.dmu.dk/International/Arctic/Oil+spill+sensitivity+atlas/).



6 Protected areas and threatened species

6.1 International agreements

According to the Convention on Wetlands (the Ramsar Convention), Greenland has designated eleven areas to be included in the Ramsar list of Wetlands of International Importance (Ramsar sites). These areas are to be conserved as wetlands and should be incorporated in the national conservation legislation; however, this has not yet been applied in Greenland. Six of the Ramsar sites are found within the assessment area (Figure 46) and one of these is so far from the outer coasts that it is not likely that it could be affected by offshore petroleum activities, while this is not so in the case of the other five.

In 2004 the Jakobshavn Isfjord was included into the UNESCO list of World heritage Sites as 'Ilulissat Icefjord'. Before inclusion it was protected according the national nature protection law. This remarkable area is situated in the inner part of Disko Bay.

6.2 National nature protection legislation

According to the Greenland nature protection law several areas within the assessment area are nature reserves (Figure 46). The bird protection law also designates bird protection areas, where access is prohibited in the breeding season (Figure 46). Moreover, seabird breeding colonies are protected. In all these areas activities are restricted and regulated in order to protect the conservation interest. According to the Mineral Extraction Law, a number of 'areas important to wildlife' are designated and, in these, mineral exploration activities are regulated in order to protect wildlife (Figure 47).

6.3 Threatened species

Greenland has not yet issued a list over threatened species (a national Red List), but it is under preparation, and preliminary red-list categories are given to the species listed in the Tables 1 and 2. Figure 48 shows the distribution of red-listed species in Greenland based on the preliminary assessment.

6.4 NGO designated areas

The international bird protection organisation BirdLife International has designated a number of Important Bird Areas (IBAs) in Greenland, and several are within the assessment area (Figure 46). These are areas where a significant proportion of the Greenland bird populations may occur during the year. Some of the IBAs are included in or protected by the national regulations, but many are without protection or activity regulations.

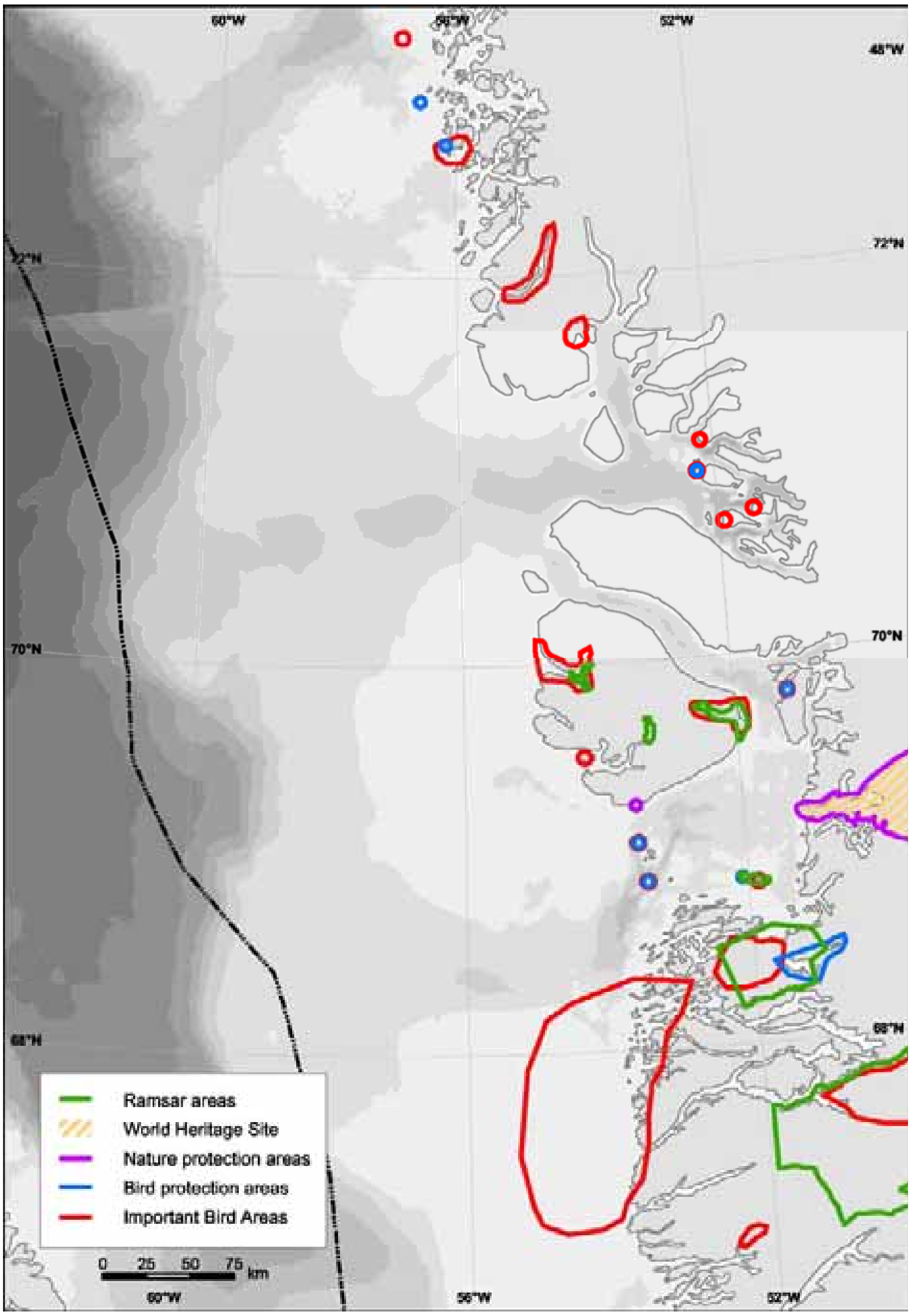


Figure 46. Nature protection areas designated according to international agreements (Ramsar areas and World Heritage Site), national legislation (Nature protection areas and bird protection areas) and Important Bird Areas designated by BirdLife International (Map by NERI).

Figure 47. The "areas importnat for wildlife" designated by BMP. Avialable at: http://arcims.mim.dk/website/DMU/AM/GL_Wildlife/viewer.htm

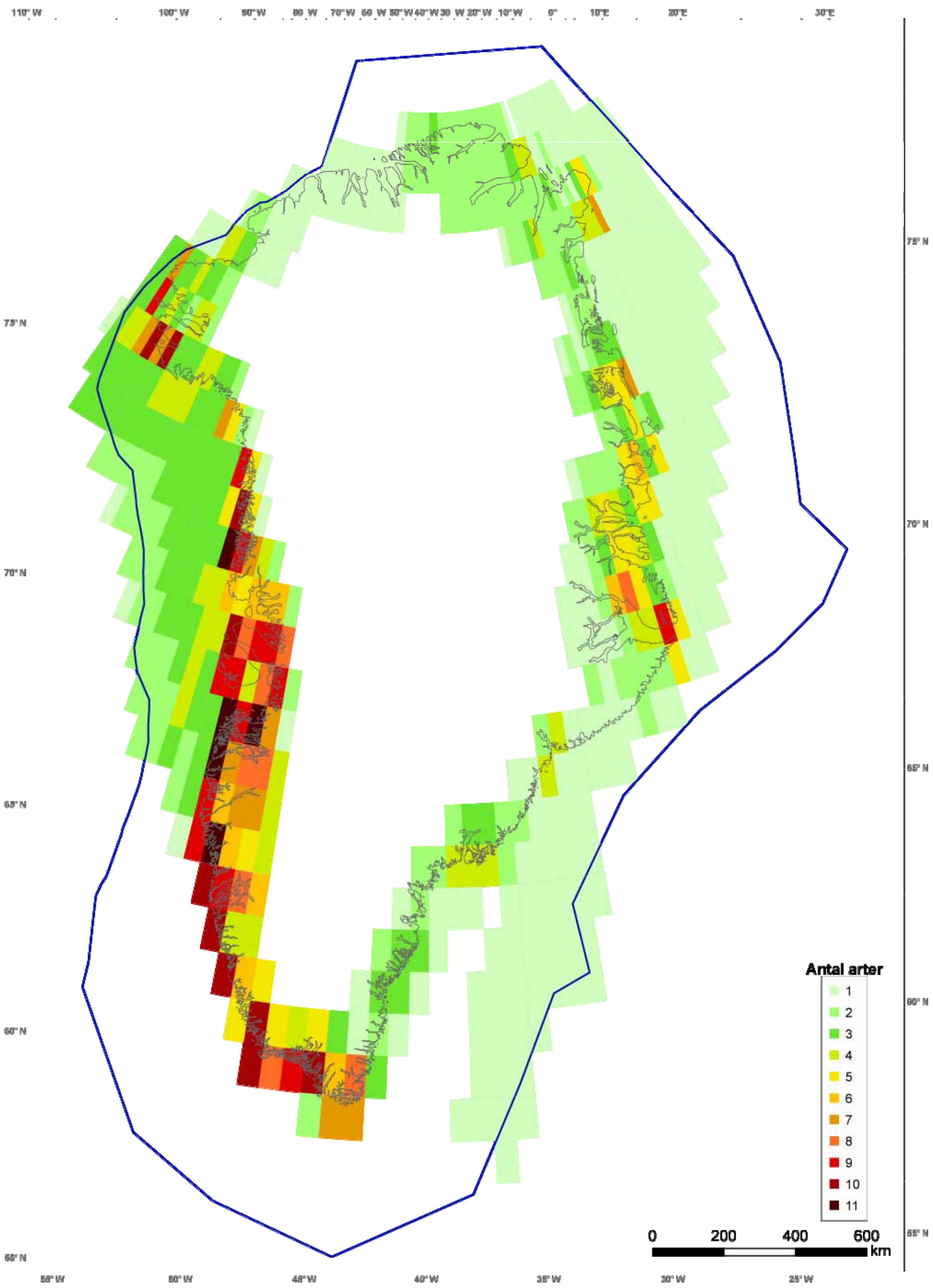


Figure 48. Distribution of redlisted species in Greenland. Mammals, birds, freshwater fish, butterflies and orchids have been evaluated, in total 115 species or discrete populations. Of these 36 are included in the redlist. The grid size is 1° x 1°.

7 Background levels of contaminants

It is important to document background levels of contaminants in the environment before drilling and production activities that could represent a source of pollution are initiated. The most important potential contaminants are hydrocarbons and heavy metals.

Available knowledge on background levels of hydrocarbons in the assessment area is limited. The relatively few samples of PAHs (Polycyclic Aromatic Hydrocarbons) and TPHs (Total Petroleum Hydrocarbons) from different compartments (marine sediments and organisms) in the Greenland environment are summarised in the report by Mosbech (2007). The general picture is that levels both of PAHs and TPHs are low.

Further studies of background levels of hydrocarbons in marine sediments in the assessment area were initiated in autumn 2006 and will be reported in 2007. Companies probably will have to document local levels of hydrocarbons (or at least collect samples for pre-activity reference) before drilling activities are initiated, as there may be local differences within the assessment area, e.g. caused by natural oil seeps.

A recent study by NERI (Mosbech 2007), initiated by this assessment, has investigated the PAH and TPH levels and their potential effects in an area where natural oil seeps are known. This area, Marraat, is situated near the tip of the Nuussuaq peninsula, in the northern half of the assessment area. The conclusions from this study are that the PAH levels generally are low, and there was no clear indication of elevated levels in marine sediment due to the seeps, perhaps because it is a high energy coast with strong currents. Elevated levels of hydrocarbon metabolites in fish (sculpin) bile could not be detected.

Contamination with heavy metals is also an issue related to discharges of drilling mud and produced water. It is therefore important to have knowledge of background levels of heavy metals. From a number of studies conducted over the past 20 years NERI has a thorough knowledge of levels on a regional basis in many different components of the Greenland environment, including sediments. Those not published will be available from a NERI database. Companies probably will have to document local levels of heavy metals (or at least collect samples for pre-activity reference) before any drilling activities are initiated as there may be local differences within the assessment area.

8 Impact assessment

8.1 Methodology and scope

The following assessment is based on available historical information on background information collected by NERI and others since 1992 (e.g. Boertmann et al. 1998, Mosbech 2002, Mosbech et al. 1996, 1998), on information from the oil spill sensitivity atlas prepared for the region (Mosbech et al. 2000, 2004), and on information specifically sampled and prepared for this assessment (Nielsen et. al. 2006, Söderkvist et al. 2006, Mosbech 2007, Heide-Jørgensen & Laidre in prep.). Some data are still under analysis and will be incorporated in updated versions of the assessment.

In some instances the available data are inadequate or even missing for a strictly scientific documentation of potential effects. In such cases expert judgement or general conclusions from EIAs carried out in other Arctic or near-Arctic areas have been applied to assess the impacts. However, some uncertainty in the assessment is inevitable and is conveyed with phrases such as 'most likely' or 'most probably'.

8.1.1 Boundaries

The assessment area is the area described in the introduction (Figure 1). This is the region which potentially can be impacted by a large and long-lasting oil spill deriving from activities within the expected licence areas. However, it cannot be excluded that the area affected may be even larger and include coasts both north and south of the assessment area and to the west across the Canadian border.

The assessment includes as far as possible all activities of an oil field from exploration to decommissioning. Exploration activities will take place in the summer and autumn months, but if and when production is decided and initiated, activities will take place throughout the year. How eventual production facilities will be constructed is unknown, but a likely setup is described by the APA (2003) study, cf. page 24.

8.1.2 Impact assessment procedures

The first step of an assessment is to identify potential interaction (overlap/contact) between all possible petroleum activities and the ecological components of the assessment area both in time and space. Interactions are then evaluated for their potential to cause impacts.

Important ecological components include flora and fauna, habitats including temporary and dynamic habitats like the marginal ice zone, and also processes like the spring bloom in primary production.

The nature and extent of environmental impacts from petroleum activities can be evaluated on different scales (or a combination of these):

- from individuals to populations
- duration from immediate over short term to long term
- geographical scale from local to regional, or for a single impact also on global scale.

8.2 Impacts of the potential routine activities

8.2.1 Exploration activities

In general all activities related to exploration are temporary and will be terminated if no commercial discoveries are made.

Environmental impacts of explorations activities relate to:

- Noise from seismic surveys and drilling
- Cuttings and drilling mud
- Different substances to be disposed of
- Emissions to the air
- Placement of structures.

In relation to exploration only the most significant impacts (from noise, cuttings and drilling mud) will be considered. The other issues will be dealt with in the production and development sections, as they are much more significant during these phases of a petroleum field life cycle.

Assessment of noise

Noise from seismic surveys

The main environmental impacts from the seismic sound generators can potentially include:

- injuries (both pathological and physiological) from the sound waves
- disturbance/scaring (behavioural impacts, including masking of underwater communication by marine mammals)

A recent review of the effects of seismic sound propagation on different biota concluded 'that seismic sounds in the marine environment are neither completely without consequences nor are they certain to result in serious and irreversible harm to the environment' (DFO 2004). But there are many potential detrimental consequences. Short-term behavioural changes (as avoiding areas with seismic activity) are known and in some cases well documented, but longer-term changes are debated and studies are lacking.

In arctic waters it cannot be assumed that there is a simple relationship between sound pressure levels and distance to source due to ray bending caused by e.g. a strongly stratified water column. It is therefore difficult to base impact assessments on simple transmission loss models (spherical or cylindrical spreading) and to apply assessment results from southern latitudes to the Arctic (Urick 1983). For example the sound pressure may be very strong in convergence zones far from (> 50 km) the sound source, and this is particularly evident in stratified arctic waters. This has recently been documented by means of acoustic tags attached to sperm whales, which recorded high sound pressure levels (160 dB re µPa, pp) more than 10 km from a seismic array (Madsen et al. 2006).

Another issue recently discovered is that airgun arrays generate significant sound energy at frequencies many octaves higher than the frequencies of interest for seismic operations, which increases concern of the potential impact particularly on toothed whales with poor low frequency hearing (Madsen et al. 2006).

The important biological components potentially impacted by seismic surveys are primarily fish and marine mammals, while habitats will not be affected.

Impact of seismic noise on fish

Adult fish will generally avoid seismic sound waves, seek towards the bottom, and will not be harmed. Young cod and redfish, as small as 30-50 mm long, are able to swim away from the mortal zone near the airguns (comprising a few metres) (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 (2D and 3D). Negative effects on fish stocks may therefore occur if adult fish are scared away from localised spawning grounds during spawning season. Outside spawning grounds, fish stocks are probably not affected by the disturbance, but fish can be displaced temporarily from important fishing grounds and consequently fisheries could be affected, although only temporarily until the fish return to the affected areas (Engås et al. 2003).

Fish larvae and eggs cannot avoid the pressure wave from the airguns and can be killed within a distance of less than two metres, and sublethal injuries may occur within five metres (Østby et al. 2003). The relative volume of water affected is very small and population effects, if any, are considered to be very limited in e.g. Norwegian and Canadian assessments (Anonymous 2003). However, in Norway, specific spawning areas may in certain periods of the year have very high densities of fish larvae in the uppermost water layers, and the Lofoten-Barents Sea area is closed for seismic activities during the cod and herring spawning period in May-June (Anonymous 2003). Generally densities of fish egg and larvae are low in the upper ten metres in Greenland waters, and moreover most fish species spawn in a dispersed manner, and in winter or spring, with no temporal overlap with seismic activities. It is therefore most likely that impacts of seismic activity (even 2D or 3D) on the recruitment to fish stocks in West Greenland waters are negligible.

Sandeel is one of the few fish species in the assessment area which spawn in summer (Table 1), and stocks could be sensitive to seismic surveys if they are scared away from their spawning areas. However, based on the available data it is most likely that spawning takes place over large areas of the West Greenland banks and large, localised spawning aggregations which could be disrupted have not been observed.

Impact of seismic noise on fisheries

Norwegian studies (Engås et al. 1995) have shown that 3D seismic surveys (a shot fired every 10 seconds and 125 m between 36 lines 10 nm long) reduced catches of Atlantic cod (*Gadus morhua*) and haddock

(*Melanogramma aeglefinus*) at 250-280 m 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 moreover more pronounced for large fish compared with smaller fish.

The only fishery which may be impacted by seismic surveys in the assessment area is the offshore trawling for Greenland halibut in the waters west of Disko Island, because it is not likely that seismic surveys will take place in the specific Greenland halibut fjords. A Canadian review (DFO 2004) concluded that the ecological effect of seismic surveys on fish is low and that changes in catchability are probably species dependent. It is therefore difficult to assess the effect on the offshore Greenland halibut fisheries, because reactions of this species have not been studied. However, if catches are reduced by a seismic survey, it is most likely temporary and will probably only affect specific fisheries for a few days. The fisheries of Greenland halibut west of Disko Island are relatively small compared with the inshore fisheries (in recent years about 350 tonnes compared with more than 10,000 tonnes). The trawling grounds are restricted to specific depths at approx. 1,500 m; therefore, alternative fishing grounds would be limited in the case of displacement of the Greenland halibut caused by seismic activity.

It should be mentioned that there also are examples where fisheries may increase after seismic shooting, which is assumed to be an effect of changes of vertical distribution of fish (Hirst & Rodhouse 2000).

Shrimp fisheries will probably not be affected by seismic surveys. Crustaceans have no specific hearing organs, and some studies with other crustacean species did not find any reduction in catchability (Hirst & Rodhouse 2000, Andriguetto-Filho 2005). The same applies to the snow crab fisheries, although some recent Canadian studies may indicate long-term effects particularly on snow crabs, which could affect populations at important reproduction areas (DFO 2004).

Impact of seismic noise on birds

Seabirds are generally not considered sensitive to seismic surveys, because they are highly mobile and able to avoid the seismic sound source. However, in inshore waters, seismic surveys carried out near the coast may disturb breeding and moulting congregations.

Impact of seismic noise on marine mammals

There are no documented cases of marine mammal mortality or of damage to body tissue caused by the airguns used for seismic surveys. However, under experimental conditions temporary elevations in hearing threshold (TTS) have been observed (National Research Council 2005). Such temporary reduced hearing ability is considered unimportant by Canadian researchers; unless it develops into permanent threshold shift (PTS) or it occurs in combination with other threats normally avoided by acoustic means (DFO 2004). In the USA a sound pressure level of 180 dB re 1µ8PA) (rms) or greater is taken as an indication of TTS or PTS (NMFS 2003).

Displacement represents another type of impact, and there are many documented cases of displacement from feeding grounds or migratory routes of marine mammals exposed to seismic sound. The extent of displacement varies between species and also between individuals within the same species. For example, a study in Australia showed that migrating humpback whales avoided seismic sound sources at distances of 4-8 km, but occasionally they came closer. In the Beaufort Sea autumn migrating bowhead whales avoid areas where the noise from exploratory drilling and seismic surveys exceeds 117-135 dB and they may avoid the seismic source by distances of up to 35 km (NMFS 2002, Brewer et al. 1993, Hall et al, 1994, Gordon et al. 2004). But minke whales have also been observed as close as 100 m from operating airgun arrays (NERI unpublished). The ecological significance of such displacement effects is generally unknown, but if alternative areas are available the significance probably will be low, and the temporary character of seismic surveys also will allow displaced animals to return after the surveys.

Preliminary evidence from West Greenland waters indicated that humpback whales satellite tracked near Maniitsoq utilised an extensive area, and therefore most likely still had access to alternative foraging areas if they were displaced from one area by seismic activities (Dietz et al. 2002).

A third type of impact has been widely discussed relating to whales and seismic sounds, and it is the masking effect of their communication and echolocation sounds. There are, however, no studies or evidence which document such effects. Moreover, masking requires overlap in frequencies, overlap in time and sufficiently high sound pressures, and it is not likely that these, particularly overlap in frequencies, are fulfilled during seismic surveys (e.g. Gordon et al. 2004). Masking is more relevant to discuss in relation to the continuous noise from drilling and ship propellers.

The most noise-vulnerable whale species in the assessment area will be white whale, narwhal and bowhead whale, and they are mostly absent from the area when seismic surveys usually are carried out (summer and autumn). There is however a risk of overlap in late autumn.

In general, seals display considerable tolerance to underwater noise (Richardson et al. 1995), but ‘hauled-out’ seals in coastal areas and particularly walruses in the drift ice may be disturbed and displaced by the activity.

Mitigation of impacts from seismic noise

Mitigation measures generally recommend a soft start or ramp up of the airgun array each time a new line is initiated. This will allow marine mammals to detect and avoid the sound source before it reaches levels dangerous to the animals. Secondly it is recommended to bring skilled marine mammal observers on board the seismic ships, in order to detect whales and instruct the crew to delay shooting when whales are within a certain distance (usually 500 m) from the array. The detection of nearby whales in sensitive areas can be more efficient if supplemented with the use of hydrophones for recording whale vocalisations. However, a problem exists with respect to visual observations, especially in Arctic waters, and that is the phenomenon of convergence zones where very high sound pressures may occur far from the sound source and out of sight of the observer. A third mitigating measure is to close areas in sensitive periods. The spawning grounds for herring and cod are closed for seismic surveys in the Lofoten-Barents Sea area during the spawning season. A preliminary EIA, including the Disko West area, recommends that seismic surveys are avoided in specific narwhal areas in the migration and wintering season (Mosbech et al. 2000a). Finally it is recommended that local authorities and the hunters' organisations be informed before seismic activities take place in their local area. This may help hunters to take into account that animals may be disturbed and displaced in certain areas at times when activities take place.

Noise from drilling rigs

This noise has two sources, the drilling process and the propellers keeping the drill ship/rig in position. The noise is continuous in contrast to the pulses generated by the seismic airguns.

Generally a drill ship generates more noise than a semi-submersible platform, which again is noisier than a jack-up. Jack-ups will most likely not be employed in the waters west of Disko, because of the very deep waters and the hazard risk from icebergs.

Marine mammals and particularly whales are generally believed to be the organisms most sensitive to this kind of underwater noise, because they depend on the underwater acoustic environment for orientation and communication. However, systematic studies on whales and noise from drill rigs are limited. It is generally believed that whales are more tolerant of fixed noise than moving sources (Davis et al. 1990). In Alaskan waters migrating bowhead whales avoided an area with a radius of 10 km around a drill ship (Richardson et al. 1990) 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). Seals and toothed whales like white whales and dolphins have in experiments and at operating rigs shown less tolerance towards noise from drilling rigs, particularly if they associate the noise with negative experiences such as hunting.

As described in Section 4.3 bowhead whales occur in the assessment area, and their spring migration routes pass through the waters between Disko Island and the marginal zone of the West Ice. They also seem to congregate, perhaps due to optimal feeding conditions, just south of Disko Island (Figures 38 and 39). The migration corridor across Baffin Bay seems to be wide (Figure 38), and displacement of single animals similar to those described from the Beaufort Sea may not have any significant effect here, as there seem to be plenty of alternative routes available; although routes are determined by the presence of suitable leads.

Other important species among the toothed whales are white whales and narwhals. Both follow specific migration pathways during spring and autumn, and particularly the narwhal stocks seem to utilise very local and delineated areas during winter (Figure 36, especially the Melville Bay stock). It is not known whether, if they are displaced by petroleum activities, these whales have alternatives to these routes and areas.

However, exploration activities are generally assessed to have low impacts on most of the especially sensitive marine mammal species, because the activities are of a temporary nature and because they are carried out in the summer and autumn months when the most sensitive species are absent: bowhead whales, narwhals, white whales and walruses.

Drilling mud and cuttings

Drilling creates substantial quantities of drilling wastes composed of rock cuttings and the remnants of drilling mud (cf. section 3). Cuttings and mud are usually deposited on the sea floor beneath the drilling vessel, where they can change the composition of the substrate and the habitat for the benthos. The liquid base of the drilling mud may be water, oil or other organic (synthetic) fluids (ethers, esters, olefins, etc.). The general pattern of impacts on benthic animals in monitoring Norwegian wells is that oil-based cuttings elicit the most widespread impacts and water-based cuttings the least. Ester-based cuttings have been shown to cause severe but short-lived effects due to their rapid degradation and resulting oxygen depletion in the sediments. Olefin-based cuttings are also degraded fairly rapidly, but without causing oxygen deficiency and hence have short-lived and modest effects on the fauna.

The effects of drilling mud and drill cuttings have been studied widely (e.g. Neff 1987, Ray & Engelhardt 1992). The disposal of drilling mud and cuttings at marine drilling sites poses a localised risk to benthic organisms nearby (e.g. Davies et al. 1984). Mud and drill cuttings are normally released during the drilling phase; although the ecological effects persist longer than the release phase. Olsgard & Gray (1995) applied sensitive statistical techniques to drill sites on the Norwegian Shelf were oil-based mud was used and found subtle effects on benthic animals extending out as far as 6 km and areas affected around sites ranged from 10 to 100 km^2. Furthermore, examination of sites no longer in production revealed that the area affected continued to increase in size for several years after discharges ceased. The effects of these releases may not be confined to benthic invertebrates. Sub-lethal effects on fish living near drill sites have been detected in some species (Davies et al. 1984). However, these results are from the time when oil-based drilling mud was used and discharged. That is not acceptable any more, and if exclusively water-based mud is used and cuttings are cleaned effectively, only localised effects on the benthos may be expected of the discharges from a single exploration drilling. More widespread effects on the benthos and the composition of benthos may be the result of the multiple drilling carried out during development of a field.

Furthermore, there will be a risk of tainting of commercial fish species if discharged cuttings are polluted with oil residues.

As the seafloor fauna generally is unknown in the assessment area, it is difficult to assess the impact of discharges of drilling mud and cuttings precisely. However, in the Lofoten-Barents Sea areas of Norway cuttings and drilling mud are not discharged due to environmental concerns, rather it is re-injected in wells or brought to land (Anonymous 2003). This on the other hand increases the amount of ship transport and the emission of CO_2; moreover, impacts at disposal sites on land have to be considered and evaluated.

Within the assessment area therefore only very local effects on the benthos may be expected from exploratory drilling using 'modern' muds. Baseline and monitoring studies at drill sites should be conducted to document effects and assess if there are unique communities or species that could be affected.

8.2.2 Development and production activities

In contrast to the temporary activities of the exploration phase, the activities in development and production are usually long lasting, depending on the amount of producible petroleum products and the production rate. The activities are many and extensive, and the effects on the environment can be summarised under following headings:

- solid and fluid waste materials to be disposed of
- placement of structures
- noise from facilities and transport
- emissions to air.

Solid and fluid waste materials: produced water

During production several bi-products and waste products are produced and have to be disposed of in one way or the other. Produced water is by far the largest contribution, reaching several million cubic metres from a large field, and the total amount produced on the Norwegian shelf was 174 millions m^3 in 2004 (OLF 2005). Produced water contains small amounts of oil, salts from the reservoir and chemicals added during the production process. Some of these chemicals are acute toxic, radioactive, contain heavy metals, have hormone disruptive effects or act as nutrients which influence the primary production (Lee et al. 2005). Some are persistent and have the potential to bio-accumulate. The produced water moreover contributes to the major part of the oil discharged during normal operations, in Norway up to 88%.

Produced water is usually discharged to the sea after a cleaning process which reduces oil amounts to levels accepted by the authorities (in the North Sea sector of Norway for example 40 mg/l and 30 mg/l as recommended by OSPAR). However, due to environmental concerns, discharges will not be allowed in the Lofoten-Barents Sea area, except during a 5% 'off-normal' operation time (Anonymous 2003).

The releases during this off-normal time have been assessed not to impact stocks of important fish species, but it is also underlined that long-term effects of the releases of produced water are unknown. It is also underlined that knowledge on the hormone disrupting phenols and on the radioactive components is too fragmentary regarding toxic concentrations, bioaccumulation, etc. (Rye et. al. 2003).

Solid and fluid waste materials: other substances

Besides produced water, discharges of oil components and different chemicals relate to deck drainage, cooling water, ballast water, bilge water, cement slurry and testing of blowout preventers. Sanitary wastewater also is usually released to the sea. The environmental impacts of these discharges are generally small from a single drilling rig or production facility, but releases from many facilities and/or over long time periods may be of concern. BAT (Best Available Technology), BEP (Best Environmental Practice), introduction of less environmentally damaging chemicals or reduction in releases are ways in which the effects can be reduced.

Ballast water from ships poses a special biological problem. That is the risk of introduction of alien species to the local ecosystem (Anonymous 2003). This is generally considered as a serious threat to marine biodiversity, and for example blooms of toxic algae have in Norway been ascribed to releases of ballast water from ships. There are also examples of introduced species which have impacted fisheries in a negative way.

Whether this will be a problem in the assessment area is not known. There are methods to minimise the risk, and the MARPOL convention has issued a management plan for ship ballast water, but it has not yet been ratified by a sufficient number of states to enter into force.

Placement of structures

The construction of subsea wells and pipelines has the potential to destroy parts of important habitats on the seafloor. However, there is limited knowledge on such sites in the assessment area; although some areas are important for walrus and king eider which live from benthic mussels and other invertebrates (Figures 30, 34 and 35). An assessment of the impact of such constructions must wait until location of production sites and site-specific EIAs and background studies have been carried out. Structures may also have a disturbance effect particularly on marine mammals, which may be displaced from important habitats. Most vulnerable in this respect are the walruses wintering on Store Hellefiskebanke.

Illumination and flaring can attract birds migrating during the night. Under certain weather conditions (fog and snowy weather) on winter nights, eider ducks are known to be attracted to the light on ships sailing in Greenlandic waters. Occasionally hundreds of eiders are killed on a single ship and not only are eiders killed, but these birds are so heavy that they destroy antennae and other structures on the ships (Boertmann et al. 2006). The Greenland authorities have initiated a study to assess the quantitative significance of the current level of these events and the potential for mitigation. The common eider population breeding in Greenland has been decreasing due to previous unsustainable harvest, and further human-induced mortality may add to this decrease or hamper a recovery of the population.

Other birds may also be attracted to and killed by the gas flare on migration at night. This phenomenon has been described for songbirds in the North Sea (Bourne 1979, Jones 1980). The extent of night-migrating birds in the Baffin Bay area is unknown, but is most likely on a much smaller scale than in the North Sea.

Placement of structures will affect the fisheries due to the exclusion (safety) zones. These however are small compared with the total fishable area. A drilling platform incl. exclusion zone with a radius of 500 m covers approx. 7 km^2. In the Lofoten-Barents Sea area the effects of exclusion zones on the fisheries are generally assessed as low except in areas where very localised and intensive fisheries 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 so it is possible to trawl across them; although a temporary exclusion zone must be expected during the construction phase of pipelines. 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).

Noise

Noise from drilling and the positioning of machinery is described under the exploration heading. These activities continue during the development and production phase, supplemented with noise from many other activities. If several production fields are active in the waters west of Disko, the impacts of noise particularly on the migration of narwhals and white whales must be addressed. Bowhead whales in the Beaufort Sea avoided close proximity (up to 50 km) to oil rigs, which resulted in significant habitat loss (Schick & Urban 2000), an impact which also could occur in the Disko West area dependent on the location. Noise from production facilities placed on Store Hellefiskebanke could also displace walruses from important feeding grounds.

One of the more significant sources of noise during development and production is ships and helicopters used for intensive transport operations (Overrein 2002). Ships and helicopters are widely used in the Greenland environment today, but the level of these activities is expected to increase significantly in the assessment area if one or more oil fields are developed in the waters west of Disko. Supply ships will sail between offshore facilities and coastal harbours. Shuttle tankers will sail between crude oil terminals and the transshipment facilities on a regular basis, even in winter. The loudest noise levels from shipping activity result from large icebreakers, particularly when they operate in ramming mode. Peak noise levels may then exceed the ambient noise level up to 300 km from the sailing route (Davis et al. 1990).

Ship transport (incl. icebreaking) has the potential to displace marine mammals, particularly if the mammals associate negative events with the noise, and in this respect white whales, narwhals and walruses which are hunted from motor boats will be expected to be particularly sensitive. Also seabird concentrations may be displaced by regular traffic. The impacts can be mitigated by careful planning of sailing routes.

Helicopters produce a strong noise which both can scare marine mammals and birds. Particularly walruses hauled-out on the ice in the waters west of Disko and on Store Hellefiskebanke are sensitive to this activity, and there is risk of displacement of the walruses from important feeding grounds. Walruses have a narrow foraging niche restricted to the shallow banks west of Disko and at Store Hellefiekebanke, as also indicated by the satellite tracking in 2005 and 2006 (Figure 35). Activities in these areas may displace the walruses to suboptimal feeding grounds or to coastal areas where they are more exposed to hunting.

Seabird concentrations are also sensitive to helicopter flyovers. The most sensitive species is thick-billed murre, at breeding sites. They will often abandon their nests for long periods of time and there is also a risk that they push their egg or chick out over the edge when scared off from their breeding ledges, resulting in a failed breeding attempt (Overrein et al. 2002). There is only one breeding colony for this species in the region – in the inner parts of Disko Bay – which would appear to be far away from the flight routes between potential oil fields and the present airports. But concentrations of feeding birds are also sensitive, as they may loose precious time in which to feed due to the disturbance. Concentrations of moulting geese and seaducks occur at several sites in the region, such as the king eiders of the fjords of Disko Island. The effects of disturbance can be mitigated by applying specific flight altitudes and routes, as many birds will habituate to regular disturbances as long as these are not associated with other negative impacts such as hunting.

Air emissions

Emissions to the air occur during all phases of petroleum development including seismic survey and exploration drilling, although the major releases occur during development and production. Emissions to air are mainly combustion gasses from the energy producing machinery (for drilling, production, pumping, transport, etc.). For example, the drilling of a well produces in the region of 5 million m^3 exhaust per day (LGL 2005). But also flaring of gas and transhipment of produced oil contribute to the emissions. The emissions consist mainly of greenhouse gasses (CO_2, CH_4), NOx, VOC and SO_2. The production activities produce large amounts particularly of CO_2, and, for example, the emission of CO_2 from a large Norwegian field (Statfjord) was more than 1.5 million tonnes in 1999 (STF 2000). This is more than twice the total Greenland CO_2 contribution, which in 2003 was 634,000 tonnes (Illerup et al. 2005). Such amounts will have a significant impact on the Greenland greenhouse gas emission in relation to the Kyoto Protocol (to the United Nations Framework Convention on Climate Change). Another very active greenhouse gas is methane (CH_4) which is released in small amounts together with other VOCs from produced oil during transshipment.

Emissions of SO_2 and NOx contribute, among other things, to acidification of precipitation and may impact particularly on nutrient-poor vegetation types inland far from the release sites. The large Norwegian field Statfjord emitted almost 4,000 tonnes NOx in 1999. In the Norwegian strategic EIA on petroleum activities in the Lofoten-Barents Sea area it was concluded that NOx emissions even from a large-scale scenario would have insignificant impact on the vegetation on land, but also that there was no knowledge about tolerable depositions of NOx and SO_2 in Arctic habitats where nutrient-poor habitats are widespread (Anonymous 2003). This lack of knowledge also applies to the West Greenland environment.

The international Convention on Long-Range Transboundary Air Pollution (LRTAP) includes all these emissions, but when Denmark signed the protocols covering NOx and SO_2 reservations were made in the case of Greenland.

Cumulative impacts

Cumulative impacts are changes to the environment that are caused by an action in combination with other past, present and future human actions. The impacts are summed up from single activities both in space and time. Impacts from a single activity can be insignificant, but the sum of impacts from the same activity carried out at many sites at the same time and/or throughout time can develop to be significant. Cumulative impacts also include interaction with other human activities impacting the environment, such as hunting and fishing; moreover, climate change is also often considered in this context (National Research Council 2003).

An example could be many seismic surveys carried out at the same time in a restricted area. Activities at this level may exclude marine mammals from all available habitats, in contrast to a single seismic survey which only affects a local area and leaves alternatives available.

Seabird hunting is widespread and intensive in West Greenland and some of the populations have been declining, mainly due to unsustainable harvest. New hunting regulations are now in force and harvesting levels have been reduced. In particular, common eider and thick-billed murre colonies in and near the assessment area have decreased in numbers over the past decades. Both species rely on a high adult survival rate, giving the adult birds many possibilities to reproduce. Extra mortality due to an oil spill or sub-lethal effects from contamination from petroleum activities have the potential to be additive to the hunting impact and thereby enhance the population decline (see also Figure 50) (Mosbech 2002). Within the assessment area there is a single breeding colony of thick-billed murre, and the numbers of breeding birds have in recent decades decreased considerably. The birds from this colony are particularly vulnerable during the swimming migration, which is performed by flightless adults (due to moult) and chicks still not able to fly (Figure 33). The birds are most concentrated in the first weeks when moving out through the Vaigat. Then they disperse in the waters west of Disko Island, and here no areas of concentration were detected in 2005 and 2006.

The wintering walruses on Store Hellefiskebanke and the banks west of Disko represents another example of a population which may suffer from cumulative impacts from activities giving rise to disturbance.

8.3 Impacts from accidental oils spills

A major potential environmental impact from offshore oil activities is a large accidental oil spill. The probability is low while the potential impact can be large and long-lasting.

Accidental oil spills can occur during drilling as a blowout either at the sea surface or from the wellhead on the seafloor (sub-sea blowout). In a production phase large accidental oil spills can also occur during transport and storage.

8.3.1 Probability of oil spills

The probability of large oil spills is low. However, the risk cannot be eliminated and in a frontier area it is difficult to calculate the risk based on experience from more developed areas. For development in the Barents Sea it has been calculated statistically that a blowout between 10,000 and 50,000 tonnes would happen once every 4,600 years in a small-scale development scenario and once every 1,700 years in an intensive development scenario (Anonymous 2003). The likelihood of a large oil spill from a tanker ship accident is estimated to be higher than for an oil spill from a blowout (Anonymous 2003).

8.3.2 The fate and behaviour of spilled oil

Experience with spilled oil in the marine environment shows that the fate and behaviour of the oil vary considerably. Fate and behaviour depend on the physical and chemical properties of the oil (light oil or heavy oil), how it is released (surface or sub-sea, instantaneous or continuous) and on the conditions of the sea into which it is spilled (temperature, ice, wind and current). Oil released to open water spreads rapidly resulting in a thin slick (often about 0.1 mm in the first day) that covers a large area. Wind-driven surface currents will move the oil with about 3% of the wind speed and cause turbulence in the surface water layer which eventually will break up the oil slick into patches and cause some of the oil to disperse in the upper water column. This dispersed oil will usually stay in the upper 10 m (Johansen et al. 2003).

The general knowledge on the potential fate and degradation of spilled oil relevant for the Greenland marine environments has been reviewed by Pritchard & Karlson (in Mosbech 2002). Ross (1992) evaluated the behaviour of potential offshore oil spills in West Greenland with special regard to the potential for cleanup. Simulations of oil spill trajectories in West Greenland waters have previously been performed by Christensen et al. (1993) using the SAW model, and by SINTEF (Johansen 1999) using the OSCAR model in preparation for the Statoil drilling in the Fylla area in 2000.

8.3.3 The DMI oil spill simulations in the Disko West area

As part of the ongoing SEA of oil activities in the assessment area, NERI contracted DMI to make a 3-D hydrodynamic model and a number oil drift and fate simulations for hypothetical oil spills in the assessment area (Nielsen et al. 2006).

The advantage of this approach was that a 3-D hydrodynamic model also can support an ecological analysis in the assessment and identification of areas with sustained upwelling (see e.g. Figures 3 and 4). The 3-D model had previously proven very valuable for modelling shrimp larvae drift on the Southwest Greenland shelf (Storm & Pedersen 2003, Ribergaard et al. 2004).

The DMI oil drift and fate model (DMOD) has been generalised and set up for West Greenland waters. The model is based on a mathematical description of tracking and weathering of a finite number (n=1000) of particles describing the total oil spill. The forcing fields are obtained from the DMI large-scale numerical weather prediction (nwp) model Hirlam-T, which covers all of the arctic and sub-arctic region, and the general 3-D hydrodynamic (hd) ocean model HYCOM (HYbrid Coordinate Ocean Model), developed by the University of Miami and the Los Alamos National Laboratory and applied to West Greenland waters (Ribergaard & Kliem 2006). The total ratio of down-mixed and dispersed particles is determined by the modelled physical conditions in the vicinity of the oil spill. However, selection of which particles in the swarm of particles that are mixed down, and to which depths (layer), is governed by random processes. In reality dispersion of the surface skin layer is not represented by a fixed percentage of the number of particles, but as a fraction of every single particle within the surface layer.

The model covers the region 65º-75º N, 72º-50º W, with an original resolution of approx. 10 km, refined to approx. 1 km (1/120º latitude by 1/48º longitude). Vertically, the particle cloud is resolved into a 0.05 m surface (skin) layer and 12 subsurface layers located between 1, 5, 10, 15, 20, 30, 50, 75, 100, 500, 1000 and 1500 m depths. Vertical extent of each particle is in the order of millimetres or less and therefore each particle is assumed to be located in one single layer. Each particle may cover more or less than one grid cell. Thickness of each surface layer grid cell is calculated based on accumulating all particles covering the grid cell, weighted by the fraction of the coverage of each particle.

Calculation of subsurface layer concentrations is more complicated. Model output contains no information about the movement history of each particle. Thus it is impossible to determine whether the particle has moved from above or below, and subsequently to determine which layers are affected by the particle on its way to the actual layer. Consequently, all subsurface output from the model is assumed to pollute only the actual layer. The fact that dispersion is represented by individual particles (grid cells) (not as a fraction of all particles or grid cells) leads to difficulties quantifying the total subsurface oil concentration. Based on the circumstances described above, it is assumed that a suitable approximation or indication of the total amount of dispersed oil can be found using the ratio between the summarised value of subsurface grid cells and the water volume defined by the thickness of the layer and the horizontal extent of the surface layer.

Simulations were carried out for seven hypothetical spill locations all located in the shelf area west of Disko Island: locations 1-5 were selected by GEUS representing potential sites for offshore well drilling or oil production platforms and locations 6-7 were selected for simulating spills from tankers near a potential oil terminal. The crude oil Statfjord, a medium type crude oil (API density 886.3 kg/m^3), was selected by GEUS among 8 types in the DMI database as the most representative oil to potentially be discovered in the assessment area. This is a medium oil type, lighter than seawater, which will evaporate by around one third during the first 24 hours of a surface spill period.

For continuous spills oil is released at a constant rate during the first ten days of the simulation period. The amount of oil released is fixed at 3,000 t/day, totalling 30,000 tonnes. For instantaneous spills the amount of oil released is 15,000 tonnes. These are very large spills with a very low probability.

Six 10-day wind periods have been selected within the design year July 2004-June 2005. The five first periods represent a predominant wind from different directions at moderate wind speeds; the sixth period has spells of a strong southerly wind. A total of 114 one-month oil drift simulations have been carried out. The simulations result in hourly tables of position and properties of a cloud consisting of 1,000 oil particles. Averaging results in bulk spill time-series. See Section 10 for examples.

Shore affected

By tracking all particles, the relative amount of oil settling on the shore as well as the lengths of shoreline affected are calculated. When the spill is located far offshore, the coast is not affected in any of the chosen wind conditions. Near-shore spills will result in coastal pollution under unfavourable wind conditions, and the near-shore tanker spills simulated will usually pollute the coast, except under very fortunate wind conditions. The polluted stretch may include the Vaigat, southern parts of Disko Bay, the west coast of Disko Island, and up to 100 km north and south of the Disko Bay area.

Sea surface area covered

The slick area after 10 days is 100-500 km^2, equivalent to a disc with a radius of 5-6 km in the case of a continuous spill, and 10-12.5 km in the case of an instantaneous spill. After 30 days, the slick radius has increased to 20-25 km, and the slick typically covers an area of 1,500-2,000 km^2 of very irregular shape (see figures in Section 9 and Appendix 1).

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. The model gives no indication of how much smaller the actual oil covered area is.

Oil spill in ice covered waters

Due to the roughness of the subsurface of the ice, oil will not move as far away from the spill site as in open waters. If an oil slick is 1 cm thick on average, a spill of 15,000 m^3 will cover 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. Fauna under the ice or in leads and cracks may therefore risk exposure to highly toxic hydrocarbon levels.

Subsurface concentrations

As described above, quantification of subsurface concentration based on output from the DMI model is complicated. To provide an indication of the magnitude of modelled results a few scenarios have been selected. The sixth wind period shows the highest driving forces (highest surface wind speed) and thus the greatest down mixing is expected to occur within this scenario. Using spill location 1 in combination with a continuous spill and an instantaneous spill leads to a maximum number of affected subsurface grid cells (within each discrete layer) of 112 and 389, respectively. This should be related to a maximum number of affected surface grid cells of 3,957 and 3,766 (cell size approximately 1 km^2), respectively, for the same time periods. During the first two days no down mixing is described by the model. Likewise the two uppermost subsurface layers are not affected by any particles until the sixth day in the continuous spill simulation and not until the third day in the instantaneous spill simulation. Also there are a few examples of affected subjacent layers during both simulations, while layers above contain no pollution. The dispersion reaches down to a maximum depth of 20 m (layer 5) during the instantaneous simulation and down to 15 m (layer 4) during the continuous situation. The majority of affected grid cells are located within the uppermost 10 metres (layer 3) in both simulations. Calculating the ratio between the total number of oil-affected grid cells and the water volume beneath the surface spill within each discrete layer produces concentrations reaching maximum values of around 225 ppb with the continuous spill and 243 ppb with the instantaneous spill. Corresponding mean values are 49 ppb and 56 ppb respectively (total fresh oil and concentration of water soluble fraction will be less).

A subsea blowout may cause high concentrations of oil in the water column, but depending on oil type, magnitude of spill and oceanographic conditions it is most likely that high concentrations will only occur in a limited area. In the subsea blowout simulations of the DMI model the oil did not disperse very much in the deeper water column but quickly rose to the surface and formed a surface spill. Thus values from the corresponding modelled surface spill can be regarded as relatively similar. However, a subsea blowout was assessed in relation to the exploration drilling in 2000 near Fyllas Bank in Davis Strait (Johansen 1999). Here it was estimated that oil would not reach the surface at all, but rather form a subsea plume at a depth of 300-500 m. High total hydrocarbon concentrations (>100 ppb by weight) were estimated in a restricted area close to the outflow.

Dissolution of oil and toxicity

Total oil concentration in water is a combination of the concentration of small dispersed oil droplets and the oil components dissolved from these and the surface slick. The process of dissolution is of particular interest as it increases the bioavailability of the oil components. The toxic components can increase the potential for acute toxicity to marine organisms. The rate and extent to which oil components dissolve in seawater depends mainly on the amount of water soluble fraction (WSF) of the oil. The degree of natural dispersion is also important for the rate of dissolution, although surface spreading and water temperature may also have some influence.

An oil slick at sea where evaporation and dissolution occur simultaneously and the oil-to-water ratio is very low, at concentrations averaging 2-20 ppb of dissolved oil or BTX (benzene, toluene and xylene) components, is measured in the seawater (1-10 metres in depth).

The highest polyaromatic hydrocarbon concentration found in Prince William Sound within a six-week period after the Exxon Valdez spill was 1.59 ppb, at a 5 m depth. This is well below levels considered to be acutely toxic to marine fauna (Short and Harris 1996).

SINTEF (Johansen et al. 2003) reviewed available standardised toxicity studies and found acute toxicity down to 0.9 mg oil /l (0.9 ppm or 900 ppb) and applied a safety factor of 10 to reach a PNEC (Predicted No Effect Concentration) of 90 ppb oil for 96-hour exposure. This is based on fresh oil which leaks a dissolvable fraction, most toxic for eggs and larvae. Later the weathered oil will be less toxic.

Water soluble components (WSC) could leak from oil encapsulated in ice. Controlled field experiments with oil encapsulated in first-year ice for up to 5 months have been performed for Svalbard, Norway (Faksness & Brandvik 2005). The results show 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 are exposed to a substantial dose of toxic water-soluble components. Leakage of water-soluble components to the ice is of special interest, because of a high bioavailability to marine organisms, relevant both in connection with accidental oil spills and release of produced water.

8.3.4 Oil spill impact on plankton and fish incl. larvae of fish and shrimp

Adult fish and shrimp

In the open sea, an oil spill usually will not result oil concentrations in the water column that are lethal to adult fish, due to dispersion and dilution. Furthermore, fish such as cod and salmon can detect oil and will attempt to avoid it, and therefore populations of adult fish in the open sea are not likely to be significantly affected by an oil spill.

Adult shrimps live on and near the bottom in relatively deep waters (100-600 m), where oil concentrations from a surface spill will be very low, if detectable at all. No effects were seen on the shrimp stocks (same species as in Greenland) in Prince William Sound in Alaska after the large oil spill from Exxon Valdez in 1989 (Armstrong et al. 1995). Whether a sub-sea blowout may cause high concentrations in the water column near the shrimp habitats is not known, but a simulation study concluded that high oil concentrations will most likely occur only in a limited area (cf. Johansen 1999).

Fish and shrimp larvae

Eggs and larvae of fish and shrimp are more sensitive to oil than adults. Theoretically impacts to fish and shrimp larvae may be significant and cause a reduced year strength/recruitment with some effect on subsequent populations and fisheries for a number of years. However, such effects are extremely difficult to identify/filter out from natural variability and they have never been documented after spills.

The distribution of fish eggs and early larval stages in the water column is governed by density, currents and turbulence. In the Barents Sea the pelagic eggs of cod will rise and be distributed in the upper part of the water column. As oil also is buoyant, the highest exposure of eggs will be under calm conditions while high energy wind and wave conditions will mix eggs and oil deeper into the water column, where both are diluted and the exposure limited. As larvae grow older their ability to move around becomes increasingly important for their depth distribution.

In general, species with distinct spawning concentrations and with eggs and larvae in distinct geographic concentrations in the upper water layer will be particularly vulnerable. The Barents Sea stock of Atlantic cod is such a species where eggs and larvae can be concentrated in the upper 10 m in a limited area. Based on oil spill simulations for different scenarios and different toxicities of the dissolved oil, the individual oil exposure and population mortality has been calculated. The population impact is to a large degree dependent on whether there is a match or a mismatch between high oil concentrations in the water column (which will only occur for a short period when the oil is fresh) and the highest egg and larvae concentrations (which will also only be present for weeks or a few months, and just be concentrated in surface water in calm weather). For combinations of unfavourable circumstances and using the PNEC with a 10 X safety factor (Johansen et al. 2003), there could be losses in the region of 5%, and in some cases up to 15%, for a blowout lasting less than 2 weeks, while very long-lasting blowouts could give losses of eggs and larvae exceeding 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 about 8 years to fully recover (Figure 49).

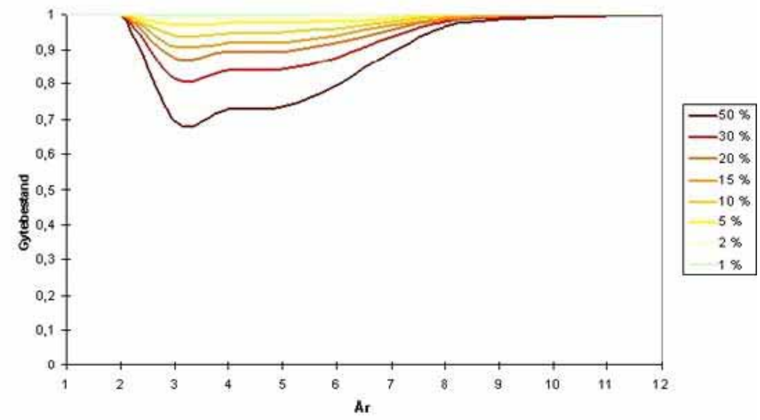


Figure 49. Estimated reduction and recovery in Barents Sea cod spawning biomass following large losses of egg and larvae due to large "worst case" oil spills. Gydebestand = spawning stock, År = year. Source: Anonymous 2003, Johansen et al. 2003

Less knowledge is available on concentrations of eggs and larvae in West Greenland than in Norwegian waters. But the much localised spawning areas with high concentrations of egg and larvae for a whole stock near the surface known from the Lofoten-Barents Sea are not documented in Greenland. Here the overall picture is that fish larvae are widespread, although occurring in patches which may hold relatively high concentrations. Another factor of importance is the vertical distribution of eggs and larvae. Eggs of Atlantic cod concentrate in the upper 10 m of the water column, whereas larvae of shrimp and Greenland halibut also are found deeper and therefore will be less exposed to harmful oil concentrations from an oil spill.

This implies that an oil spill most likely only will impact on a much smaller proportion of a season's production of eggs and/or larvae in Greenland than modelled for cod in the Barents Sea, and that impacts on recruitment to the Greenland halibut and deep-sea shrimp stocks most likely will be insignificant.

Copepods, the food chain and important areas

Copepods are very important in the food chain and can be affected by the toxic oil components (WSF, water soluble fraction) in the water below an oil spill. However, given the usually restricted vertical distribution of these components (0-10 m) and the wider depth distribution of the copepods this is not likely to cause major population effects. Ingestion of dispersed oil droplets at greater depth from a sub-sea blowout or after a storm can also be a problem. Studies of the potential effects of oil spills on copepods in the Barents Sea (Melle et al. 2001) showed that populations were distributed over such large areas that a single oil spill only would impact a minor part and not pose a major threat (Anonymous 2003).

Important areas for plankton including fish and shrimp larvae are where hydrodynamic discontinuities occur. Special attention should therefore be given to the implication of oil spills in connection with such sites, particularly during the spring bloom. Fronts, upwelling areas and the marginal ice zone are examples of such hydrodynamic discontinuities where high surface concentrations of phytoplankton, zooplankton, including shrimp and fish larvae, can be expected.

The most sensitive season for primary production and plankton – i.e. where an oil spill can be expected to have the most severe ecological consequences – is April to June where high biological activity of the pelagic food web from phytoplankton to fish larvae are concentrated in the surface layers.

The chlorophyll study in spring 2006 (p. 47) indicates large spatial and temporal variability in the chlorophyll levels and that high chlorophyll levels (spring bloom) are distributed over large areas in the assessment area. Moreover, areas of high importance for primary production vary both during seasons and between years, depending for example on ice conditions. An oil spill therefore has the potential to impact small and localised primary production sites, while primary production as a whole will only be slightly impacted even during a large spill in open waters.

8.3.5 Oil spill impacts on benthos

Bottom-living organisms (benthos) are generally very sensitive to oil spills and high hydrocarbon concentrations in the water. However, effects will occur in shallow water (<50 m) where toxic concentrations can reach the seafloor. In such areas intensive mortality has been recorded following an oil spill, for example among crustaceans and molluscs (McCay et al. 2003a, 2003b). Oil may also for example 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 is apparent, and a sub-lethal effect may, if the same happens in the assessment area, be transferred to seals and walruses feeding on bivalves and other benthos. The knowledge about benthos in the assessment area is too fragmentary to assess impacts of eventual oil spills.

8.3.6 Oil spill impacts in coastal habitats

In coastal areas where oil can be trapped in shallow bays and inlets, oil concentrations can build up in the water column to levels that are lethal to adult fish and invertebrates.

An oil spill from an activity in the assessment area which reaches the coast has the potential to reduce stocks of lumpsucker and capelin, because these fish spawn here and the sensitive eggs and larvae may be exposed to high oil concentrations. Arctic char may be forced to stay in oil-contaminated shallow waters when they move towards their native river to spawn and winter.

In coastal areas where oil may be buried in sediment, among boulders and imbedded in crevices in rocks, a situation with chronic oil pollution may persist for decades and cause small to moderate effects (see page 123 and Table 4, p. 124). Many coastlines in the assessment area are similar to the coasts of Prince William Sound where oil was trapped below the surface after the Exxon Valdez oil spill.

Oil may also contaminate terrestrial habitats occasionally inundated at high water levels. Salt marshes are particularly sensitive and they represent important feeding areas for geese.

The coastal areas of the assessment area have been mapped and classified according to their sensitivity to oil spills (Mosbech et al 2004). This is described in section 10.2.

8.3.7 Oil spill impacts on fisheries

Tainting by oil residues in fish meat is a serious 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). 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 to low levels. Tainting may also occur in fish living where oil-contaminated drill cuttings have been disposed of.

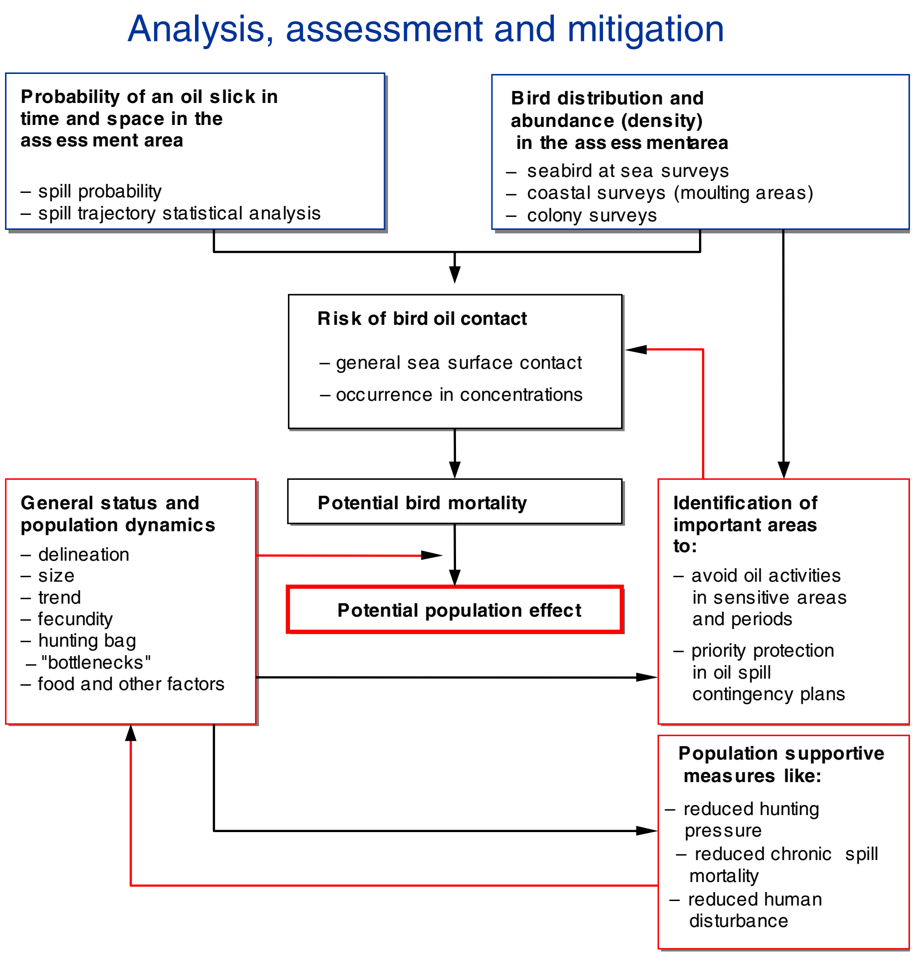
In case of oil spills, it will be necessary to suspend fishery activities in the affected areas, mainly to avoid the risk of marketing fish that are contaminated or even just tainted by oil (Rice et al. 1996). This may apply to the deep-sea shrimp and halibut fisheries within the assessment area. Large oil spills may cause heavy economic losses due to problems arising in the marketing of the products. Strict regulation and control of the fisheries in contaminated areas are necessary to ensure the quality of the fish available on the market. In offshore areas suspension usually will last some weeks and in coastal waters longer. The coastal fishery was banned for four months after the Braer incident in Shetland Islands in 1993, and for nine months after the Exxon Valdez incident in Alaska in 1989 (Rice et al. 1996). However, some mussel fishing grounds were closed for more than 18 months after the Braer incident.

8.3.8 Oil spill impacts on seabirds

It is well documented that birds are extremely vulnerable to oil spills in the marine environment (Schreiber & Burger 2002). Birds which rest and dive from the sea surface, such as auks, seaducks, cormorants and divers (loons) are most exposed to floating oil. But all seabirds face the risk of coming into contact with spilled oil on the surface. This particular vulnerability is attributable to feather plumage. Oil soaks easily into the plumage and destroys its insulation and buoyancy properties. Therefore, oiled seabirds readily die from hypothermia, starvation or drowning. Birds may also ingest oil by cleaning their plumage and by feeding on oil-contaminated food. Oil irritates the digestive organs, damages the liver, kidney and salt gland function, and causes anaemia. Oiled plumage is the main cause of seabird losses following an oil spill, but long-term effects after intoxication also occur.

Many seabirds aggregate in small and limited areas for certain periods of their life cycles. Small amounts of oil in such areas may cause very high mortalities among the birds present. The high concentrations of seabirds found at coasts (e.g. breeding colonies, moulting areas, Figures 26 and 27) or in offshore waters at important feeding and wintering areas (Figures 29, 30, 31 and 32) are particularly vulnerable.

Oiled birds which have drifted ashore are often the focus of the media when oil spills occur. However, seen from a resource management and scientific point of view the concern is whether the oil spill induced mortality also affects the seabird populations both in the short term and long term. Or, in other words, the relevant ecological question must be: how are seabird populations affected by the oil spill? To answer this question, extensive studies of the natural dynamics of the affected populations and the surrounding ecosystem are necessary (Figure 50).



Mosbech & Boertmann: Seabirds and oil spills in the Arctic

Figure 50. Basic principles of an analysis for assessing seabird population vulnerability to oil spills. Black lines indicate main analysis of effects on bird populations, red lines indicate analysis of possible mitigative measures (indirect effects omitted for simplicity).

The seabird populations most vulnerable to oil spills are those with low reproductive capacity and a corresponding high average lifespan (low population turnover). Such a life strategy is found among auks, fulmars and many seaducks. Thick-billed murres for example do not breed before 4-5 years of age and the females only lay a single egg per year. This very low annual reproductive output is counterbalanced by a very long expected life of 15-20 years. Such seabird populations are therefore particularly vulnerable to additional adult mortality caused for example by an oil spill.

If a breeding colony of birds is completely wiped out by an oil spill it must be re-colonised from neighbouring colonies. Recolonisation is dependent on distance, size and productivity in relation to these colonies. If the numbers of birds in neighbouring colonies are declining, for example due to hunting as in West Greenland, there will be no or only few birds available for re-colonisation of a site.

Only one breeding colony of thick-billed murre is known from the assessment area. This is situated in the inner part of Disko Bay and an oil spill is not likely to drift this far. However, as the adult birds feed far from the breeding site e.g. off the outer coast, the breeding population at this colony could be seriously affected if an oil spill was to hit the feeding areas. Another risk situation is when the chicks and flightless adults leave the colony on a swimming migration. The satellite tracking studies of birds from this colony in 2005 and 2006 showed that these swimming birds may move both south and north of Disko and thereafter stay in the waters west of Disko for some weeks (Figure 33). These birds are most concentrated during the first weeks when a substantial number move out through the Vaigat. When they arrive in the open sea they disperse over extensive areas (Figure 33). The population is therefore most vulnerable to oil spills occurring in the Vaigat in late July. This population is declining and therefore particularly sensitive to additional mortality.

Other important bird colonies where the population could be severely impacted by an oil spill in the assessment area include an Arctic tern colony at Kitsissut/Grønne Ejland, which is the largest in Greenland (and one of the largest in the world) with about 20,000 pairs, and also several colonies of Atlantic puffin on the islands south of Disko Island.

The king eider moulting areas on the west coast of Disko Island, and the important king eider wintering area on Store Hellefiskebanke and the adjacent coast (Figures 27, 28, 29 and 30) are highly vulnerable to oil spills. Here very large fractions of the entire population wintering in Greenland may occur in limited areas and be affected by a large oil spill. Probably almost the whole Greenland winter population was present in the area in November 2003.

The number of thick-billed murres occurring in the assessment area in spring is also very high. The aerial survey in April/May 2006 resulted in an estimate at 400,000 birds with large concentrations at the northeast corner of Store Hellefiskebanke (an important upwelling area) and in the southern part of Disko Bay (Figure 32).

Particularly important and vulnerable bird populations in the assessment area include the moulting and wintering king eiders, wintering thick-billed murres and the breeding colonies of seabirds (thick-billed murres, Atlantic puffins, Arctic terns). A large oil spill has the potential to deplete these populations, but it is not likely that entire populations can be wiped out. However, the small and restricted breeding colonies of e.g. Atlantic puffin are at risk of being completely exterminated. The recovery of the seabird populations may, nevertheless, be hindered after an oil spill, if other factors, such as hunting or by-catch (in fisheries), reduce the growth potential of the population.

8.3.9 Oil spill impacts on marine mammals

Marine mammal populations are generally less sensitive to oiling than many other organisms, because individuals (except polar bears) are rather robust in response to fouling and contact with oil. They are not dependent on an intact fur layer for insulation, and they can avoid oil in the open sea (Geraci & St Aubin 1990). However, especially in ice-covered waters where oil may fill the spaces between the ice floes marine mammals may be forced to surface in an oil spill. It is however not known how damaging inhaling oil vapours can be for marine mammals during a spill. There is also concern for damage to eye tissue on contact with oil, for the toxic effects and injuries in the gastrointestinal tract if oil is taken in during feeding at the surface (particularly in the case of the bowhead whale) (Albeert 1981, Braithwaite et al. 1983, St Aubain et al. 1984).

It is therefore not likely that even a large oil spill in the assessment area will cause major decline in relation to marine mammal populations. Mortality may occur but the populations are distributed over large areas. However, occurrence of marine mammals in local areas can be significantly altered because of localised mortality, change in habits and avoidance of habitats. The species affected by an oil spill during winter and spring could include walrus, bowhead whale, narwhal, white whale and polar bear. Of these, walrus, white whale and narwhal are especially vulnerable because their populations are declining due to unsustainable harvest. The bowhead whale may also be considered as vulnerable because the population is very small and the survival of single individual is crucial for the recovery of the population.

A reservation to the overall assessment of the whale populations exploiting the area must be made. Preliminary evidence indicates that the assessment area is the main feeding ground (on an annual basis) particularly for the winter whales, and that the survival of the populations may be dependent on the rich food resources in the area. Oil spill effects on these food resources may therefore have implications also on the survival of the whale populations (M.P. Heide-Jørgensen GINR, pers. comm).

Among marine mammals in the Arctic, polar bears are particularly sensitive to oil spills at the individual level. Contact with oil through grooming of fouled fur, consumption of tainted food or even direct consumption (because polar bears are attracted to fatty substances) can be lethal (Durner & Amstrup 2000). Polar bears live in ice-covered waters and the population density is low and probably also declining. In the study described above, the maximum fraction of one of the polar bear stocks in the assessment area occurring within an area of 10 x 10 km^2 during a season is 20% (corresponding to about 800 bears). However, all these polar bears do not occur within the grid cell at the same time; their presence is distributed over three or four months with a typical home range size of 80,000 km^2 (mean home range size for winter, n = 85). The dense ice in the polar bear habitat will typically contain or restrain the spread of oil (cf. section 8.3.3 and spill scenario 7). Therefore it is expected that only a fraction of the 800 bears will coincide with the oil spill, and even a large oil spill under the ice will probably only affect a few individuals and have little impact on population level. However, there are many uncertainties in this assessment and many more bears may come into contact with an oil spill, with possible population level impacts as a result. Polar bears are already considered as vulnerable (IUCN 2006) due to climate change, which is expected to reduce their habitat, the ice-covered arctic waters.

Furthermore, in recent years the Greenlandic catch of polar bears from the Baffin Bay population that ranges in the assessment area has increased significantly reaching a maximum of 206 in 2004 (Born & Sonne 2006). This may partially be a result of an increased coastal availability – and perhaps increased local abundance – of polar bears as a response to a reduction and earlier break up of sea ice in the eastern Baffin Bay/Davis Strait areas (Stirling & Parkinson 2006). The quotas for the years 2007-2009 Greenlandic kill of polar bears from the Baffin Bay population are 73, 71 and 68/year, respectively, and 2 for each of the years from the Davis Strait population (Greenland Homerule 2006). Hence, in a worst-case scenario an oil spill may kill 10 times the annual Greenlandic take of bears from this area or more than 3.5 the combined Canadian-Greenlandic catch of approx. 225/year.

8.3.10 Long-term effects

A synthesis of 14 years of oil spill studies in Prince William Sound since the Exxon Valdez spill has been published in the journal "Science", and here is it documented that delayed, chronic and indirect effects of marine oil pollution occur (Table 4). Oil persisted in certain coastal habitats beyond a decade in surprisingly high amounts and in highly toxic forms. The oil was sufficiently bio-available to induce chronic biological exposure and had long-term impacts at the population level. Heavily oiled coarse sediments formed subsurface reservoirs of oil where it was protected from loss and weathering in intertidal habitats. In these habitats e.g. harlequin ducks, preying on intertidal benthic invertebrates, showed clear differences between oiled and un-oiled coasts: at oiled coasts they displayed the detoxification enzyme CYP1A nine years after the spill. Harlequin ducks at oiled coasts displayed lower survival, their mortality rate was 22% instead of16%; lower body mass; and showed a decline in population density as compared with stable numbers on un-oiled shores (Petersen et al. 2003).

Many coasts in the assessment area in Greenland have the same morphology as the coasts of Prince William Sound where oil was trapped, indicating that similar impacts must be expected if spilled oil is stranded on these coasts.

Table 4. Changing paradigms in oil ecotoxicology, moving from acute toxicity based on single species toward an ecosystem-based synthesis of short-term direct plus longer-term chronic, delayed, and indirect impacts. (From Petersen et al. 2003).

Old paradigm	Emerging appreciation
Physical shoreline habitat	
Oil that grounds shorelines other than marshes dominated by fine sediments will be rapidly dispersed and degraded microbially and photolytically.	Oil degrades at varying rates depending on environment, with subsurface sediments physically protected from disturbance, oxygenation, and photolysis retaining contamination by only partially weathered oil for years.
Oil toxicity to fish	
Oil effects occur solely through short-term (~4 day) exposure to water-soluble fraction (1- to 2-ringed aromatics dominate) through acute narcosis mortality at parts per million concentrations.	Long-term exposure of fish embryos to weathered oil (3- to 5-ringed PAHs) at ppb concentrations has population consequences through indirect effects on growth, deformities, and behaviour with long-term consequences on mortality and reproduction.
Oil toxicity to seabirds and marine mammals	
Oil effects occur solely through short-term acute exposure of feathers or fur and resulting death from hypothermia, smothering, drowning, or ingestion of toxics during preening.	Oil effects also are substantial (independent of means of insulation) over the long term through interactions between natural environmental stressors and compromised health of exposed animals, through chronic toxic exposure from ingesting contaminated prey or during foraging around persistent sedimentary pools of oil, and through disruption of vital social functions (care giving or reproduction) in socially organized species.
Oil impacts on coastal communities	
Acute mortality through short-term toxic exposure to oil deposited on shore and the shallow seafloor or through smothering accounts for the only important losses of shoreline plants and invertebrates.	Clean-up attempts can be more damaging than the oil itself, with impacts recurring as long as clean-up (including both chemical and physical methods) continues. Because of the pervasiveness of strong biological interactions in rocky intertidal and kelp forest communities, cascades of delayed, indirect impacts (especially of trophic cascades and biogenic habitat loss) expand the scope of injury well beyond the initial direct losses and thereby also delay recoveries.

8.4 Assessment summary

8.4.1 Normal operations

Noise from seismic activities has the potential to scare adult fish away from fishing grounds; but if scared away the effect is temporary and normal conditions will re-establish after some days or weeks, probably mainly depending on fish species. It is assessed that shrimp distribution will not be affected by seismic activities.

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

Noise from drilling platforms is known to displace migration routes of whales in Alaska, and dependent on the location in the area, displacement of migrating and staging whales (mainly narwhal, white whale and bowhead whale), walrus and seals (bearded seal) must be expected. This can in certain areas displace populations from feeding grounds and also result in reduced availability of quarry species for local hunters.

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

The sound pulse from the seismic array may kill or injure fish eggs and larvae up to a distance of 5 m. In Norway it has been assessed that very intensive seismic surveys coinciding with high concentrations of fish eggs and larvae in the upper part of the water column may possibly impact recruitment to adult stocks. However, as such high concentrations are not seen in West Greenland waters, and moreover most fish species spawn dispersed and in late winter or early spring when no seismic surveys take place, it is concluded that the risk of effects of seismic surveys on fish stocks is negligible.

Discharges from drilling and other operations e.g. development and production operations can be kept at a minimum, and if strict Health Safety and Environment regulation, Best Available Technology, Best Environmental Practice and close monitoring are applied, only slight and local impacts are expected.

Development of an oil field and production of oil are energy-consuming activities which will contribute significantly to the Greenland emission of greenhouse gasses. A single large Norwegian production field emits more than twice the total Greenland emission of today.

A specific impact on fisheries is comprised by the exclusion zones which will be established around both temporary and permanent installations.

An issue difficult to evaluate when the level of activity is unknown is cumulative impacts. These will depend on number of activities, the density of operation sites and on the duration of the activities, and must be further assessed at later stages.

8.4.2 Accidents

The environmentally most serious accident would be a large oil spill. This has the potential to impact on all levels in the marine ecosystem from primary production to the top-predators. In general, oil slicks occurring in the coastal zone are more harmful and cause longer-lasting effects than do oil spills staying in the open sea, but there some reservation to this statement should be expressed in an area like Disko West. This is due to the presence of winter ice which may trap and transport oil over long distances, but on the other hand also may limit the dispersion compared with the situation in ice-free waters. Knowledge on the behaviour of spilled oil and the technology for its clean up in ice-covered waters is limited.

It is concluded that the impact of an oil spill in the assessment area on primary production, plankton and fish/shrimp larvae in open waters will be low due to the large temporal and spatial variation in the occurrence of these. There is, however, a risk of impacts (reduced production) on localised primary production areas; although overall production probably will not be significantly impacted. The same may be true for eventual localised concentrations of plankton and fish/shrimp larvae if they occur in the uppermost part of the water column, but on a broad scale no effects or only slight effects on these resources are expected.

In coastal areas there is a risk of impacts on spawning concentrations of capelin and lumpsucker in spring, and on many seabird populations both in summer and winter.

Bottom living organisms (benthos) such as bivalves and crustaceans are vulnerable to oil spills, but effects will probably only occur in shallow waters, where highly toxic concentrations of hydrocarbons can reach the seafloor.

Impacts on adult fish stocks in the open sea are not expected.

In open waters seabirds are usually more dispersed than in coastal habitats. There are, however, in the assessment area some very concentrated and recurrent winter seabird occurrences (king eiders), and during spring and autumn large concentrations of migrating seabirds are also expected. Such concentrations are extremely sensitive to oil spills and population effects may occur.

Among the marine mammals the polar bear is sensitive to oiling, and many may become fouled with oil in case of a large oil spill in the marginal ice zone. The impact of an oil spill may add to the general decrease expected for the polar bear stocks as a consequence of reduced ice cover (global warming).

White whales, narwhals, bowhead whales and walruses are also vulnerable to oil spills, as they may surface in oil slicks and bowhead whales may get their baleens smothered with oil and ingest oil. It is unknown to what extent marine mammals actively will avoid an oil slick and also how harmful the oil will be to fouled individuals. All these species have small or declining populations and, for the whales, the assessment area probably is particularly important because it appears to be where they their main food intake takes place (on annual basis). Effects from oil spills (and disturbance) may therefore have disproportionably high impacts on the populations.

It is not likely that indirect impacts on walrus and bearded seal stocks through contamination of the benthic fauna may occur, because high oil concentrations probably will not reach the seafloor at the feeding grounds of these species, due to the depths involved (>50 m). However impacts cannot be ruled out if fresh oil sinks to the seafloor.

For some animal populations oil spill mortality can to some extent be compensatory to natural mortality while for others it will be largely additional. Some populations may recover quickly while others will recover very slowly to pre-spill conditions depending on their life strategies. A general decline in a population may be enhanced by the oil spill induced mortality. For species which are vulnerable to oil spills and are also harvested, the risk of long-term population damage from an oil spill can be reduced if populations are harvested in a safe and sustainable way.

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

An oil spill in the open sea will affect fisheries mainly by a temporary closure in order to avoid contamination of catches. Closure time will depend on the duration of the oil spill, weather, etc. Oiled coastal areas will also be closed for fisheries for a period depending on the behaviour of the oil. There are examples of closure for many months due to oil spills, particularly if oil is caught in sediments or on beaches.

9 Oil spill scenarios in the Disko West area

In Appendix 1 a series of oil spill scenarios are described. Six of them are based on the oil spill modelling carried out by DMI (Nielsen et al. 2006). Spill locations are shown in Figure 51. The spill scenarios selected for the modelling of oil drift and weathering focus on covering different wind situations, and some seasons are under-represented. Therefore some of the spill scenarios described in the appendix are transposed to other seasons to get a more comprehensive picture of the annual variation of possible impacts. The last scenario is based on the ice drift tracking carried out in spring 2006 (see Figure 7). Table 5 summarises the scenarios. Only two of the modelled spills are shown in figures here, one with a large and one with a limited extension (Figures 52 and 53). Further model results are shown in Appendix 1.

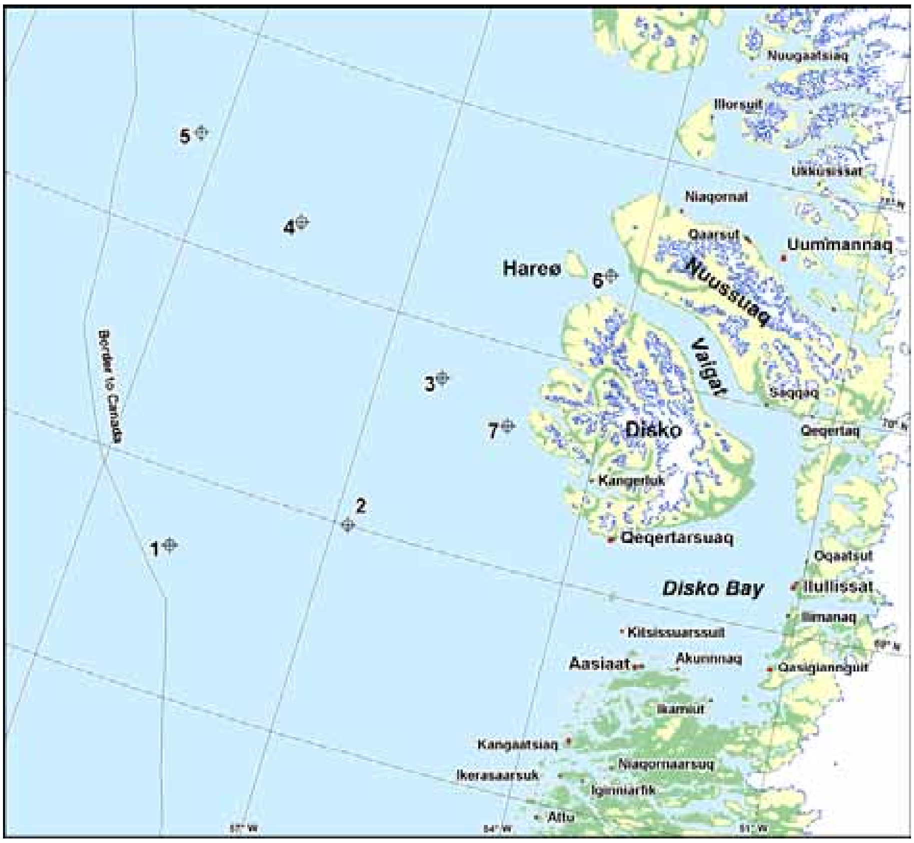


Figure 51. The seven spill locations and towns and settlements in the region.

The scenarios indicate that spills reaching coastal waters and eventual stranding on the shorelines have the potential to cause high impacts on several resources and also long-term effects. Along the coasts spawning stocks of capelin and lumpsucker can be impacted; breeding, moulting and wintering seabird populations will be exposed; and some fisheries will be closed to avoid contamination of catches. Oil spills far from the coast, on the other hand, may under fortunate circumstances cause very small impacts. However, offshore fisheries for deep-sea shrimp risk closure to avoid contaminated catches, important feeding grounds for walrus may also be hit, and some very vulnerable and concentrated bird occurrences are also at risk. Oil spills in ice-covered waters are very difficult to evaluate as the oil may be trapped for long periods of time and released during melt far from the spill site.

Table 5. The impacts from the seven scenarios and alternative scenarios summarised (see Appendix for details). R = reversible, r = slowly reversible, No = no significant impacts expected. No* = No immediate impacts expected, but impacts possible following spring during ice melt. L = low impacts expected, M = moderate impacts expected, H = high impacts expected, ? = possible.

Scenario	Scenario alternative	Extent sq. km	Duration years	Season	Marine mammals	Birds	Fish	Benthos	Primary prod. plankton	Shorelines	Local use	Commercial use	Long-term effects likely
1		9000	>10	summer	L R	H r	M r	H r	L R	H r	H R	H R	yes
1	alt. drift	13000	>10	summer	L R	H r	L r	H r	L R	H r	H R	H R	yes
1	March alt.	9000	>10	spring	M R	H r	H r	H r	M R	H r	H R	H R	yes
2		1500	>10	autumn	L R	M R	L R	H r	L R	H r	L R	H R	yes
3		22000	1	winter	L R	L R	H? R	No	L R	No	No	L R	
3	Sept. alt.	22000	1	autumn	L R	H R	No	No	L R	No	No	H R	
4		8000	1	winter	M R	L R	H? R	No	No*	No	L R	L R	
4	alt. drift	10000	>5	winter	M R	H R	L R	No	L R	No	L R	L R	yes
5		10000	>10	summer	L R	H r	M R	H r	L R	H r	H R	H R	yes
6		30000	1	winter	M R	L R	H? R	No	No*	No	L R	L R	
6	Aug. alt.	30000	1	autumn	M R	H r	L R	No	L R	No	L R	H R	
7		unknown	1	spring	L R	L-M R	H? R	No	M R	No	L R	L R	

Summary of scenario 1

The impacts of an instantaneous oil spill in the summer period from spill location 3 will be high if the oil moves as indicated by the DMI spill drift model (Figure A2 in Appendix 1). Most of the effects will be reversible, but for some specific coast types and some seabird breeding colonies effects are likely to be apparent for decades.

If this oil spill is continuous instead of instantaneous, the modelling shows that oil also will drift northwards and hit the coasts of northwest Disko and the western Nuussuaq peninsula (Figure 52). The region northeast of the spill location is a very important moulting area for king eiders, and large concentrations will be exposed. There is a risk of substantial die-off, with long-term effects on the population as the result. The long coast lines of western Disko and Nuussuaq will be contaminated with oil. The northwards drift of oil will also pass the important deep-sea shrimp fishing grounds at Hareø (cf. scenario 2). The effects of an oil spill with these characteristics will probably be more severe than for the instantaneous spill described.

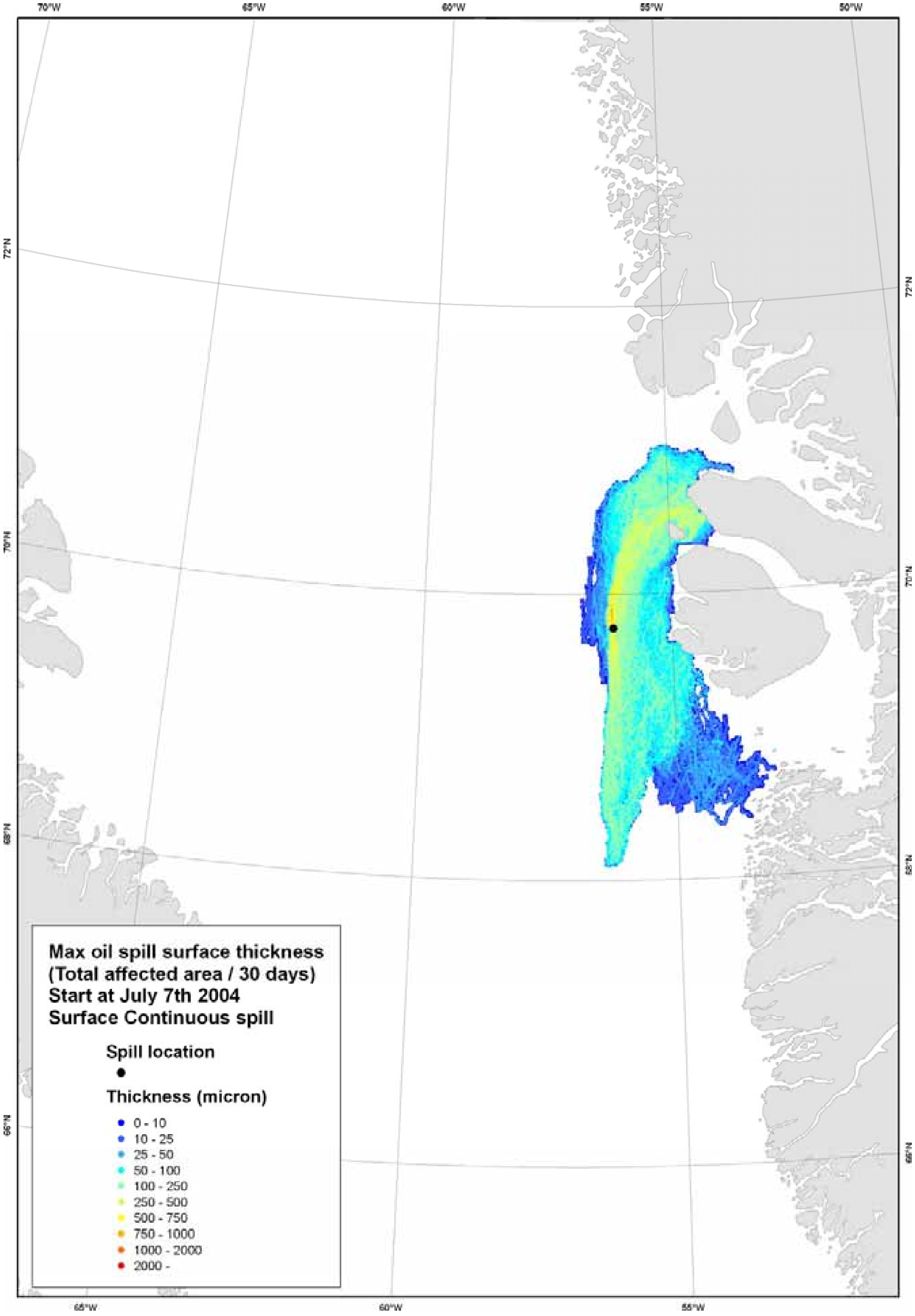


Figure 52. Maximum surface layer thickness and entire area swept by a continuous oil spill at location 3 for wind period 1. From Figure 39 in the DMI report (Nielsen at al. 2006).

A much more sensitive period in the region hit by the scenario 1 spill is late winter and early spring. If the drift pattern for spilled oil here is transposed to March the risk of high impacts is much higher than in summer. This is due to the presence of large concentrations of wintering and migrating seabirds, mainly common and king eiders and thick-billed murres; the presence of wintering marine mammals as bowhead whales, narwhals, white whales and walruses; the longer coast lines (>1800 km) hit by the oil; and because the oil may be trapped in bays and coasts where lumpsucker and capelin spawn (and are fished) in the spring. However, ice will also limit the spread of oil both by ice floes offshore and by land fast ice at the coast. Finally, the primary production of the spring bloom starts in this period and the marginal ice zone could be particularly sensitive in this respect. There is a risk for oil accumulation in this zone (particularly if the oil spill moves as in Figure 52), with associated risk of impacts on plankton. If the oil on the other hand is spread over large areas ('sheen' or dispersed 'mousse'), as predicted, the amount per square unit will be low and subsurface concentration will probably therefore also be low, with a reduced risk of impact on plankton.

Summary of scenario 2

The impacts of an oil spill in the early autumn period from spill location 6 will be low to moderate and the spatial extent will restricted, if the oil moves as predicted by the DMI oil spill drift model (Figure 53). This is due to the limited extent of the spill and because most of the oil settles on the shores within a short period. The most sensitive seabird occurrences have left the area and the most significant effects will be the closure of the shrimp fisheries in the waters around Hareø and heavy contamination of the shoreline habitats. There is a risk for long-term effects from stranded and preserved oil in boulder beaches.

Summary for scenario 3

The impacts of an oil spill in the early winter period from spill location 6 will be low if the oil moves as predicted by the DMI oil spill drift model (Figure A5 in Appendix 1) mainly due to the long distances to coasts and to the season. However, there is a risk of preservation, transportation and spring release of oil in much more sensitive areas such as the marginal ice zone, and there is also a risk of impacts on narwhal populations.

Other seasons in the affected area are much more sensitive than the early winter. In the autumn period, September and October, large numbers of seabirds – mainly little auks and thick-billed murres – move from breeding sites in North Greenland and Canada through Baffin Bay. As many as 100 million birds may perform this migration. Routes and concentration areas along routes are not known, but such areas will be highly sensitive to oil spills, and substantial numbers of birds may be affected. Ivory gulls from the Arctic Canadian and northwest Greenland breeding populations may also perform an autumn migration through this region. Ivory gull are not as sensitive to oil spills as alcids, but the population is decreasing and extra mortality particularly for adult birds may enhance this trend.

The Greenland halibut fishery takes place in the period July-October, and a two month closure of the fishery in this period will have a strong effect on the catch landed.

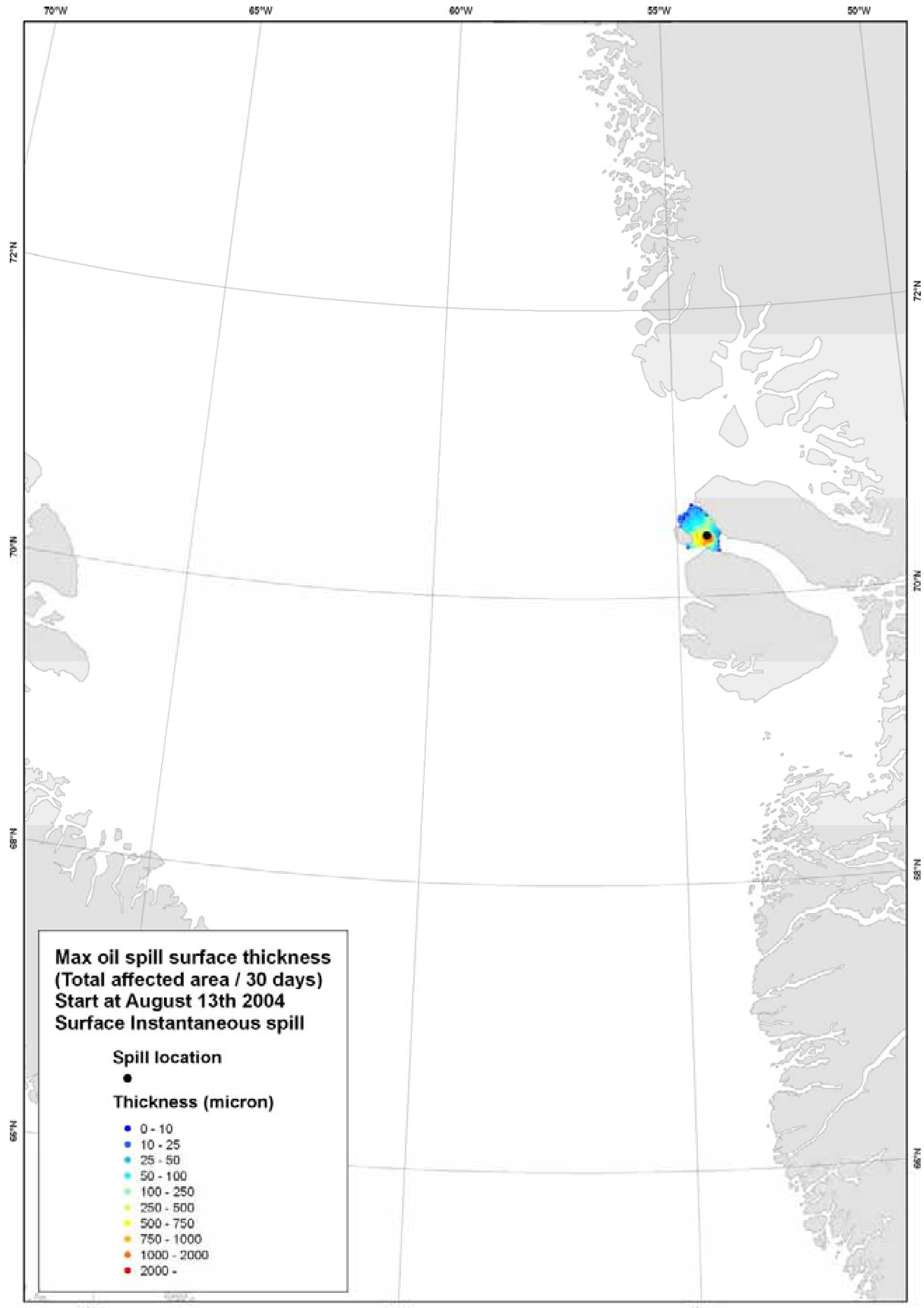


Figure 53. Maximum surface layer thickness and entire area swept by an instantaneous oil spill at location 6 for wind period 2. From Figure 38 in the DMI report (Nielsen at al. 2006).

Summary of scenario 4
The impacts of an oil spill in mid-winter from spill location 6 will probably be low to moderate if the oil moves as predicted by the DMI oil spill model (Figure A6 in Appendix 1), due to the season and the distance to the coasts. However, as impacts on marine mammals wintering in the affected area are difficult to assess there is a risk of more severe impacts. A slightly different trajectory of the spill will also increase the impact level to high, as this will affect the most important winter habitat for king eiders in Greenland, where almost the entire winter population often occurs in the limited open water areas.

Summary of scenario 5
The impacts of an oil spill in mid-summer from spill location 7 will be high if the oil moves as predicted by the DMI oil spill model (Figure A7 in Appendix 1). This is because oil will contaminate long coastlines with local fisheries, will hit important seabird breeding colonies in the most sensitive time of the year, and because very important commercial fisheries will be temporarily closed.

Summary of scenario 6
The impacts of an oil spill in mid-winter from spill location 2 will be low to moderate if the oil moves as predicted by DMI oil spill model (Figure A8 in Appendix 1), because of the season and the drift away from the coasts. However, ice may change the drift pattern considerably and oil may therefore be forced towards the coast or may be entrapped and later released at much more sensitive areas in the spring resulting in high impacts.

Other seasons in the affected area are much more sensitive than the winter. In August and September thick-billed murres performing swimming migration disperse in the waters west of Disko. These birds comprise the entire successful breeding population from the single breeding colony of the species in the Disko Bay region. The breeding population numbers approx. 1,500 pairs, and it has been decreasing over recent decades. The proportion of pairs fledging chicks is unknown but is estimated at approx. 75%, resulting in a chick population of approx. 1,100. These are followed by one of the parent birds. The other parent bird stays at the nesting site for some time after the departure of the chick. This means that a part of the breeding population and the breeding result of a season may be exposed to an oil spill with a drift pattern such as the one in Scenario 6. However, the birds performing this swimming migration are highly dispersed (Figure 33) and most likely only a small number will be exposed to the oil. But the population in this colony is declining and even a small extra mortality particularly on the adult birds may thereby contribute to a further decrease in the breeding population, or at least hamper a recovery. The commercial fisheries for Greenland halibut and deep-sea shrimp will be much more impacted in seasons other than in winter. The main part of the halibut fishery takes place in summer and autumn, and fisheries may be closed for months in order to avoid contamination of catches.

Summary for scenario 7
The impacts of an oil spill in spring from spill location 4 will be most likely be low to moderate if the oil moves as indicated by the DMI oil spill model. They will be low because the oil never reaches coasts and

only few individuals of birds and mammals will be exposed to the oil. However, effects on narwhals, white whales and walrus are unknown, and effects under the ice and in the marginal ice zone may also have the potential to cause effects on polar cods and other ice fauna.

10 Mitigation of risk of oil spill impacts

Risk of oil spills and their potential impact can be minimised with high HSE standards, BAT, BEP and a high level of oil spill response. An important tool in oil spill response planning and implementation is oil spill sensitivity mapping (see below). A supplementary way to mitigate the potential impact on animal populations sensitive to oil spills, e.g. seabirds, is to try to manage populations by regulation of other population pressures so that they are fitter and better able to compensate for extra mortality due to an oil spill (see Figure 50).

10.1 Information campaigns

Before activities are initiated, information on the local society both on a regional and local scale is very important. In the context of mitigating impacts, information on activities potentially causing disturbance should be communicated to e.g. local authorities and hunters' organisations which may be impacted, for example, by the displacement of important quarry species. Such information may help hunters and fishermen to plan their activities accordingly.

11 Oil spill sensitivity mapping

Two oil spill sensitivity atlases which together cover the coastal and offshore parts of the assessment area have been issued by NERI. One covers the region between 62° and 68° N (Mosbech et al 2000) and the other 68°-72° N (Mosbech et al. 2004). They integrate all available knowledge on coastal morphology, biology, resource use and archaeology; and classify coastal segments of approx. 50 km lengths according to their sensitivity to marine oil spills. This classification is shown on map sheets, and other map sheets show coast types, logistics and proposed oil spill countermeasure methods. Included are also extensive descriptions of ice conditions, climate and oceanography. The atlases are available on the following website: Link.

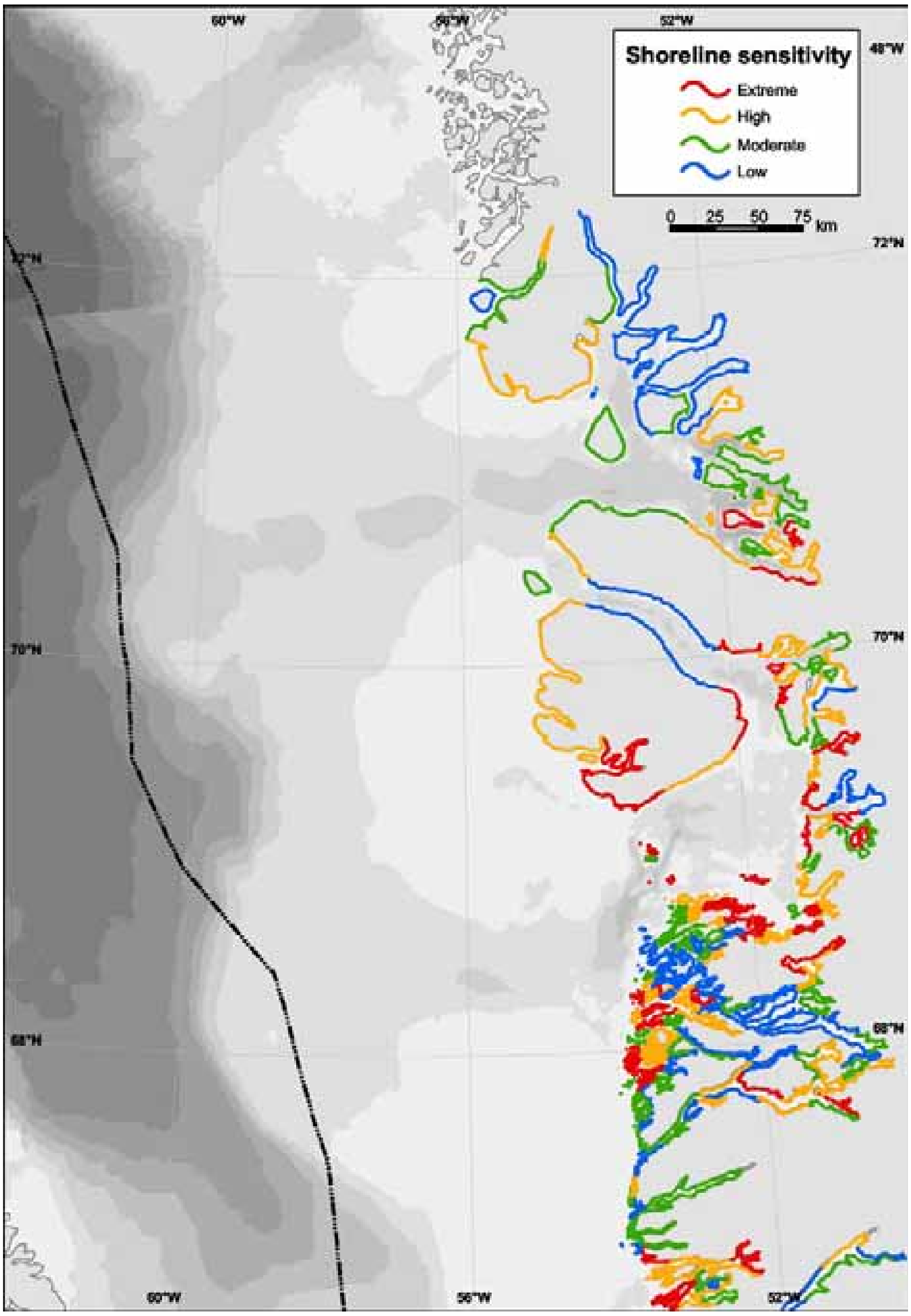
In relation to this assessment the classification of the offshore areas is particularly relevant and this has been updated with the newest available data (Figure 55). The offshore areas were defined on the basis of a cluster analysis in order to obtain ecologically meaningful areas and the four seasons were calculated separately. The cluster analysis included twelve variables: air temperature, air pressure, sea surface temperature (2 different measurements), temperature at 30 m depth, salinity at surface and at 30 m depth, wind speed, ice coverage, sea depth, slope of seabed and distance to coast (for details see Mosbech et al. 2004).

The environmental oil spill sensitivity atlases have been prepared to provide oil spill response planners and those involved in response activities with tools to identify resources at risk, establish protection priorities and identify appropriate response and clean-up strategies.

The atlases are designed for planning, prioritisation and implementation of year-round oil spill countermeasures in both coastal and offshore areas in West Greenland. An important component of the atlases is a sensitivity ranking system which is used to calculate an index value describing the relative sensitivity of coastal and offshore areas. The sensitivity index value is calculated based on information on resource use (human use), biological occurrences, and physical environment.

Summary maps of both coastal and offshore sensitivity are presented here as Figures 54 and 55.

Figure 54. Environmental oil spill sensitivity of coast lines in the assessment area. The coasts north of 72° N have not been classified. From the oil spill sensitivity atlases issued by NERI (Mosbech et al. 2000, 2004).



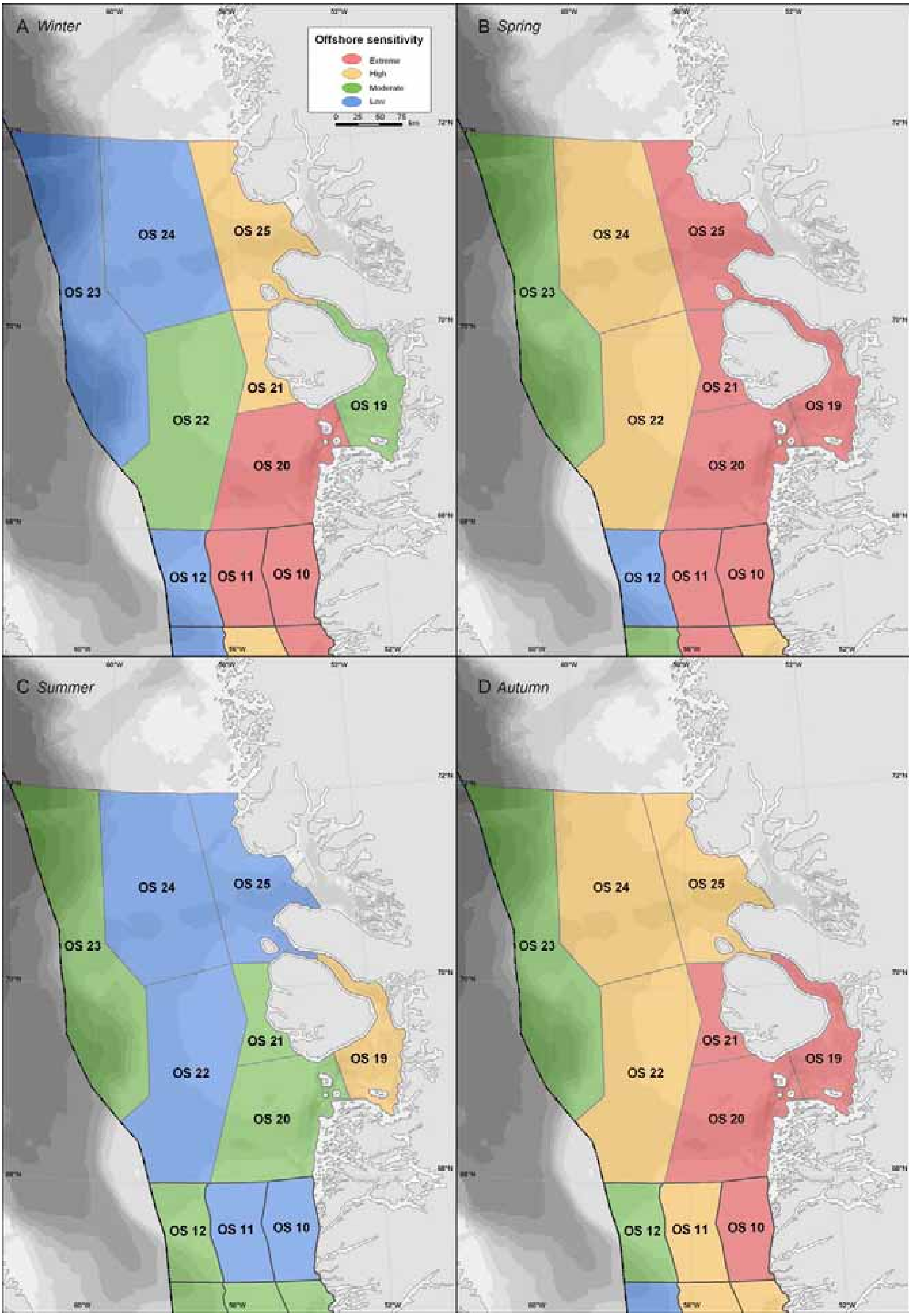


Figure 55. The environmental oil spill sensitivity of the offshore areas of the assessment area. The waters north of 72° N have not been classified. Updated with new information since the oil spill sensitivity atlases issued by NERI in 2000 and 2004 (Mosbech et al. 2000, 2004).

11.1 A new offshore oil spill sensitivity classification

In the environmental oil spill sensitivity atlases for West Greenland (Mosbech et al. 2000, 2004) sensitivity was calculated for the offshore areas for the four seasons winter (January-March), spring (April-May), summer (June-August) and autumn (September-December). As a part of this assessment new information has been obtained, explaining why a new and updated description of each of the offshore areas for each season is given here. Resources which are affiliated to the coastal segments are not included, e.g. capelin and lumpsucker fisheries and seabird breeding colonies. The inner part of Uummannaq Fjord, offshore area 26, has been omitted as it generally includes inshore and coastal waters, where it is more convenient to apply the shoreline sensitivity classification. Figure 56 shows the frequency of the four sensitivity classes in the four seasons. The apparent relatively higher oil spill sensitivity in spring and autumn is mainly caused by the presence of migrating populations of seabirds and marine mammals which pass in high numbers through and stage for some time in the assessment area.

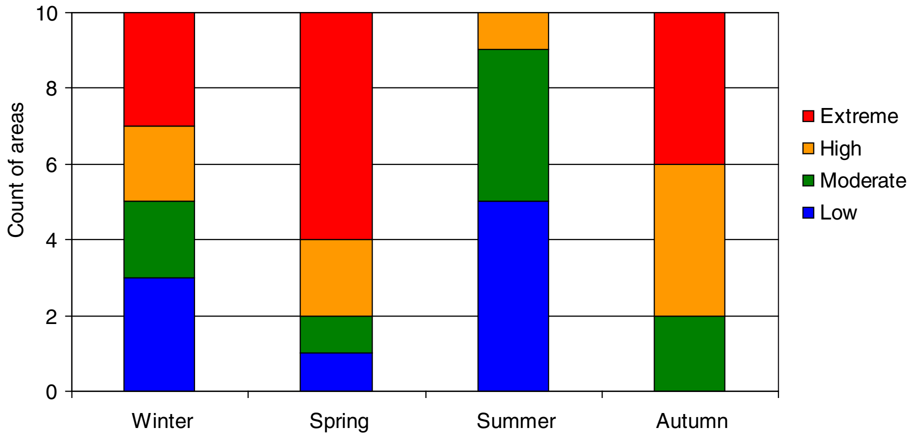


Figure 56. Frequency distribution of oil spill sensitivity values by season for the offshore areas. The oil spill sensitivity classes are relative and the classification levels have been defined to illustrate differences between areas and seasons during the year.

Offshore area 10

This area is situated on the north-eastern part of Store Hellefiskebanke and has relatively shallow waters. In the northeasternmost corner of the area, a deepwater wedge is found between the bank and the coast, and upwelling phenomena are significant here (Figure 3). In winter the coastal waters are more or less free of ice, while drift ice is frequent in January to May further offshore. The marginal ice zone will often be situated in this offshore area in April (depending on the amount of ice and wind conditions) and primary production is expected to be high in the period. The area has an extreme sensitivity to oil spills in winter, spring and autumn, while in summer the sensitivity is assessed as low. In winter and spring the area is important for wintering and migrating seabirds particularly the king eider for which a new survey indicates that 400,000 birds were present in April 2006. Earlier surveys have given results in the same order of magnitude. This figure indicates that almost the entire flyway population of king eiders (wintering in West Greenland) occurs here during specific times of the year. White whales winter here in important concentrations and bowhead whales occur at least from February. A very important walrus winter habitat is shared between this area and offshore area 11. At least 370 animals were present in April 2006. These walruses probably arrive in autumn from the Canadian side of the Davis Strait. From May, minke whales, humpback whales and fin whales arrive from the south and stay until October. Polar bears occur, but are not common when ice is present.

In autumn large numbers of seabirds arrive from the north – thick-billed murres, king eiders and common eiders are the most important – and later, in November, the winter whales (narwhal and white whale) also arrive from the north.

Resource use is limited to the deep-sea shrimp fishery which takes place in the northeastern part of the area in the deep-water wedge. Hunting for walrus, white whale, minke whale and fin whale also takes place.

Offshore area 11

This area covers the northwestern part of Store Hellefiskebanke inclusive the slope (shelf break). The area is usually covered by drift ice in January-May. Particularly along the slope, significant upwelling events occur which nourish primary production throughout the summer (Figures 3 and 4). The area is very similar to area 10 with respect to the oil spill sensitivity. In both winter and spring the area is assessed as being extremely sensitive to oil spills, while in summer sensitivity is expected to be low and in autumn it is classified as high (Figure 55). The occurrence of winter ice, seabirds and marine mammals resembles the occurrence in area 10, although the waters are generally too deep for the king eiders. The walruses which occur here in winter and spring are shared with offshore area 10.

Resource use is limited to the deep-sea shrimp fishery which takes place along the outer slope of the fishing bank and to hunting for walrus, white whale, minke whale and fin whale.

Offshore area 12

This is situated in the deep waters to the west of Store Hellefiskebanke. The area is usually covered by drift ice in January-May. The sensitivity to oil spills is assessed as low in winter and spring and moderate in summer and autumn, because of the relatively dispersed occurrences of birds and mammals and only a limited fishery for deep sea shrimp.

Offshore area 19

This area covers the inner parts of Disko Bay and Vaigat. The sensitivity to oil spills is assessed as moderate in winter – mainly due to the presence of ice. In spring and autumn the sensitivity is extreme, and in summer it is high. The area used to be ice covered in winter from December to May, but in recent years the ice cover, if any, has been restricted and of short duration. The huge glacier Jakobshavn Isbræ is a significant source of fresh meltwater, which contributes to the stratification of the water column and which again enhances the primary production in spring and summer. The southern part is shallow with numerous islands which house many seabird breeding colonies including a very important Arctic tern colony. Other important seabird breeding colonies include one with thick-billed murres and several with thousands of kittiwakes. In spring 2006 the southern part was a significant concentration area for thick-billed murres (Figure 32) and bowhead whales occurred almost throughout the bay. Thick-billed murres with chicks disperse from the breeding colony in late July and swim/drift towards the Davis Strait/Baffin Bay (Figure 33).

Resource use is significant. There are important fisheries for deep-sea shrimp in the area, and the Greenland halibut fishery near Ilulissat is the most important in Greenland (Figures 41 and 42). Snow crabs and scallop are also fished in the area. Seabirds and seals are hunted throughout the area.

Offshore area 20

The area covers the entrance to Disko Bay, the northern part of the shallow Store Hellefiskebanke, the shallow Disko Bank and the deep water between these two banks. This area is assessed as having an extreme sensitivity to oil spills in winter, spring and autumn. Only in summer is it lower and assessed as moderate. This classification is mainly due to the large numbers of staging seabirds outside of summer and the presence of winter whales. Upwelling events are frequent along the northern edge of Store Hellefiskebanke (particularly at the northeastern corner) and at the islands in the Disko Bay entrance (Figures 3 and 4). These sites are important primary production areas also in summer. A part of this area is usually free of ice even in severe winters, facilitating the occurrence of seabirds such as eiders and murres. In winter and spring narwhals, white whales and bowhead whales occur, and particularly bowheads have a concentration area off southwest Disko (Figure 39), and bearded seal occur in high densities in the northern part of Store Hellefiskebanke. Thick-billed murres occurred in large numbers in spring 2006 west and southwest of the entrance of Disko Bay (Figure 32). In summer the waters are utilised by birds from several important seabird breeding colonies on the islands and mainland Disko. In August thick-billed murres arrive with chicks from the breeding site in the Disko Bay (Figure 33). Minke whales, fin whales and humpback whales arrive in spring and stay until October. In autumn large numbers of seabirds arrive from the north, of which thick-billed murres, king eiders and common eiders are the most important, and later, in November, the winter whales (narwhal and white whale) also arrive from the north.

Resource use includes the fisheries for deep-sea shrimp (very important), scallop and snow crab (Figures 41, 43 and 44), and hunting for seabirds and seals in summer and white whales, narwhals and walrus in autumn, winter and spring.

Offshore area 21

This area covers the relatively shallow waters just west of Disko Island. The oil spill sensitivity of this area is assessed as high in the winter, extreme in spring and autumn, and moderate in summer. The relatively low oil spill sensitivity in summer is caused by the low numbers of seabirds and the absence of winter whales.

This area is as a rule covered with ice in winter, although large open waters, cracks and leads form early in the spring. In spring bowhead whales and white whales are frequent and large flocks of common eiders are found in the leads near the coast. Polar bears occur when ice is present.

Resource use includes fisheries for scallop and snow crab (Figures 43 and 44), and hunting for seabirds, seals, minke whales, white whales, narwhals and walrus. In summer large numbers of fulmars breeding in colonies on the coast utilise the waters, and minke, fin and humpback whales are frequent. In autumn seabirds arrive from the north and in particular common eiders are numerous.

Offshore area 22
This area mainly covers the deep waters west of the fishing banks. It is usually covered by drift ice from late December to May. The sensitivity to oil spills is assessed as moderate in winter, high in spring and autumn, and low in summer. In spring high numbers of thick-billed murres arrive from the south heading for breeding sites further north. Narwhals and white whales initiate their movements towards the north in April and May. Polar bears occur when ice is present. In summer the most frequent bird is the fulmar, but in August thick-billed murres with chicks arrive from the breeding colony in Disko Bay. In September many more murres arrive from the north together with little auks.

Resource use includes the fishery for deep-sea shrimp (Figure 43) and occasional hunting for white whales, narwhals and walrus in winter.

Offshore area 23
This area covers the very deep waters adjacent to the border to Canada. It is covered by drift ice from December to May. The oil spill sensitivity is assessed as low in winter, and moderate in spring, summer and autumn (Figure 55). The area is an important winter habitat for narwhals. In spring bowhead whales move through the area on their way to Canadian summer habitats. Polar bears occur when ice is present.

Resource use includes the fisheries for deep-sea shrimp and Greenland halibut (Figures 41 and 42).

Offshore area 24
This area covers the deep waters to the north of the fishing banks. It is covered by drift ice from December to May. Oil spill sensitivity is assessed as low in winter and summer, and as high in spring and autumn (Figure 55). The higher classification in spring and autumn is mainly caused by seasonal movements of seabirds (thick-billed murres, little auks) and whales. Narwhals occur in the area in winter, and in spring both white whales and bowhead whales migrate through on their way to summer habitats in Arctic Canada. Polar bears occur when ice is present. Thick-billed murres move through the area both in spring and autumn.

No resource use is known for the area.

Offshore area 25
This area covers the mouth of Vaigat, the outer parts of Uummannaq Fjord and the shallow waters off Svartenhuk Peninsula. Oil spill sensitivity is assessed as high in winter and autumn, extreme in spring and low in summer (Figure 55). The area is ice covered December-May, with some open waters areas in the Vaigat entrance around Hareø. Upwelling events are significant in the waters near Hareø (Figure 3). In spring, narwhals, white whales and bowhead whales move through the area and seabirds such as thick-billed murrres and common eiders are numerous. In summer the waters are utilised by seabirds breeding in many colonies along the coasts and by minke and fin whales. In autumn narwhals and white whales arrive from the north in October and November

and seabirds move in from the north. Polar bears occur when ice is present.

Resource use includes the fishery for deep-sea shrimp in the Vaigat and around Hareø (important), as well as hunting for narwhal, white whale, seals and seabirds.

12 Recent and further studies

This strategic environmental impact assessment is the result of a co-operation between the BMP and NERI. To support the EIA a number of background studies have been initiated in collaboration with the Greenland Institute of Natural Resources and others. Some of these studies are still in progress and will be terminated in 2007 and 2008. Further studies are expected to be initiated to strengthen the knowledge base for planning, mitigation and regulation of oil activities in the assessment area. The northwest Baffin Bay is considered opened for hydrocarbon activities and another SEIA has to be prepared. Just like the present SEIA, background data are needed and a series of new projects are in the planning phase, some of which represent extensions to the projects from the Disko West Area.

It should be noted that the ecology of the assessment area is dependent on several biophysical factors that manifest themselves in areas outside the area and that a comprehensive assessment of the area in question will require studies and understanding of processes in adjacent areas as well.

NERI is developing a spatial database with relevant environmental data from these background studies as well as other sources. Data include spatial and temporal distribution of key animal species and fishing areas. The data will be made available on DVDs in a Geographic Information System in ArcGIS format in support of the companies' own environmental analyses.

Ongoing and finished projects include:

- Development of hydrodynamic model and oil spill trajectories (Nielsen et al. 2006).
- Identification of productive zones and fish and shrimp larvae key areas (Söderkvist et al. 2006).
- A baseline study of oil concentrations and potential biological response to an anticipated natural oil seep on the coast of Nuussuaq (Mosbech 2007).
- A study of the ecology in the marginal ice zone during spring. Large numbers of birds and marine mammals pass the area during spring migration, and the spring bloom is an important event in the arctic often determining the production capacity of arctic marine food webs. The study will improve the identification of key areas and linkages with lower levels in the food web including areas important for plankton, seabirds and marine mammals. Field work was carried out in April and May 2006, and included ship-based and aircraft-based surveys. From the ships, systematic observations of seabirds and marine mammals were conducted and both physical and biological data were obtained simultaneously at 116 stations along the transect routes. The aerial survey included systematic observations of marine mammals and seabirds (Figures 10, 11 and 12).
- Thick-billed murre swimming migration and colony development at the only murre colony in the area Ritenbenk. The murre chicks leave

the colony before they can fly and embark on a long swimming migration together with one of the parent birds to winter quarters. The routes for this swimming migration have not previously been known. But in 2005 and 2006 10 and 17 breeding murres were equipped with satellite transmitters and their movements tracked (Figure 33).
- Bowhead whale occurrence and behaviour in the assessment area. Based on satellite tracking data and aerial survey data a detailed analysis has been performed describing temporal and spatial distribution, behaviour in the area and the importance of the area for the population (Heide-Jørgensen & Laidre in prep.).
- A study of walrus migration and population delineation. Based on satellite tracking the habitat use of walrus wintering at the banks in the area is studied and the population delineation between Greenland and Canada supported by genetic analysis (preliminary tracking results are included in this assessment). The study continues in spring 2007.
- An analysis of polar bears habitat use and movements in Baffin Bay based on satellite tracking in the years 1991-2001 (included in this assessment).

New projects to be initiated as part of a background study programme for the area north of the Disko West Area include:

- A study of the thick-billed murres autumn migration routes through Baffin Bay by satellite tracking. Perhaps as many as two million thick-billed murres migrate through Baffin Bay in autumn from the large and important breeding colonies in northwest Greenland and northeast Canada. Migration routes and offshore key foraging areas during the autumn migration are unknown. During the first month of the migration most birds are flightless due to moult, and they move southwards by swimming - successful breeders accompanied by the chick which also is flightless. These flightless birds are particularly vulnerable to oil pollution.
- Satellite tracking of white whales to increase knowledge on habitat selection and population delineation.

Further studies proposed for the Disko West area to strengthen the knowlegde base for assessment and regulation include:

- **Baseline study and mapping of benthos and macro algae with focus on the coasts and Store Hellefiskebanke**
  A study of bottom fauna and its linkages to higher trophic levels on the west coast of Disko Island and the shallow areas at Store Hellefiskebanke and the adjacent coasts. Important concentrations of walrus, king eider and common eider feed on this bottom fauna, and along the coast there are spawning grounds for lumpsucker and capelin. If oil from an oil spill settles in the intertidal zone or in shallow water the impact can be substantial, and it is also at the coasts that there is a risk of embedding of oil which leaks slowly, causing a more chronic pollution situation which can also affect higher trophic levels.
- **Acoustic recordings of bowhead whales, other marine mammals and background noise in the Disko Bay**
  A study of marine mammals and background levels of ambient noise in the sea by means of autonomous data loggers deployed under the

ice. The study will focus on increasing the knowledge on distribution and abundance of bowheads in the Disko West area during winter.

- **Further studies of bowhead whale occurrence, biology and sensitivity to hydrocarbon activities**
- **Further satellite tracking studies of polar bears**
  The satellite tracking data used in this assessment was collected from 1991 to 2001 and it seems that the polar bear distribution has changed recently in response to changing ice conditions. It is therefore proposed to conduct new supplementary satellite tracking of polar bears. In particular information is needed on the use by polar bears of the eastern edge of the Baffin Bay/Davis Strait drift ice. Previous tracking studies have been geographically biased because satellite tags were almost exclusively deployed on the western side of Baffin Bay and Davis Strait.
- **Further studies of migration and area use by walruses in western Greenland (GINR)**
- **Further satellite tracking of narwhals to increase knowledge on habitat selection and population delineation**
- **A study of seabird migration and marine ecology in Baffin Bay**
  During autumn large numbers of seabirds migrate from breeding sites on the coasts of northwest Greenland and northeast artic Canada through the Baffin Bay to wintering sites in the sea off southwest Greenland and the sea off Labrador and Newfoundland. The main objective of the study is to get an understanding of the distribution and occurrence of the migrating seabirds in relation to physical and biological oceanography (e.g. ice, depths, up-welling areas and zooplankton (including fish larvae) abundance) and to identify potential offshore ecological hot spots. The study includes remote-sensing data and two types of surveys in southern Baffin Bay:
    - ship-based, sailing east-west between Greenland and Canada, involving simultaneous collection of data on seabirds, marine mammals and biological oceanography (water temperature, salinity, plankton, etc.)
    - aerial surveys of seabirds and marine mammals to obtain data on a regional scale.

  The most important seabird species are: little auk (dovekie), with an estimated breeding population size in northwest Greenland of 35 million pairs, thick-billed murre, with a breeding population in northwest Greenland of 300,000 pairs and in Canada of 400,000 pairs. Several other species move along the same routes but in smaller numbers. One of the most important in a conservation context is the ivory gull. In recent years the Canadian breeding population has shown a severe population decline and it is red listed both globally and in a national context (in Canada and Greenland). These numbers indicate that at least a hundred million (adults and juveniles combined) seabirds move through Baffin Bay and the Davis Strait during September, October and November. Migration routes, concentration areas and important feeding areas in relation to these moving seabirds are unknown, but a substantial fraction of the birds occurs within the Disko West area and in the northwest Baffin Bay. This study has relevance to both the Disko West Area and northwest Baffin Bay.

13 List of report in preparation or issued as a part of the SEIA

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Appendix 1

Oil spill scenarios

The following oil spill scenarios are based on the spills modelled by Danish Meteorological Institute (DMI) in the report "Oil drift and fate modelling at Disko Bay" (Nielsen et al. 2006). The spill simulation periods are selected based on the wind statistics in the model year, so there are spill examples with wind from all directions, as the wind is the most important factor determining the movement and fate of the oil when it is not contained or restrained by ice. This means that some seasons are not covered by the modelling and to get adequate examples from all seasons some of the spill scenarios we describe here are transposed to other seasons to get a more covering picture of the annual variation of the biology of the region.

The spill locations are shown in Figure A1. These are selected based on potential development areas as suggested by Geological Survey of Denmark and Greenland (GEUS). A medium crude oil of type "Statfjord" with a density of 886.3 kg/m^3 was chosen to represent the spilled oil (Nielsen et al. 2006).

Two different spill situations were modelled at each site by the DMI report: A continuous (3000 tons released each day over 10 days, in total 30,000 tons) and an instantaneous spill where 15,000 tons are released, corresponding to the total loss of one or two tanks in a large tanker. The APA (2003) feasibility study indicates that the shuttle tankers which will be used in a future production situation may carry as much as 100,000 tons of oil.

Only surface spills are considered here, but the DMI-report states that the behaviour of subsurface spill is almost identical, as oil will surface quickly from a subsurface blow-out.

The drift-modelling maps from the DMI modelling are used to estimate the drift, coverage and extension of oil spills. These maps show the maximum area affected by of the oil spills modelled for 30 days, and not the maximum area covered at a specific time after the spill.

The described scenarios do not include oil spill recovery. The effects of such actions have been estimated for Southwest Greenland with the best available technology in 1992 and it was found that max. 17- 25% of the oil on the sea surface could be recovered (Ross 1992), mainly due to harsh weather conditions, presence of ice, darkness and reduced visibility.

Impacts are classified as none, low, moderate, and high, or in a few cases – mainly fishery – they have been quantified.

In Table 0.1 the scenarios are summarised.

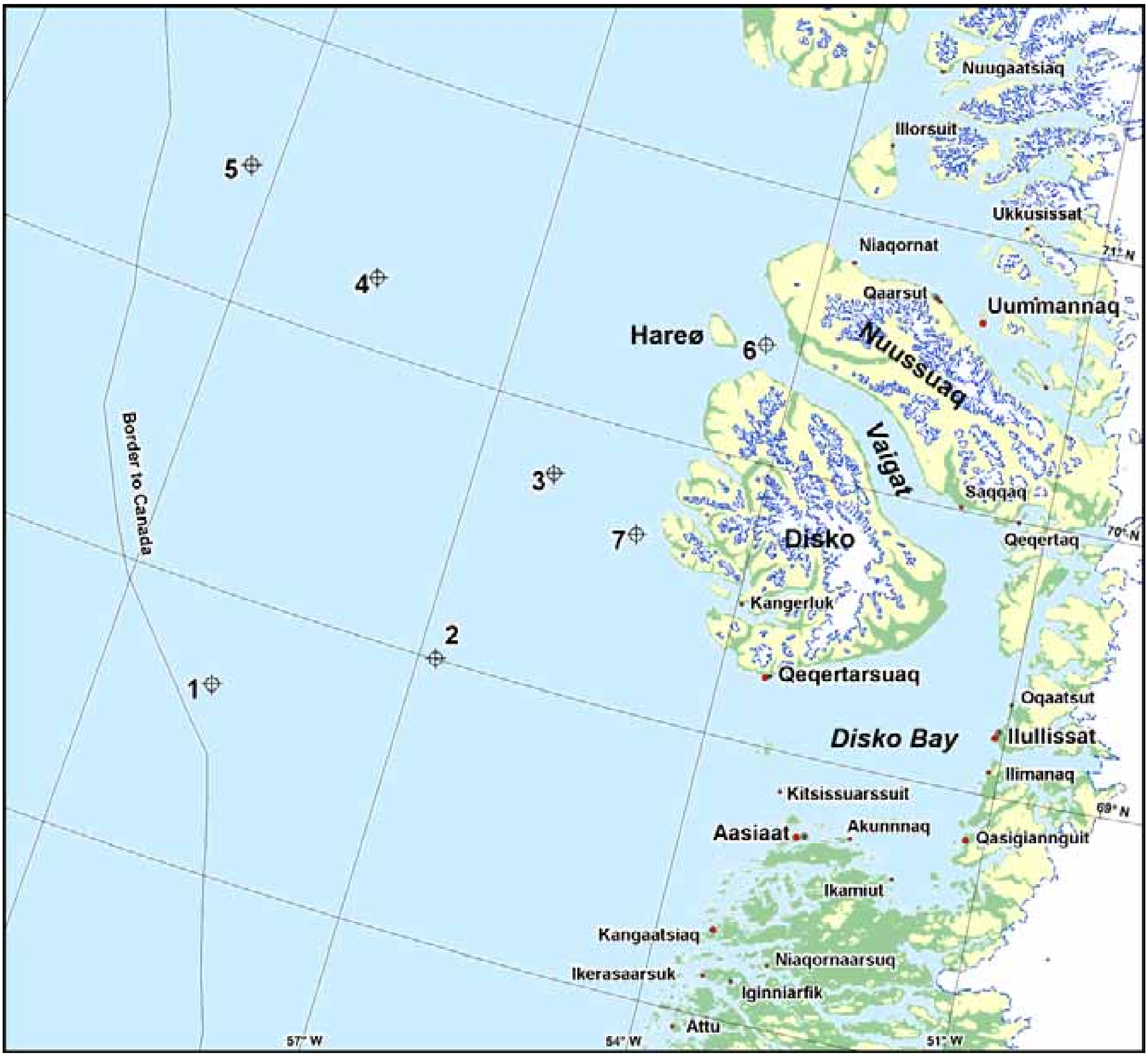

Figure A1. The seven spill locations and towns and settlements in the region.

Table 0.1 The impacts from the seven scenarios and alternative scenarios summarised (see Appendix for details). R = reversible, r = slowly reversible, No = no significant impacts expected. No* = No immediate impacts expected, but impacts possible following spring during ice melt. L = low impacts expected, M = moderate impacts expected, H = high impacts expected, ? = possible.

Scenario	Scenario alternative	Extent sq. km	Duration years	Season	Marine mammals	Birds	Fish	Benthos	Primary prod. plankton	Shorelines	Local use	Commercial use	Long-term effects likely
1		9000	>10	summer	L R	H r	M r	H r	L R	H r	H R	H R	yes
1	alt. drift	13000	>10	summer	L R	H r	L r	H r	L R	H r	H R	H R	yes
1	March alt.	9000	>10	spring	M R	H r	H r	H r	M R	H r	H R	H R	yes
2		1500	>10	autumn	L R	M R	L R	H r	L R	H r	L R	H R	yes
3		22000	1	winter	L R	L R	H? R	No	L R	No	No	L R	
3	Sept. alt.	22000	1	autumn	L R	H R	No	No	L R	No	No	H R	
4		8000	1	winter	M R	L R	H? R	No	No*	No	L R	L R	
4	alt. drift	10000	>5	winter	M R	H R	L R	No	L R	No	L R	L R	yes
5		10000	>10	summer	L R	H r	M R	H r	L R	H r	H R	H R	yes
6		30000	1	winter	M R	L R	H? R	No	No*	No	L R	L R	
6	Aug. alt.	30000	1	autumn	M R	H r	L R	No	L R	No	L R	H R	
7		unknown	1	spring	L R	L-M R	H? R	No	M R	No	L R	L R	

Spill scenario 1

15,000 tons of oil is released instantaneously at spill location 3, 48 km west of Disko Island. Release date is July 7th, and the oil drifts towards east and southeast and hit the coasts of southwest Disko and coasts between Aasiaat and Kangaatsiaq. The geographic extend of the affected sea will be app. 9,000 km^2, and more than 1500 km coastline is exposed for oil settlement.

Resources at risk

Marine mammals: Seals mainly harp seals, and whales: Minke, fin, humpback whales and harbour porpoise.

Seabirds: Breeding colonial species such as gulls, fulmars and alcids (black guillemot, razorbill, Atlantic puffin, little auk), moulting seaducks as common eiders, king eiders and harlequin ducks (Figure 26, in Figure section).

Fish: Arctic char occur in coastal waters and capelin roe and newly hatched larvae are present in the subtidal zone.

Benthos: The benthos has not been studied in the affected areas, but generally the West Greenland coasts have rich and diverse benthos communities.

Primary production and plankton (incl. fish and shrimp egg and larvae): In July the spring bloom is over and high production and plankton concentrations may be found at hydrodynamic discontinuities (Söderkvist et al. 2006). The most conspicuous and predictable hydrodynamic discontinuity in the area affected by the oil spill is the upwelling area at the northeast corner of Store Hellefiskebanke (Figure 3, in Figure section).

Shoreline sensitivity: The shorelines of southwest Disko are classified as having an extreme and high sensitivity to oil spills, and the shorelines south of Aasiaat are classified as having an extreme, high moderate and low sensitivity (Figure 54, in Figure section).

Off shore sensitivity: The affected offshore areas are classified as having a moderate sensitivity to oil spills in the summer period (Figure 55, in Figure section).

Local use: Citizens from the towns of Qeqertarsuaq, Aasiaat and Kangaatsiaq and from the settlements of Kangerluk, Kitsissuarssuit, Niaqornaarsuk, Ikerasaarsuk, Iginniarfik and Attu all use the near shore parts of the affected region for fishing and hunting.

Commercial fisheries: Important fisheries for deep sea shrimp (annual average catch 1995-2004 was 3000 tons) and snow crab (annual average catch 2002-2005 was 750 tons) takes place almost throughout the region swept by the oil spill.

Impacts

Marine mammals: Low and reversible. The oil spill will not have any serious effects on the marine mammal populations, but the occurrence within the affected areas will be lower and marine mammals will probably avoid heavily affected areas.

Seabirds: High and for some species very slowly reversible. The important breeding colonies of Atlantic puffin and razorbill in the outer Disko Bay (Brændevinsskær, Rotten) and along the coast south of Aasiaat will be impacted and a high proportion of the breeding adult birds will be exposed. There is a risk of complete extermination of these colonies. Other breeding birds in the affected area include fulmar, Iceland gull, kittiwake, great cormorant and arctic tern. These populations will also be impacted, but probably to a lower degree than the alcids. A high mortality among the great cormorants is expected, but this population has a high recovery potential. The moulting common eiders along the west coast of Disko will be impacted, but it is difficult to asses the numbers hit and killed by the oil. Particularly sensitive are the moulting harlequin ducks, which occur in dense flocks at some specific off-shore islands (e.g. Brændevinsskæret). These flocks may be exterminated, and they probably represent all the males from the breeding population of a large region of northwest Greenland.

Fish: Medium and probably reversible. Capelin eggs and larvae may be affected in coastal waters and likewise will arctic chars that occur in the affected coastal waters will be exposed.

Benthos: Potentially high. Impacts on coastal benthos communities will probably be an immediate reduction in diversity and a subsequent increase in abundance in opportunistic species. A recovery will depend on the degree of fouling, oil type and local conditions. There is a risk for fouling of the mussel beds, on which wintering and staging eider concentrations depend on.

Primary production and plankton (incl. fish and shrimp egg and larvae): Low and reversible. In general will the extensive vertical and horizontal distribution of plankton preclude high impacts. The most significant upwelling area in the region affected by the oil spill is more than 150 km away from the spill site. Here the layer of the oil on the surface will be less than 10µm thick (Figure A2), which if all is mixed down into the water column below (to 10 meters depth) results in a concentration below the 90 ppb which is the Predicted No Effect Concentration (PNEC) applied in the Barents Sea (Johansen et al. 2003). In localised high concentration areas close to the spill site effects on the primary production and the plankton may occur, but on the broad scale these impacts will be low because of their small geographic extend and the movements of the oil. Therefore impacts on primary production and plankton in general must be assessed as low.

Shorelines: High. Extensive shore lines (estimated to more than 1500 km) risk contamination with oil from this spill, and it is estimated that 30% of the oil will have settled on the coast after 30 days (Nielsen et al. 2006). Some of the coasts of southwest Disko are boulder coasts, where stranded oil may be caught for extensive periods.

Local use: High and reversible. The coastal fishery for Arctic char, blue mussel collection and hunting will be temporarily closed in order to avoid contamination of catches and consumption of contaminated products.

Commercial fisheries: High and reversible. Although the populations of deep sea shrimp and snow crab will not be impacted, the fisheries for these species are at risk. If the fishing grounds swept by the spill are closed for two months (July and August) the in catches will be reduced with 16% for shrimps and 19% for snow crabs based on average annual catches (shrimps: 1995-2005 and crabs 2002-2005).

Long term effects

Oil trapped in boulder coast may be preserved in a relatively fresh state for decades and will slowly be released to the environment causing a local chronic pollution (cf. Prince Williams Sound after the Exxon Valdez incident in 1989).

The recovery potential of the breeding populations of Atlantic puffin and razorbill is low in the affected region, due to decreasing numbers. Affected colonies will probably recover very slowly.

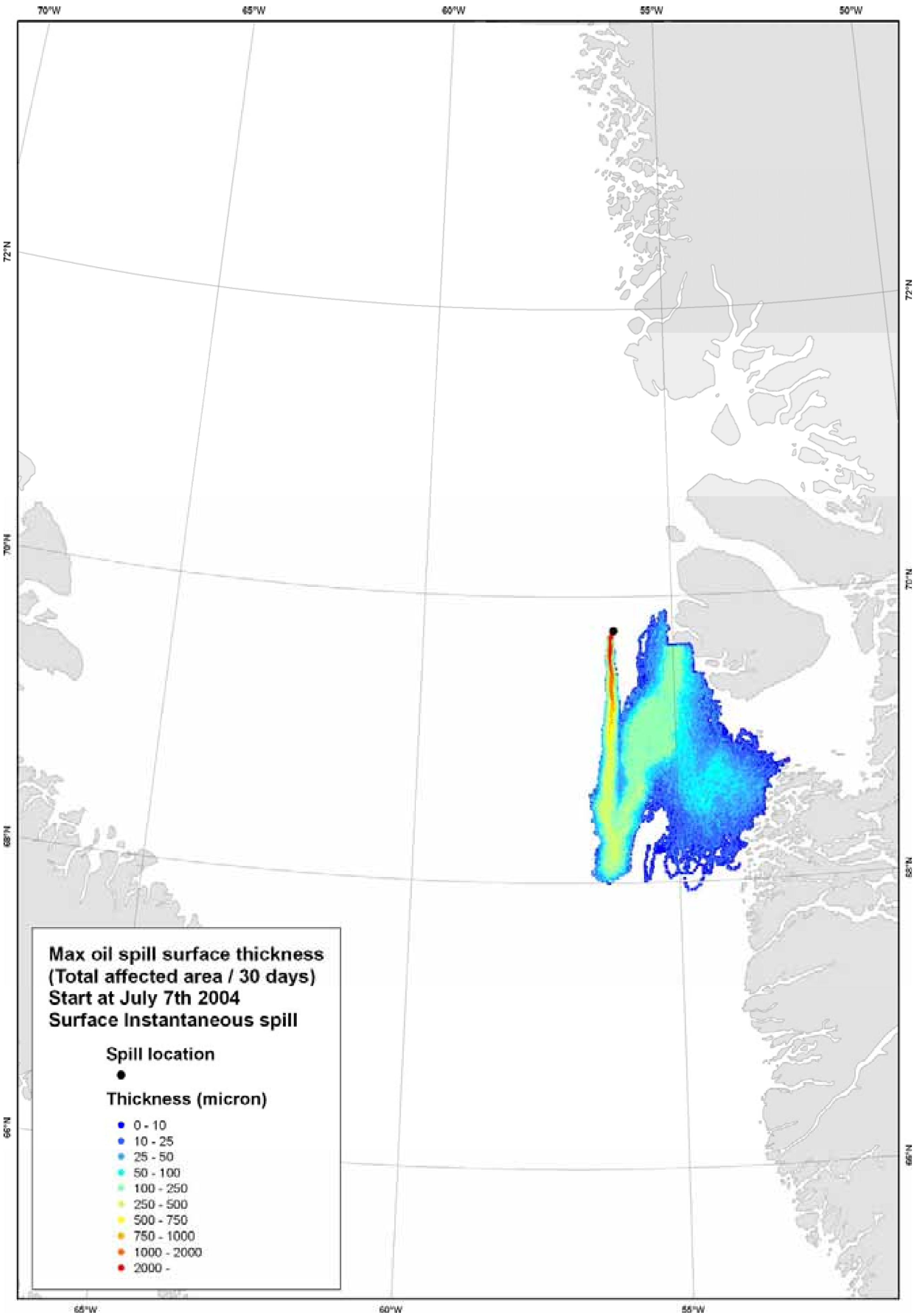

Figure A2. Maximum surface layer thickness and entire area swept by an instantaneous oil spill at location 3 for wind period 1 (starting on July 7th 2004). From the DMI oil spill modelling report (Nielsen at al. 2006).

Summary for scenario 1

The impacts of an oil spill in the summer period from spill location 3 will be high if the oil moves as indicated by the DMI spill drift model (Figure A2). Most of the effects will be reversible, but for some specific coast types and some breeding colonies of seabirds effects probably will be apparent for decades.

Alternative drift pattern

If the oil spill in July is continuous instead of instantaneous, oil will also drift northwards and hit the coasts of northwest Disko and western Nuussuaq peninsula (Figure A3). The region northeast of the spill location is a very important moulting area for king eiders, and large concentrations will be exposed. There is a risk for substantial die-off, with long term effects on the population as the result. Long coast lines of western Disko and Nuussuaq will be contaminated with oil. The northwards drift of oil will also sweep the important deep sea shrimp fishing grounds at Hareø (cf. Scenario 2). The effects of an oil spill with these characteristics will probably be more severe than for the instantaneous spill described in Scenario 1.

Scenario 1 transposed to March

A much more sensitive period in this region is late winter and early spring. If the drift pattern for spilled oil at location 3 is transposed to March the risk of high impacts is much higher than in summer. This is due to the presence of large concentrations of wintering and migrating seabirds, mainly common and king eiders and Thick-billed murres, to the presence of wintering marine mammals as Bowhead whales, narwhals, white whales and walrus, to the longer coast lines (>1800 km) hit by the oil and because the oil may be trapped in bays and coasts where lumpsucker and capelin spawn (and are fished) in the spring. However, ice will also limit the spreading of oil both by ice floes offshore and by land fast ice at the coast. Finally, the primary production spring bloom start in this period and the marginal ice zone is particularly sensitive in this respect. There is a risk for oil accumulation in this zone over long distances (particularly if the oil spill move as in Figure A3), with risk for impacts on both primary production and plankton. If the oil is spread over large areas as predicted (Figure A3), the amount per square unit will be low (a sheen or dispersed pieces of mousse) and therefore also the subsurface concentration will be low reducing the risk for impacts on both primary production and plankton.

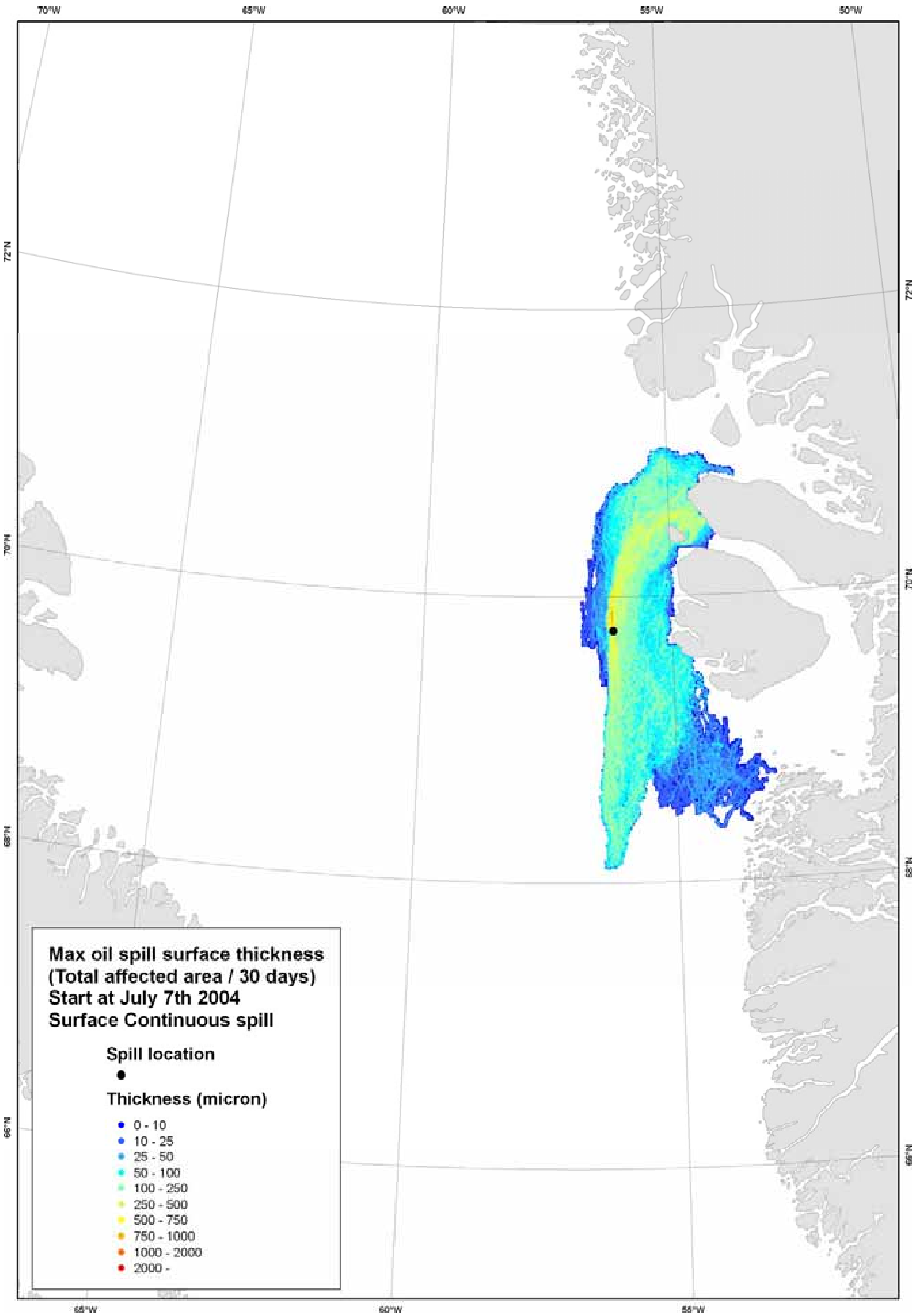

Figure A3. Maximum surface layer thickness and entire area swept by a continuous oil spill at location 3 for wind period 1. From the DMI oil spill modelling report (Nielsen at al. 2006).

Spill scenario 2

15,000 tons of oil is released instantaneously at spill site 6 in the mouth of Vaigat 11 km east of Hareø. Release date is August 13th and almost all oil settle quickly after the spill on the coasts of outer Vaigat and Hareø. The DMI model indicates that 67% of the oil is settled on the coast after 10 days and 100% after 30 days. The spill will affect app. 1500 km^2 sea surface and app. 150 km coastlines will probably be fouled with oil.

Resources at risk

Marine mammals: Harp seals and different whales occur in the area.

Seabirds: Several small seabird breeding colonies are found on the coast of Vaigat and Hareø. The most important is a kittiwake colony on the north coast of Disko Island where app. 100 pairs nested in 1994. At the time of the spill most of the breeding seabirds have fledged chicks and have left the area, and only small numbers will be exposed to the oil. Thick-billed murres on swimming migration pass through the Vaigat from late July and the major part is assessed to have passed through the spill site at the time of the spill (Figure 33, in Figure section).

Fish: Arctic char occur along the coast.

Benthos: The benthos communities have not been studied in the affected areas, but generally have the West Greenland coast rich and diverse benthos communities.

Primary production and plankton (incl. fish and shrimp egg and larvae): There are some significant upwelling areas at Hareø, and these will be impacted by the oil spill.

Shoreline sensitivity: Most of the affected shore lines of Vaigat are classified as having high sensitivity to oil spills. The shore lines of Hareø are classified as having moderate sensitivity (Figure 54, in Figure section).

Off-shore sensitivity: The outer Vaigat is classified as having low sensitivity to oil spills in August, increasing to high in September (Figure 54, in Figure section).

Local use: Citizens from the town of Qeqertarsuaq and from the settlements of Kangerluk, Qeqertaq and Saqqaq probably use the affected area for fishing and hunting, but to a limited degree, because of the long distances.

Commercial fisheries: Deep sea shrimp and snow crab are fished in the affected area, and particularly the shrimp fishery is important with annual average catches (1995-2004) of 11,000 tons, while the crab fishery landed 30 tons a year in 2002-2005.

Impacts

Marine mammals: Low, due to the limited spatial distribution of the spill and the probably low numbers of individuals present in the area.

Seabirds: Moderate, as most of the breeding birds have left the breeding sites, and the majority of the Thick-billed murres from the breeding colony in inner Disko bay have passed through the Vaigat.

Fish: Low, due to the small spatial distribution of the spill.

Benthos: Potentially high. Impacts on coastal benthos communities will probably be an immediate reduction in diversity and a subsequent increase in abundance in opportunistic species. A recovery will depend on the degree of fouling, oil type and local conditions.

Primary production and plankton (incl. fish and shrimp egg and larvae): Probably low. Upwelling areas at Hareø will be affected by the spill, but due to their restricted spatial extend effects will probably be local and not significant on larger scale.

Shorelines: High, as the shorelines adjacent to the spill location will be heavily contaminated, and cleaning operations are probably extremely difficult.

Local use: Low, due to the long distance from towns and settlements.

Commercial use: High. If the fishery for deep sea shrimp and snow crab will be closed for two months, due to the contamination risk of catches, the catches of shrimp will be reduced with 17% and the catches of snow crab with 43% (based on annual average catches in respectively 1995-2004 and 2002-2005).

Long term effects

Oil caught in boulder beaches may be preserved and slowly released to the environment.

Summary for scenario 2

The impacts of an oil spill in the early autumn period from spill location 6 will be low to moderate and the spatial extend will restricted, if the oil moves as predicted by the DMI oil spill drift model (Figure A4). This is due to the limited extend of the spill and because most of the oil settle on the shores within a short period. The most sensitive seabird occurrences have left the area and the most significant effects will be the closure of the shrimp fisheries in the waters around Hareø and heavy contamination of the shoreline habitats. There is a risk for long term effects from stranded and preserved oil in boulder beaches.

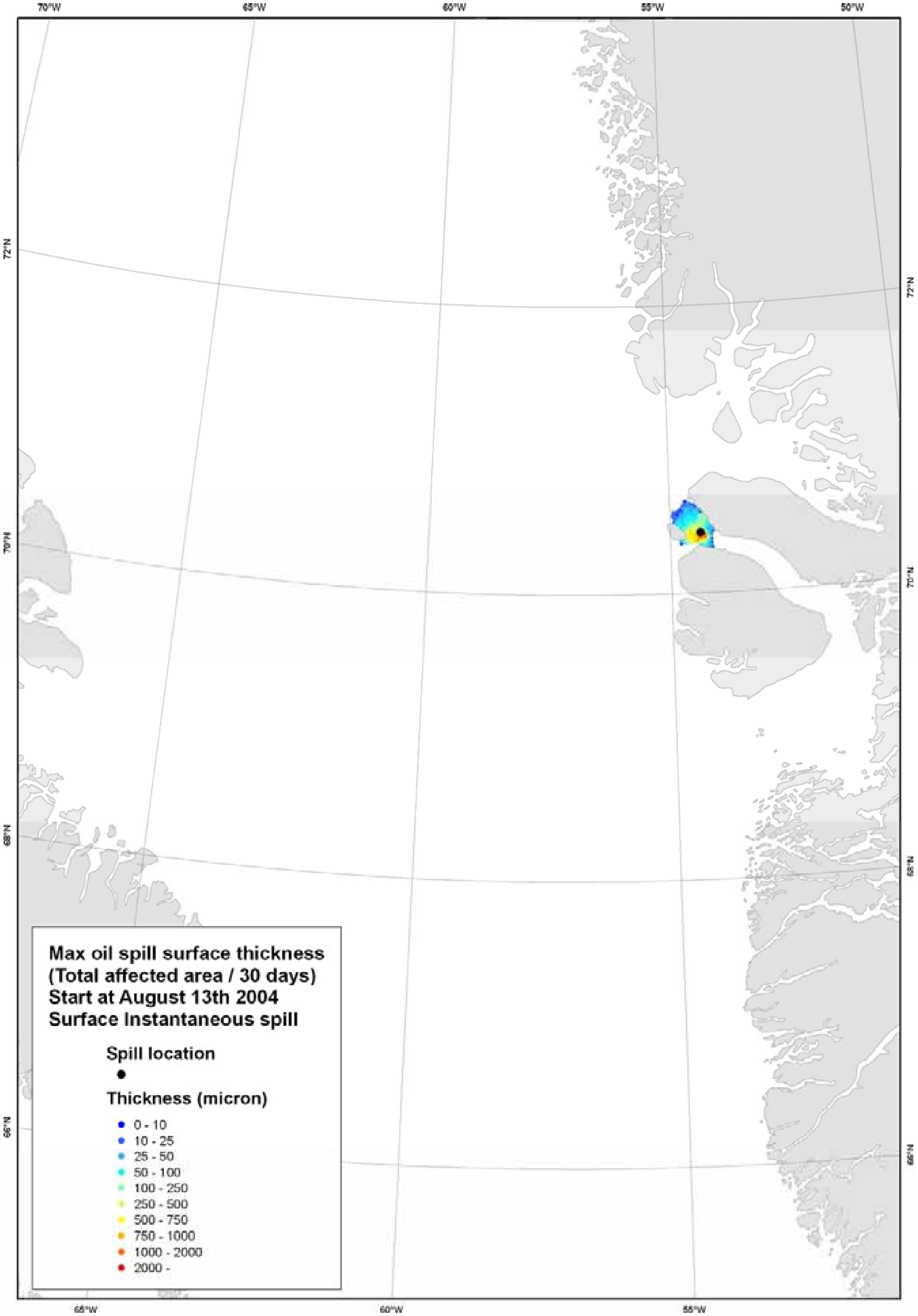

Figure A4. Maximum surface layer thickness for an instantaneous and entire area swept by an oil spill at location 6 for wind period 2 (starting on Aug. 13th 2004). From the DMI oil spill modelling report (Nielsen at al. 2006).

Spill scenario 3

30,000 tons of oil is released continuously from a production site at site 5, 194 km west of Hareø and 36 km east of the Canadian border. Release date is Nov. 16th, and the oil drift towards north, east and south (Figure A5). The oil will enter Canadian waters and will not hit the coasts. The spill occurs when sea ice in Baffin Bay starts to form and there is a risk of entrapment of large amounts in the ice for later release during melt in spring. The affected area covers app. 22,000 km^2 if ice does not prevent the spreading of oil.

Resources at risk

Marine mammals: The affected area is an important winter habitat for narwhals, which arrive from October; most other marine mammals have left the affected area for the winter. Polar bears also occur, when ice is present and usually in late winter.

Seabirds: Substantial numbers of thick-billed murres and little auks migrate through the affected area during the autumn; however, most birds probably have passed through by mid-November. Fulmars also occur, but due to the late season probably in low numbers.

Fish: The most likely fish at risk in this region is polar cods living in the ice habitats. It is an ecological key species, being very numerous and constituting an important prey for whales, seals and seabirds. The spawning period is winter and the eggs float under the ice. There is however, no information on the occurrence of this species in the affected area.

Benthos: The waters of the affected area are too deep for oil spill impacts on the benthos.

Primary production and plankton (incl. fish and shrimp egg and larvae): In winter there are low concentrations of plankton in the upper water columns and there is no primary production.

Shoreline sensitivity: The spill never reaches coasts.

Off shore sensitivity: In November the Greenland part of the affected area is classified as having moderate oil spill sensitivity and in December a low sensitivity (Figure 55, in Figure section).

Local use: There are no local use activities in the affected area due to the long distances from the coasts.

Commercial use: Greenland halibut is fished in the affected area, but this fishery have until now been carried out in the period July-October.

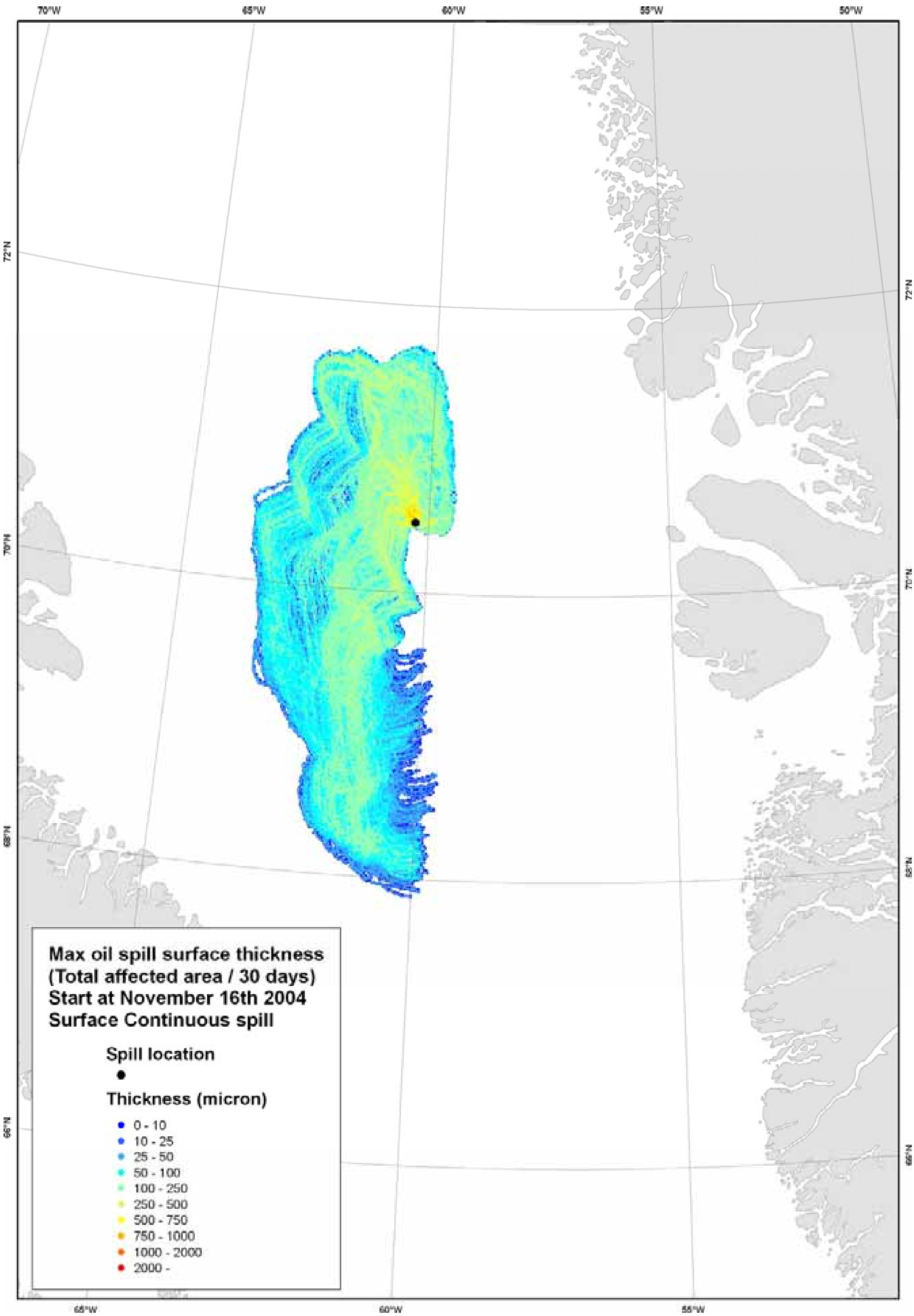

Figure A5. Maximum surface layer thickness and entire area swept by a continuous oil spill at location 5 for wind period 3 (starting at Nov. 16th 2004). From the DMI oil spill modelling report (Nielsen at al. 2006).

Impacts

Marine mammals: Probably low and reversible, but there is concern particularly for narwhals. They are dependent on open waters for breathing. Discrete narwhal populations apparently winter in restricted areas where the number of breathing sites in cracks and lead in the dense drift ice can be few. If all these are covered with oil, whales are forced to inhale oil vapours when surfacing. The effects of this impact are unknown, but both lethal and sublethal effects cannot be excluded. Polar bear occurs in low densities, and some may be fouled with oil and subsequently die, but most likely in such small numbers that the population will not be affected.

Seabirds: Low impacts as most birds have left the affected area.

Fish: High impacts are possible, if the oil spread under the ice and if there are large stocks of spawning polar cod in the area. These may be impacted, particularly if the oil spill coincides with the spawning (occur in winter) and egg period, as both eggs and oil tend to accumulate under the ice. However, if the oil is released under ice, the affected area will be much more restricted than in Figure A5, because the roughness of the ice prevents spreading.

Benthos: No impacts likely, as the oil spill stay in deep waters.

Primary production and plankton (incl. fish and shrimp egg and larvae): Low and reversible, due to the season. However oil may become entrapped in the winter ice, and later released during spring melt. This may affect the primary production in the marginal ice zone far from the spill site, and oil may also be released at much more sensitive areas far from the spill location.

Shorelines: No impacts.

Local use: No impacts.

Commercial use: Low. The spill sweeps the off shore fishing grounds for Greenland halibut, and the fishery will be closed for November and perhaps again in May (oil released from the melting sea ice), in order to avoid contamination of catches. However, fishery is not possible in periods with ice cover, and the fishery has until now taken place in the period July-October, why effects of a closure period will be negligible.

Long term effects:

Probably none. But an increased mortality on discrete narwhal populations may have a long term effect as Greenland narwhal populations suffer from unsustainable harvest and are decreasing in numbers.

Summary for scenario 3

The impacts of an oil spill in the early winter period from spill location 6 will be low if the oil moves as predicted by the DMI oil spill drift model (Figure A5). They will be so, mainly due to the far distances to coasts and to the season. However there is a risk of preservation, transportation and spring release of oil in much more sensitive areas such as the ice edge zone, and there is also a risk of long term impacts on narwhal populations.

Scenario 3 transposed to September

Other seasons in the affected area are much more sensitive than the early winter. In the autumn period, September and October, huge numbers of seabirds – mainly little auks and thick-billed murres move from breeding sites in North Greenland and Canada through Baffin Bay. As many as 100 million birds may perform this migration. Routes and concentrations areas along routes are not known, but such sites may be highly sensitive to oil spills, where substantial numbers of birds may be affected. Ivory gulls from the Arctic Canadian and northwest Greenland breeding populations may also perform an autumn migration through this region. Ivory gull are not as sensitive to oil spills as alcids, but the concerned populations are severely decreasing and extra mortality on particularly adult birds may enhance this trend.

The Greenland halibut fishery takes place in the period July-October, and a two month closure of the fishery in this period will have a strong effect on the landed catches. It is however not possible to estimate the reduction as the catch data are reported for 3 months periods.

Spill scenario 4

15,000 tons of oil is released instantaneously at spill site 2, 103 km southwest of Disko Island. Release date is January 3rd, and the oil drift towards north and south, and will not hit the coast (Figure A6). However, the model does not account for the presence of sea ice, which is abundant at this time of the year. If the oil is released under ice, the oil may be trapped and transported for long distances and released far from the spill location when the ice melts in spring. Ice edges close to the spill location in open waters will also prevent spreading and will accumulate oil. The spill will affect app. 8,000 km^2 if ice does not prevent the spreading.

Resources at risk

Marine mammals: The spill area is habitat for wintering narwhals and probably also for bowhead whales. The southern part of the affected area is also a very important winter habitat for walrus and bearded seal. When ice is present polar bears also occur.

Seabirds: Very few birds are present in the affected area during the winter, even if ice is absent. But the spill will approach a very important winter habitat for king eiders, where more than 400,000 birds representing almost the total flyway population may be present.

Fish: Possible polar cods in the ice habitats cf. Scenario 3.

Benthos: The waters of the affected area are too deep for oil spill impacts on the benthos.

Primary production and plankton (incl. fish and shrimp egg and larvae): None, at this time of the year.

Shoreline sensitivity: None, the oil will never settle on the coasts.

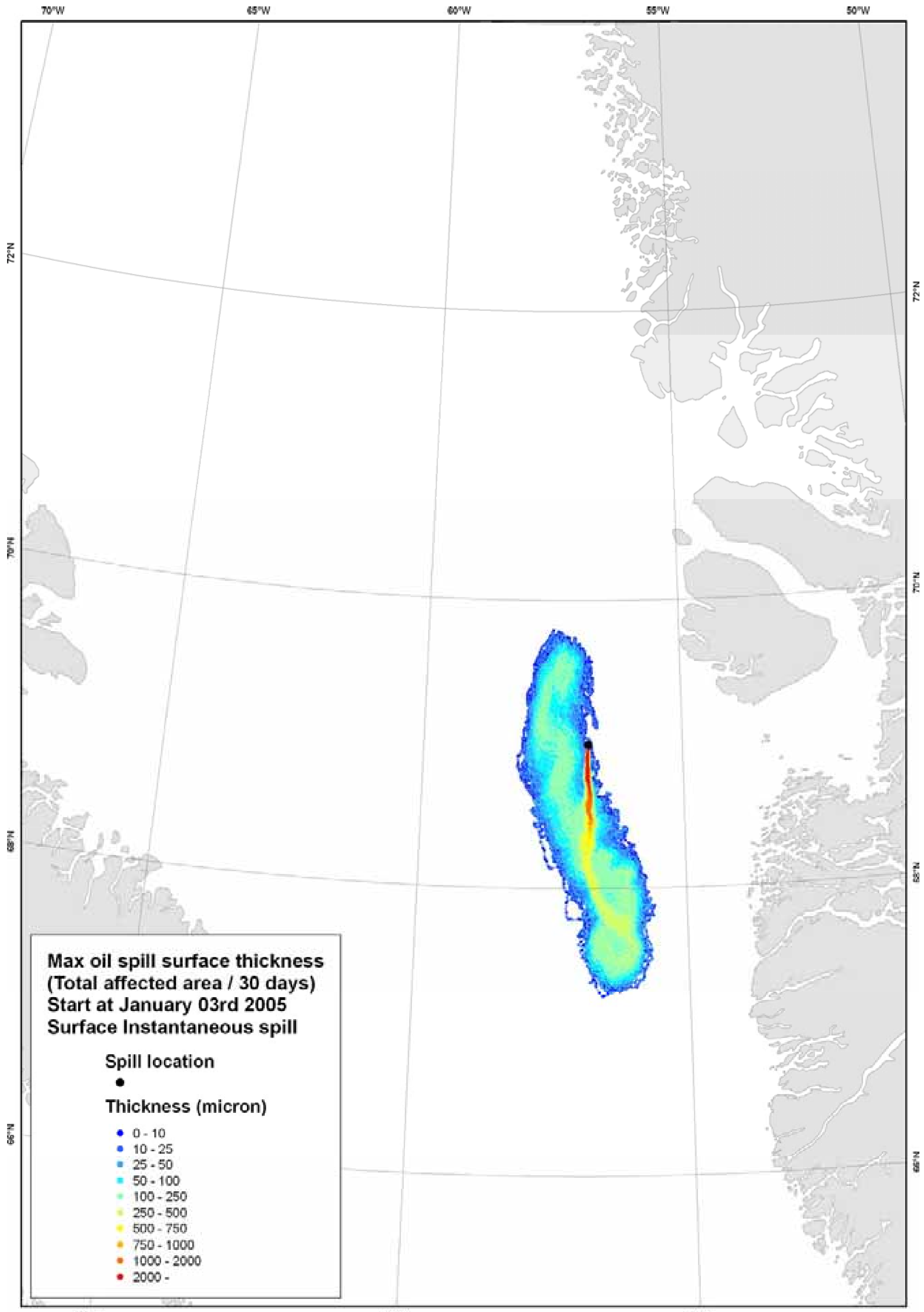

Figure A6. Maximum surface layer thickness and entire area swept by an instantaneous oil spill at location 2 for wind period 4 (starting at Jan. 3rd 2005). From the DMI oil spill modelling report (Nielsen at al. 2006).

Off shore sensitivity: The affected areas are classified as having a low sensitivity to oil spills in winter (Figure 55, in Figure section).

Local use: Hunters primarily from Sisimiut, Attu, Aasiaat and Qeqertarsuaq hunt walrus in late winter in the affected area.

Commercial use: Important deep sea shrimp fisheries takes place in the affected area. The annual average catch in the area was in 1995-2004 app. 5000 tons. However, in winter the fishery effort is relatively low due to the presence of sea ice.

Impacts

Marine mammals: Probably moderate. Oil spill impacts on narwhal populations are unknown, cf. Scenario 3. Polar bears will also be exposed, but only few bears occur in the area and increased mortality among these will not affect the population as a whole. A very important winter habitat for walrus will be affected by the oil. In spring 2006, app. 400 walruses were estimated to stay on the ice in the region here (correcting for individuals in the water will perhaps double this figure). How these will respond to an oil spill is unknown. This population is subject to unsustainable hunting and their numbers are decreasing, why an oil spill may enhance this trend.

Seabirds: Low, due to the absence of seabirds. But if the oil moves along a slightly more south-easterly course a very important king eider habitat will be threatened, where high impacts are likely. A significant proportion of the population will be exposed to the oil and the recovery of a substantial die-off will probably take many years.

Fish: If the oil is released under ice with large numbers of spawning polar cod, high impacts are possible cf. Scenario 3.

Benthos: No impacts.

Primary production and plankton (incl. fish and shrimp egg and larvae): No impacts in winter, but there is a risk of impacts in spring if oil is transported and released during melt at the ice edge zone.

Shorelines: No impacts, as the spill never settles on the coast.

Local use: Low impacts, which mainly will be a closure of the walrus hunting to avoid catches of contaminated animals.

Commercial fisheries: Low impacts, due to the low fishery effort when ice is present. A closure of the fishery in January and February means an average reduction in landings of 0.5%. However if May also is closed due to release of oil from melting ice, the reduction in catches will increase to 13% in the area swept by the oil spill (based on annual average catches 1995-2004).

Long term effects

Probably none, but narwhal populations may suffer from long term impacts cf. Scenario 3. Effects on the walrus population cannot be excluded.

Summary for scenario 4

The impacts of an oil spill in mid-winter from spill location 6 will probably be low to moderate if the oil moves as predicted by the DMI oil spill model (Figure A6, in Figure section). They will be so, due to the season and the distance to the coasts. However, as impacts on marine mammals wintering in the affected area is not known there is a risk for more severe impacts. A slightly different trajectory of the spill will also increase the impact level to high, as this will affect the most important winter habitat for king eiders in Greenland, where almost the entire winter population often occur in the limited open water areas.

Spill scenario 5

15,000 tons of oil is released instantaneously at spill site 7, 10 km off the west coast of Disko Island. Release date is June 10th, and the oil drift towards south and east into the Disko Bay all the way to Ilulissat. App. 10,000 km^2 will be affected by the spill. Oil settles on the south and east coast of the bay and on the southwest coast of Disko and more than 1200 km coastline is exposed to the spill.

Resources at risk

Marine mammals: Minke, fin and humpback whales, harbour porpoises and seals, mainly harp seals.

Seabirds: Colonial breeding seabirds on the coast of Disko Island and on the many islands in Disko Bay. Particularly species at risk are great cormorants, Arctic terns, Atlantic puffins, little auks, razorbills, fulmars and Iceland gulls. The oil spill will not reach the breeding colony for Thick-billed murres at Ritenbenk in inner Disko Bay, but will probably affect feeding areas for birds from this colony.

Fish: Capelin spawning along the coasts peak in mid June and lump-sucker spawning still occur in late June.

Benthos: The benthos communities have not been studied in the affected areas, but generally have the West Greenland coast rich and diverse benthos communities.

Primary production and plankton (incl. fish and shrimp egg and larvae): In July the spring bloom is over and high production and plankton concentrations may be found at hydrodynamic discontinuities (Söderkvist et al. 2006). The most conspicuous and predictable hydrodynamic discontinuity in the area affected by the oil spill are the upwelling area at the northeast corner of Store Hellefiskebanke some smaller upwelling areas in outer Disko Bay and off the mouth of the glacier fjord at Ilulissat.

Shoreline sensitivity: Most of the coastlines of the affected area are classified as having an extreme and high sensitivity to oil spills (Figure 55, in Figure section).

Off shore sensitivity: The affected off shore areas are classified as having a high sensitivity (inner parts of the bay) and moderate sensitivity (outer parts of the bay) to oil spills in summer (Figure 55, in Figure section).

Local use: Citizens from the towns of Qeqertarsuaq, Aasiaat, Kangaatsiaq, Qasigiannguit and Ilulissat and from the settlements of Kangerluk, Kitsissuarsuit, Niaqornaarsuk, Ikerasaarsuk, Iginniarfik, Akunnaq, Ikamiut and Ilimanaq use the affected area for hunting and fishing.

Commercial use: Important fisheries for Greenland halibut off Ilulissat (annual catch in 2001 5500 tons) and for deep sea shrimp (average annual catch 1995-2004 were app. 6000 tons) and snow crab (annual average catches 2002-2005 were 550 tons) in the Disko Bay.

Impacts

Marine mammals: Low, as no important concentrations areas are known and because seals and whales generally are little vulnerable oil spills.

Seabirds: High, as many breeding colonies will be affected and particularly the breeding sites for Atlantic puffin, razorbill and little auk are sensitive (cf. Scenario 1). The breeding population of Thick-billed murres will also be affected if the feeding areas are contaminated.

Fish: Moderate, as Arctic char may be forced to migrate through contaminated coastal waters.

Benthos: Potentially high. Impacts on coastal benthos communities will probably be an immediate reduction in diversity and a subsequent increase in abundance in opportunistic species. A recovery will depend on the degree of fouling, oil type and local conditions. There is a risk for fouling of mussel beds.

Primary production and plankton (incl. fish and shrimp egg and larvae): Low and reversible. The spill occurs after the spring bloom, and generally is plankton widely dispersed both horizontally and vertically. The most significant primary production areas in the region affected by the oil spill are more than 130 km away from the spill site. This means that the oil is old and more or less weathered (less toxic), dispersed and very thin (less than 10 µm) resulting in very low concentrations (less than 90 ppb) in the upper water column when it hit the high-production areas (cf. Scenario 1). Therefore impacts on primary production and plankton must be assessed as low. Higher impact on local upwelling phenomena and other discontinuities may occur, but these will be short lived due to their dynamic nature and the movements of the oil, and in the overall picture such impact will be low.

Shorelines: High impact as extensive shorelines will be contaminated.

Local use: High, as capelin, lumpsucker and Arctic char fisheries will be closed at contaminated coastlines and likewise will blue mussel collection be closed. Seal hunting probably also will be affected if seal abundance decrease at contaminated sites.

Commercial use: High. The shrimp fishery and snow crab fishery will be closed for at least two months and the same apply to the very important Greenland halibut fishery off Ilulissat. If the fishery is closed in June and July the reduction of shrimp catches will be 30% and the snow crab catches 31%. It is not possible to evaluate the reduction in the Greenland halibut fishery because the data are based on whole year landings.

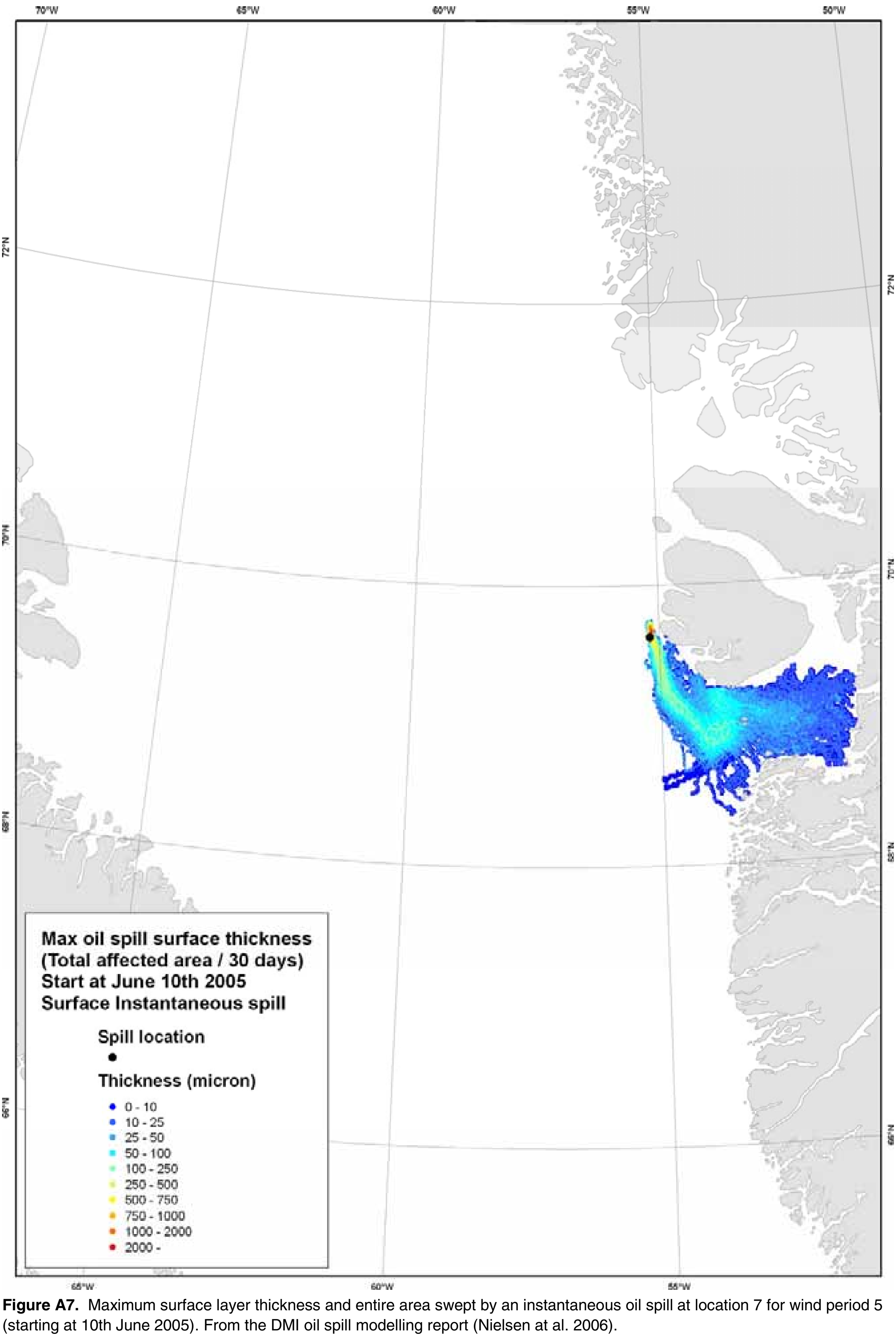

Figure A7. Maximum surface layer thickness and entire area swept by an instantaneous oil spill at location 7 for wind period 5 (starting at 10th June 2005). From the DMI oil spill modelling report (Nielsen at al. 2006).

Long term effects

Oil caught in boulder beaches may be preserved and slowly released to the environment.

Breeding colonies of Atlantic puffin and razorbill in the affected region have shown decreasing numbers in recent years, why increased mortality due to an oil spill may hamper recovery.

Summary for scenario 5

The impacts of an oil spill in mid-summer from spill location 7 will be high if the oil moves as predicted by the DMI oil spill model (Figure A7). This is because oil will contaminate long coastlines with local fishery, will hit important seabird breeding colonies in the most sensitive time of the year and because very important commercial fishery will be temporarily closed.

Spill scenario 6

30,000 tons of oil is released continuously at spill location 2, 103 km southwest of Disko Island. Initial release date is January 28th, and the oil drift towards north and northwest, and will not hit the coast. It will affect 25,000-30,000 km^2. However, the oil spill drift model does not take account for the presence of sea ice, which is abundant at this time of the year. If the oil is released under ice, the oil may be trapped and transported for long distances and released far from the spill location when the ice melts in spring. Dense ice usually occurs north and northwest of the spill site in winter, and this will prevent the spreading as shown in the model. The oil will therefore probably accumulate along the ice edge, in the lead systems, or spread to the adjacent coastal waters and coasts.

Resources at risk

Marine mammals: White whales, narwhals, walrus and polar bears occur in the affected area in winter.

Seabirds: Many wintering seabirds in the coastal leads west of Disko, but in the off shore areas very few birds occur.

Fish: Polar cod living in the icy habitats cf. Scenario 3.

Benthos: Only if the oil moves towards the coast will benthos communities be at risk.

Primary production and plankton (incl. fish and shrimp egg and larvae): No production and very low plankton concentrations in winter.

Shoreline sensitivity: According to the oil spill model no oil will settle on the coast, but if the oil moves towards the coast of Disko, shorelines classified as having a high sensitivity to oil spill will be at risk (Figure 54, in Figure section).

Off shore sensitivity: In winter the affected waters close to the Greenland coast are classified as having a high sensitivity to oil spills, while those further west are classified as having low sensitivity (Figure 55, in Figure section).

Local use: Citizens at least from Qeqertarsuaq, Uummannaq, Illorsuit, Niaqornat and Kangerluk hunt narwhals, white whales and walrus in the affected region.

Commercial use: Although the Greenland halibut fishing grounds will be hit, no fishery takes place in the winter months. If the oil spreads as the model indicates deep sea shrimp fishing grounds will only be hit marginally, and at a time of the year when no fishery takes place. However, if the oil is caught by an ice edge north of Disko, the important fishing grounds at Hareø may be affected if the oil moves more easterly, and here fishery takes place when ice conditions allows (cf. Scenario 2).

Impacts

Marine mammals: Probably low to moderate, cf. Scenario 3.

Seabirds: Low, as there are very few seabirds in the affected areas indicated by the model. However, if the oil drifts is prevented by the ice and accumulates along ice edges and subsequently moves more easterly to the coastal leads along the Disko coast, high numbers of particularly common eiders may be exposed.

Fish: Impacts on polar cod living in the icy habitats are unknown, but may be locally high (cf. Scenario 3).

Benthos: No impacts if the oil spreads as in Figure A8, but if the oil moves to the shores of Disko high impacts must be expected.

Primary production and plankton (incl. fish and shrimp egg and larvae): Low impacts due to the season, but oil released in the marginal ice zone later during spring melt may impact primary production.

Shorelines: No impacts if the oil moves as shown in Figure A8, but high if it settles on the Disko coasts.

Local use: Low impacts, and mainly by a temporal closure of the hunt in order to avoid contaminated catches.

Commercial use: Low impacts due to the season.

Long term effects

Probably none as long as the oil stays off shore, but long term effects must be expected if the oils drift towards the west coast of Disko.

Summary for scenario 6

The impacts of an oil spill in mid-winter from spill location 2 will be low to moderate if the oil moves as predicted by DMI oil spill model (Figure A8), because of the season and the drift away from the coasts. However, ice may change the drift pattern considerably and oil may therefore be forced towards the coast or may be entrapped and later released at much more sensitive areas in the spring resulting in high impacts.

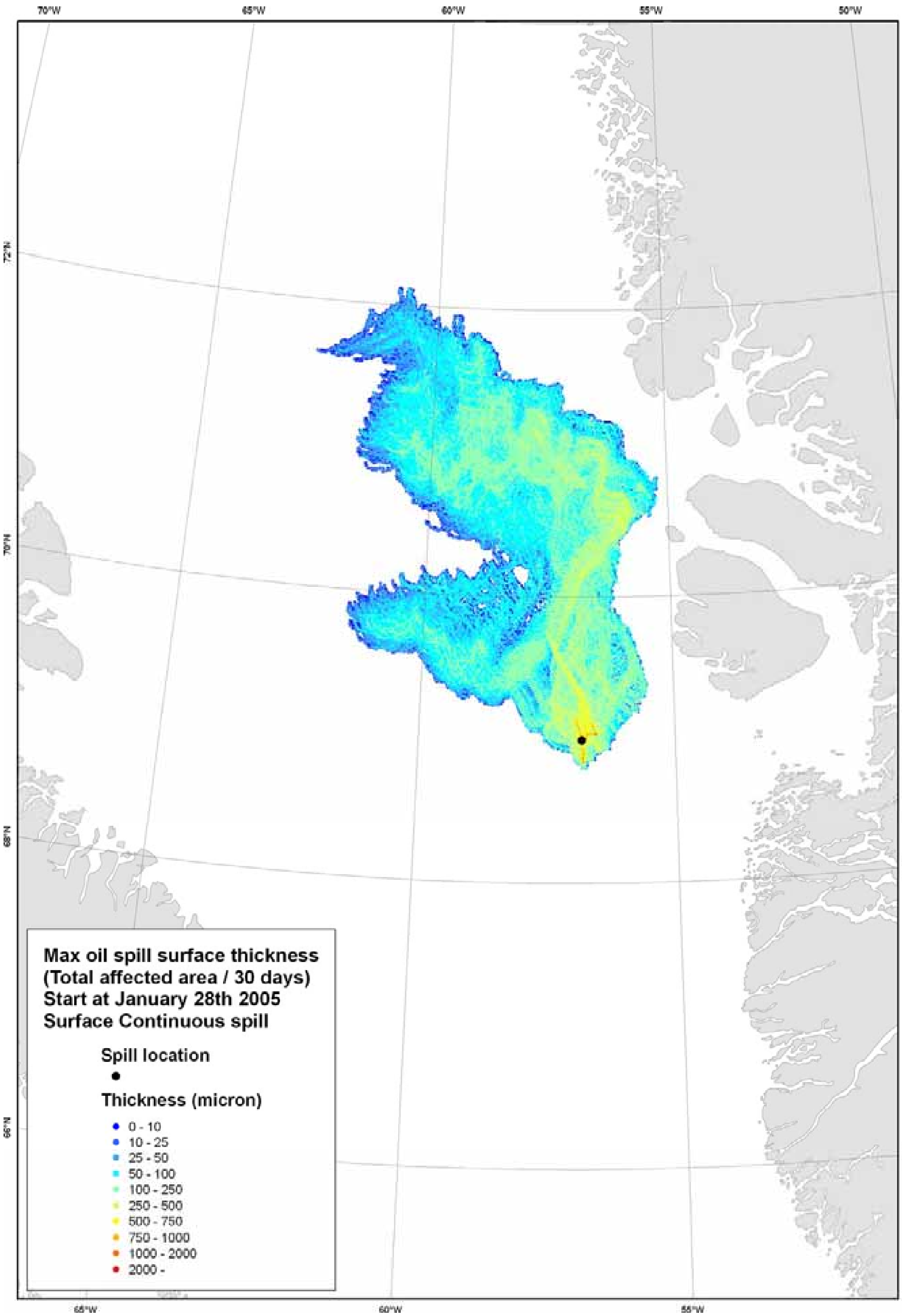

Figure A8. Maximum surface layer thickness and entire area swept by a continuous oil spill at location 2 in wind period 6 (starting on 28th Jan. 2005). From the DMI oil spill modelling report (Nielsen at al. 2006).

Scenario 6 transposed to August and September

Other seasons in the affected area are much more sensitive than the winter. In August and September Thick-billed murres performing swimming migration disperse in the waters west of Disko. These birds comprise the entire successful breeding population from the single breeding colony of the species in the Disko Bay region. The breeding population is app. 1500 pairs, and it has been decreasing during the recent decades. The proportion of pairs fledging chicks is unknown but is estimated at app. 75% resulting in a chick population of app. 1100. These are followed by one of the parent birds. The other parent bird stays at the nesting site for some time after the departure of the chick. This means that a part of the breeding population and the breeding result of a season may be exposed to an oil spill with a drift pattern like the one in Scenario 6. However the birds performing this swimming migration are much dispersed (Figure 33, in Figure section) and most likely only a small part will be exposed to the oil. But the population in this colony is declining, why even a small extra mortality particularly on the adult birds may contribute to a further decrease in the breeding population, or may at least hamper a recovery. The commercial fisheries for Greenland halibut and deep sea shrimp will be much more impacted than in winter. The main part of the halibut fishery takes place in summer and autumn, and fisheries may be closed for months in order to avid contamination of catches.

Spill scenario 7

This scenario is based on the sea ice movements tracked by satellite in spring 2006. Two satellite transmitters were placed on the ice near spill site 4 (Figure A9). If 15,000 tons of oil is released at spill site 4 (135 km west of Hareø and 98 km east of the Canadian border) in late April the oil will most likely accumulate below a very dense ice cover with only small leads and cracks. How far it will spread below the ice is unknown and a.o. dependent on the roughness of the underside of the ice. The oil will move with the ice until release from the melting ice zone during May and June.

Resources at risk

Marine mammals: During April and May walrus, polar bear, bowhead whale, narwhal and white whale occur in the area and will initiate their spring migration towards the summer habitats in Canada. In June these species have left the area and in summer only few marine mammals are present in the area.

Seabirds: Very few in April and May. Migrating Thick-billed murres will be present in leads throughout the area with increasing numbers through May. In June only fulmars and probably kittiwakes will be present in fair numbers.

Fish: The most likely fish at risk in this region is polar cods living in the ice habitats (cf. Scenario 3).

Benthos: None, if the oil stays off shore.

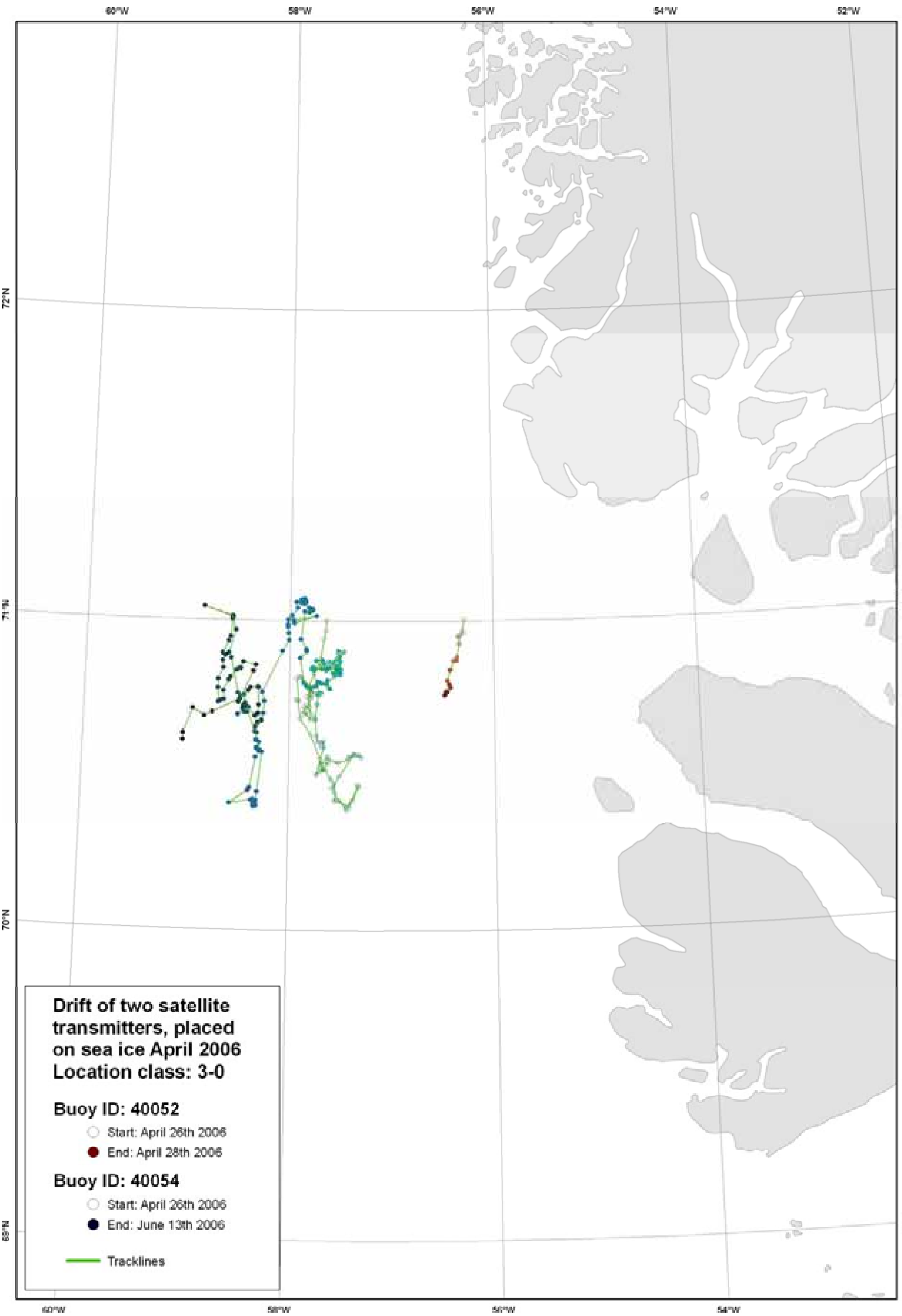

Figure A9. Drift pattern of two satellite transmitters placed on sea ice on 27th April 2006. One (ID 40052) stopped transmitting after 2 days when it had moved 21 km southwards. The other transmitter ID 40054)) was tracked until June 13th. The drift track is app. 500 km, but over all it moved 66 km towards southwest (Study carried out at the request of BMP and GEUS).

Primary production and plankton (incl. fish and shrimp egg and larvae): In spring primary production initiates under the ice and in the marginal ice zone.

Shoreline sensitivity: No shores will be affected.

Off shore sensitivity: The affected waters are classified as having a low sensitivity in winter and a moderate sensitivity in spring.

Local use: Citizens at least from the town of Uummannaq and the settlements Niaqornat and Illorsuit hunt marine mammals in the area.

Commercial use: The oil spill will sweep the off shore fishing grounds for Greenland halibut.

Impacts

Marine mammals: Probably low. Oil spill impacts on narwhals and white whales populations are unknown (cf. Scenario 3). The same apply to walrus and white whale. Bowhead whales often feed in the surface and may get their baleen fouled with oil. The effect of such fouling is temporary and low.

Seabirds: Probably low to moderate, due to the scarcity of birds present in the affected region. During spring melt more seabirds may be present in the ice edge zone and may be exposed to the oil.

Fish: Impacts on polar cod living in the icy habitats are unknown, but may be high (cf. Scenario 3).

Benthos: No effects as long as the oil stay off shore.

Primary production and plankton (incl. fish and shrimp egg and larvae): Probably low. Spring bloom in and under the ice and in the marginal ice zone will be affected during spring, but to an unknown extend.

Shorelines: No effects as long as the oil stay off shore.

Local use: Low, but quarry species may be less abundant, and hunting may also be closed for a period to avoid intake of contaminated hunting products.

Commercial fisheries: Fishery for Greenland halibut will be closed for a period during the presence of oil. But a two months closure in May-June will have no effect, as the fishery usually starts in July.

Long term effects

Probably none.

Summary for scenario 7

The impacts of an oil spill in spring from spill location 4 will be most likely be low to moderate if the oil moves as indicated by the DMI oil spill model. They will be low because the oil never reaches coasts and only few individuals of birds and mammals will be exposed to the oil. However, effects on narwhals, white whales and walrus are unknown and effects under the ice and in the marginal ice zone may also have the potential to cause effects on the primary production, polar cod stocks and other ice fauna.

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This publication is a strategic environmental impact assessment of activities related to exploration, development and exploitation of hydrocarbons in the sea off West Greenland between 67° and 71° N (= the Disko West Area).

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