# 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.

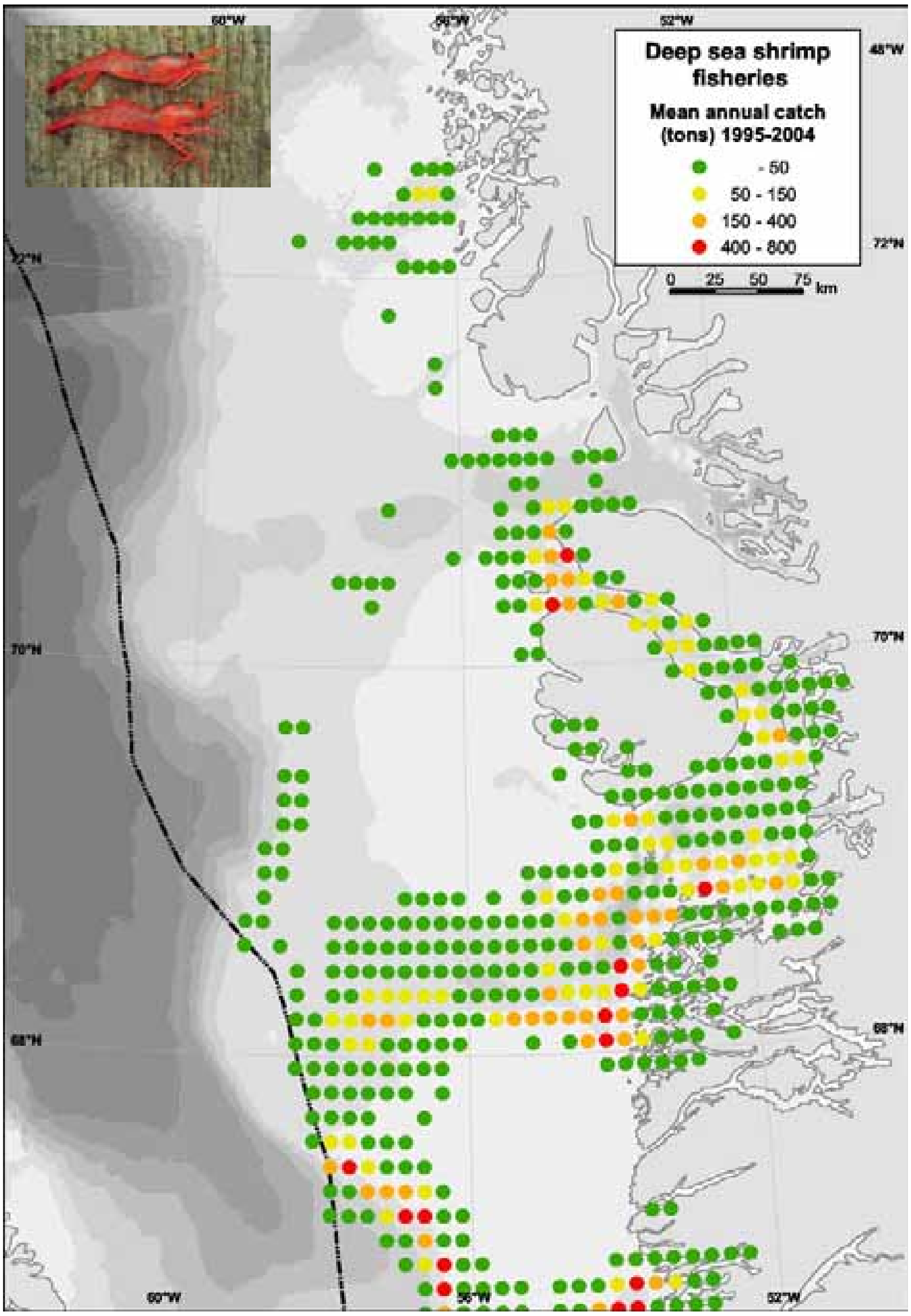


**Figure 42.** Distribution of Greenland halibut fisheries within the study region. The inshore fisheries are shown with squares, and only catches from 2001 have been available. The Ilulissat Isfjord is by far the most important areas for the inshore fisheries (red square). The offshore fisheries show 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.

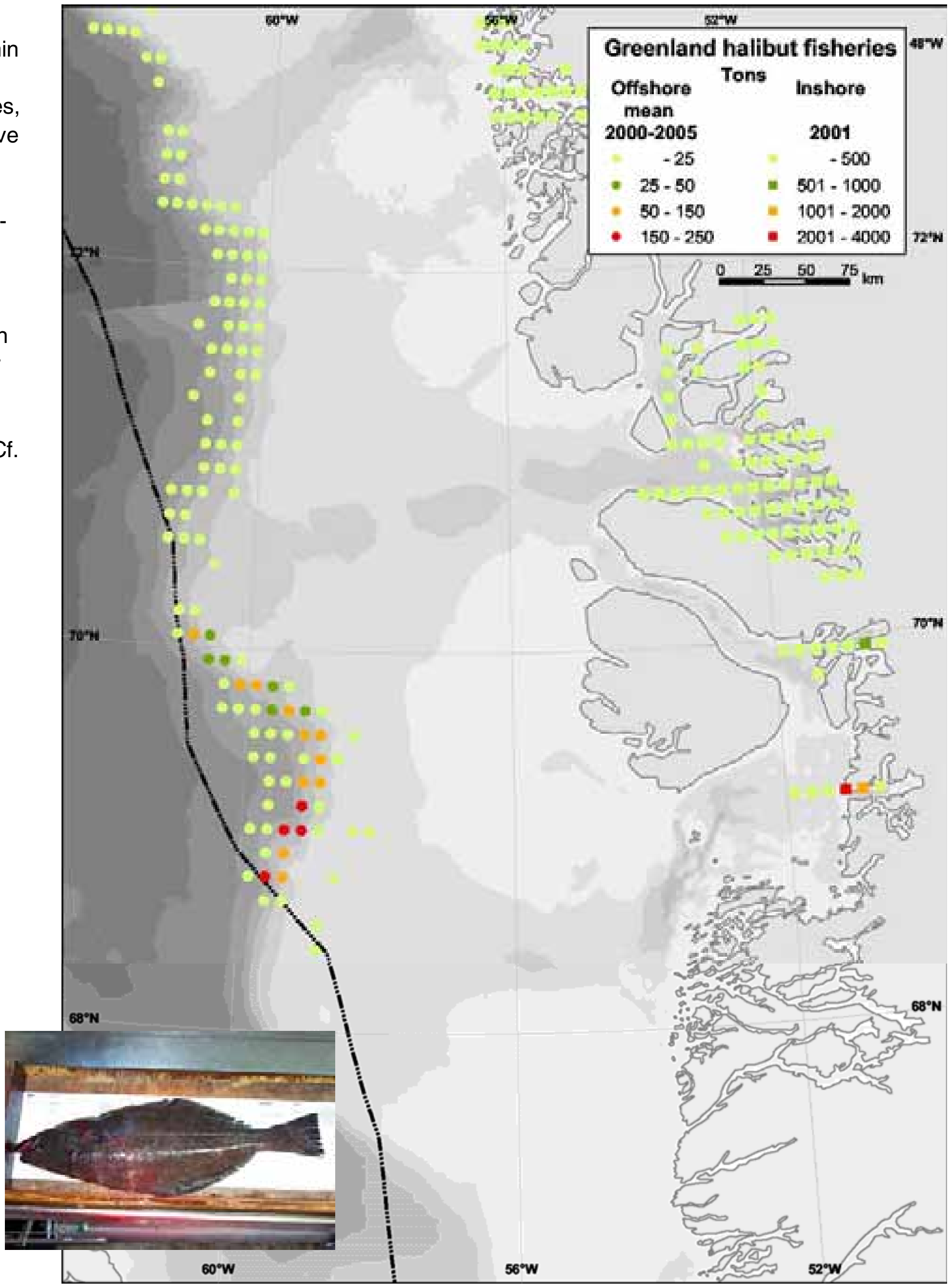
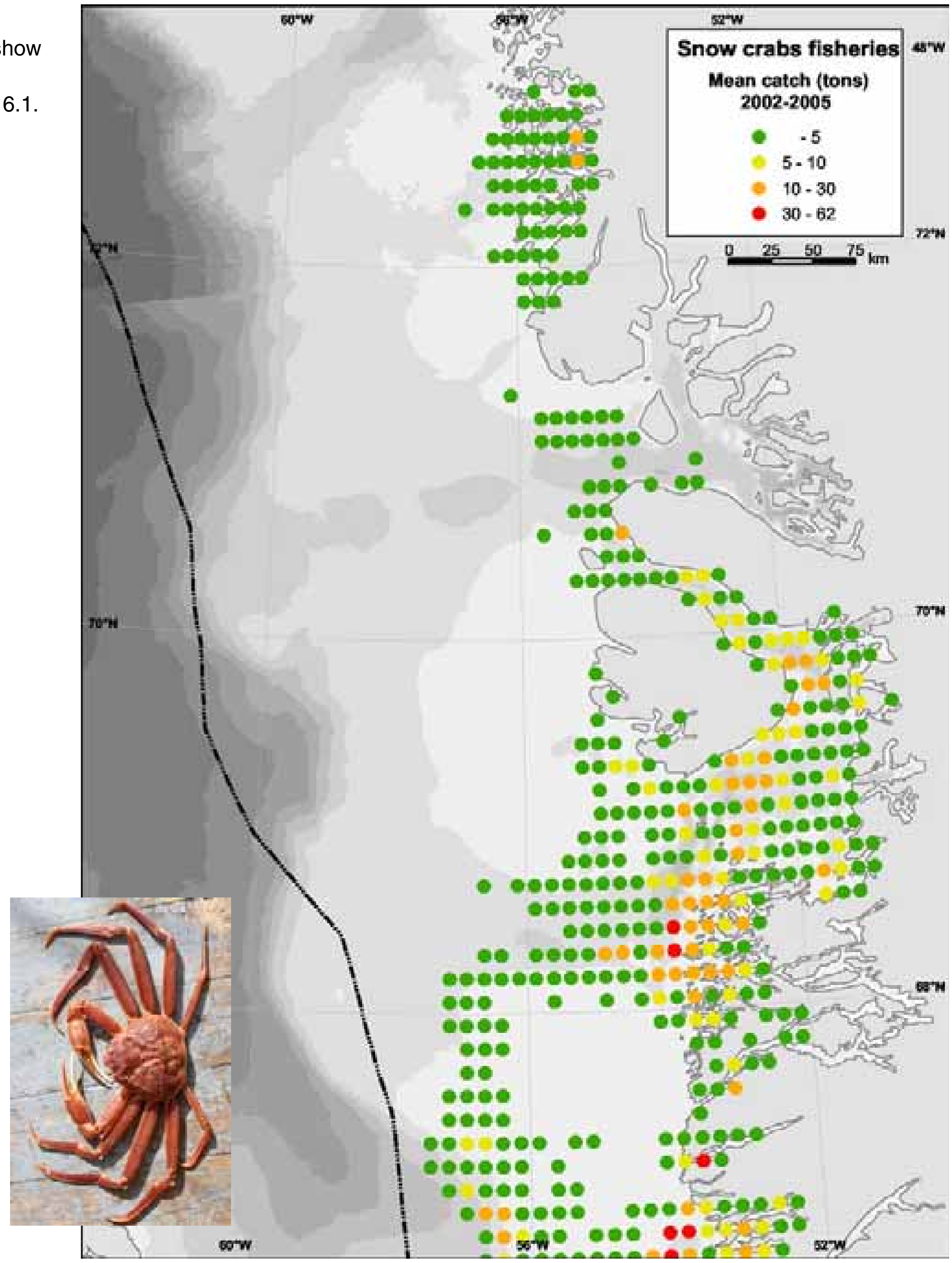


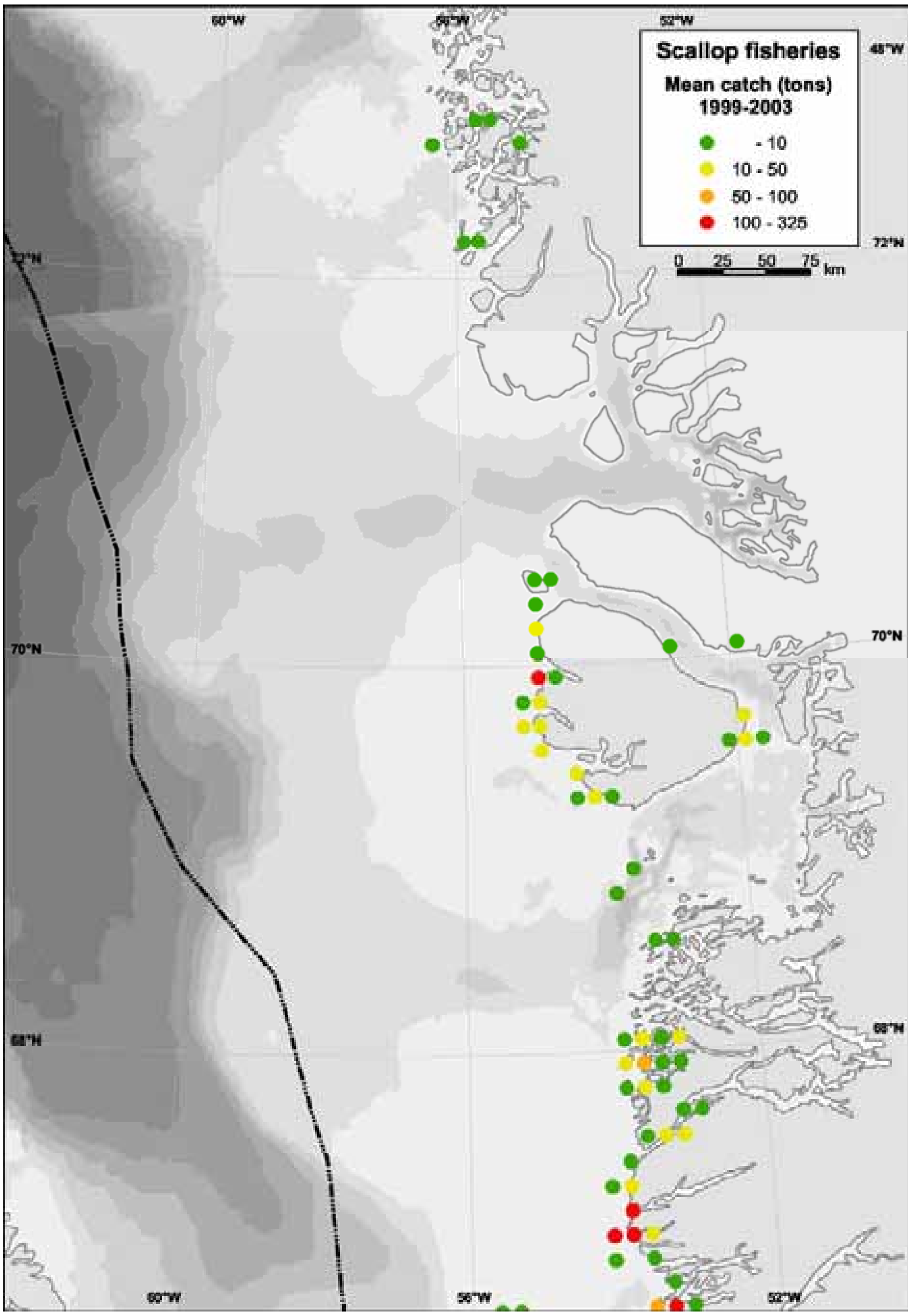
Figure 43. Distribution of the snow crab fishery. The dots show mean annual catch over the period 2002-2005. Cf. Figure 6.1. Data provided by GINR.




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.

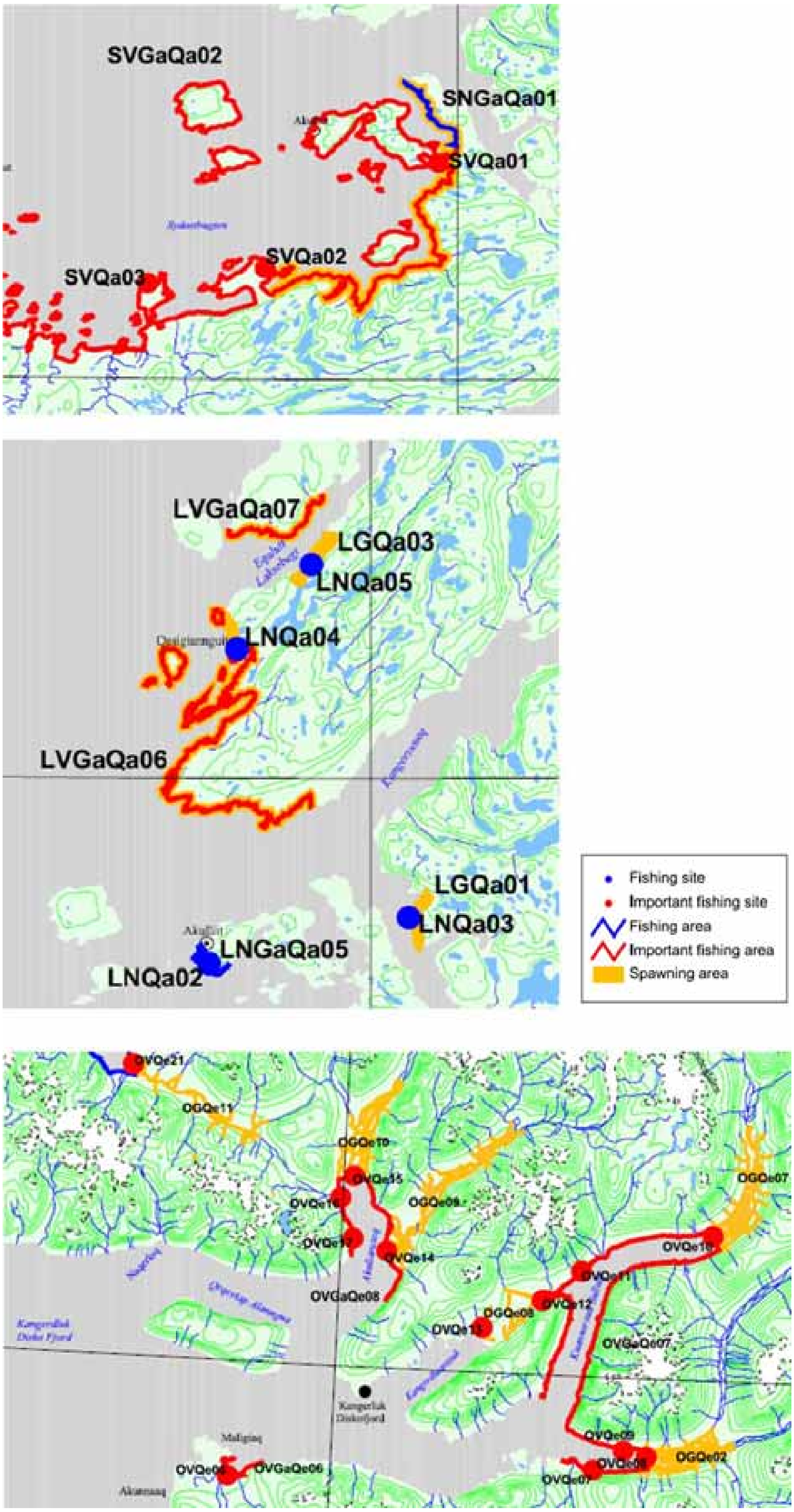
Hunted marine mammal species include all the seals, walrus, white whale, narwhal, minke whale and fin whale. In 1993, the following numbers of seals were reported to the official bag record for the Disko Bay region (Greenland Home Rule 1995): ringed seal 15,000, harp seal 15,000, hooded seal 600, bearded 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).

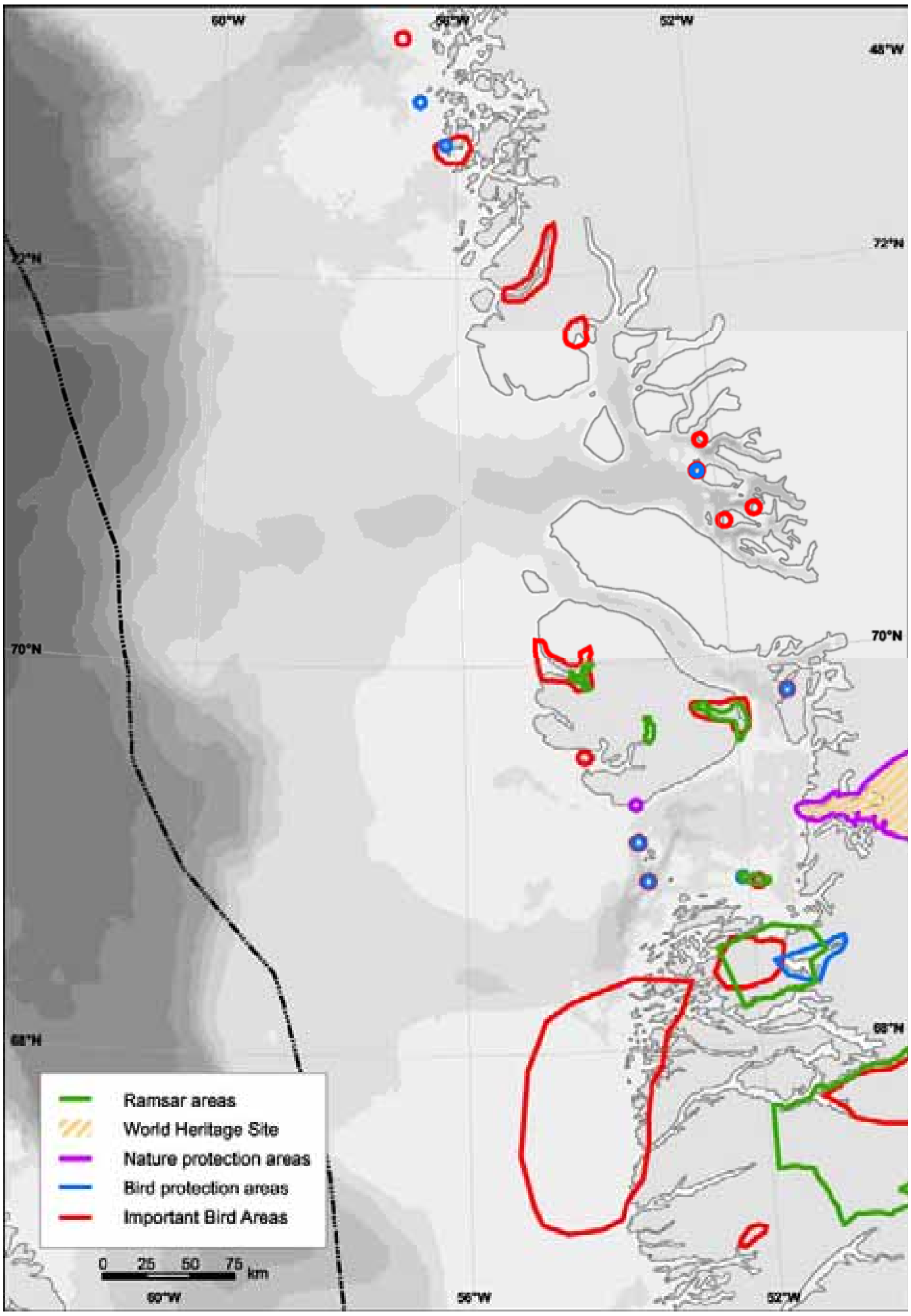


**Figure 47.** The "areas importnat for wildlife" designated by BMP. Avialable at: http://arcims.mim.dk/website/DMU/AM/GL_Wildlife/viewer.htm

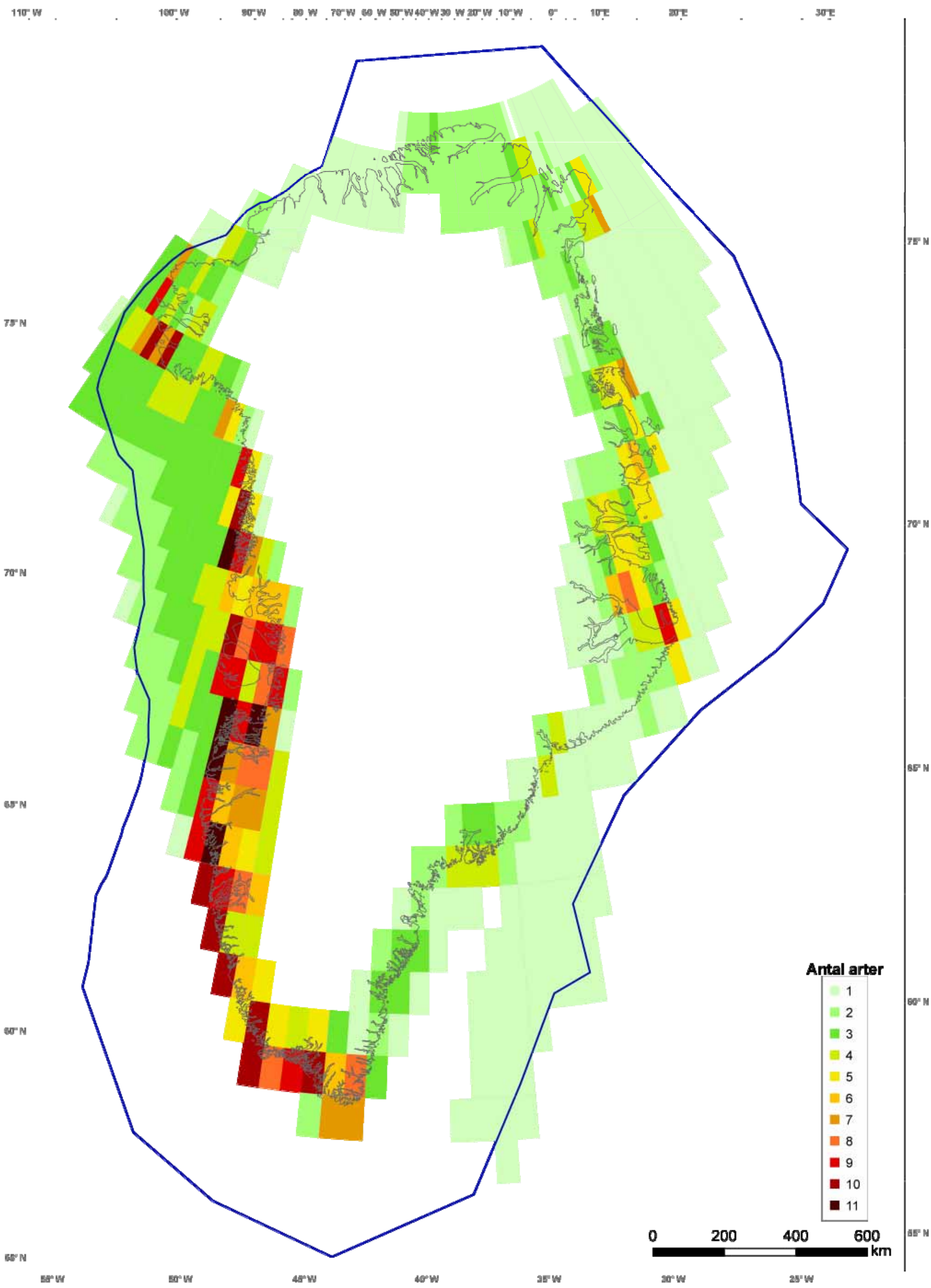



**Figure 48.** Distribution of redlisted species in Greenland. Mammals, birds, freshwater fish, butterflies and orchids have been evaluated, in total 115 species or discrete populations. Of these 36 are included in the redlist. The grid size is 1° x 1°.

# 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).

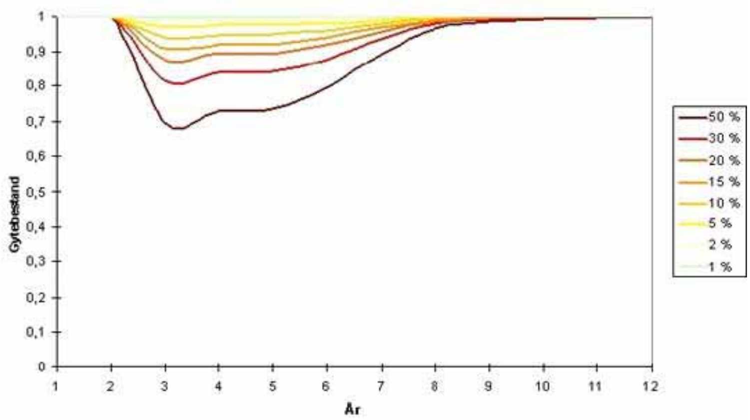



**Figure 49.** Estimated reduction and recovery in Barents Sea cod spawning biomass following large losses of egg and larvae due to large "worst case" oil spills. Gydebestand = spawning stock, År = year. Source: Anonymous 2003, Johansen et al. 2003

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).

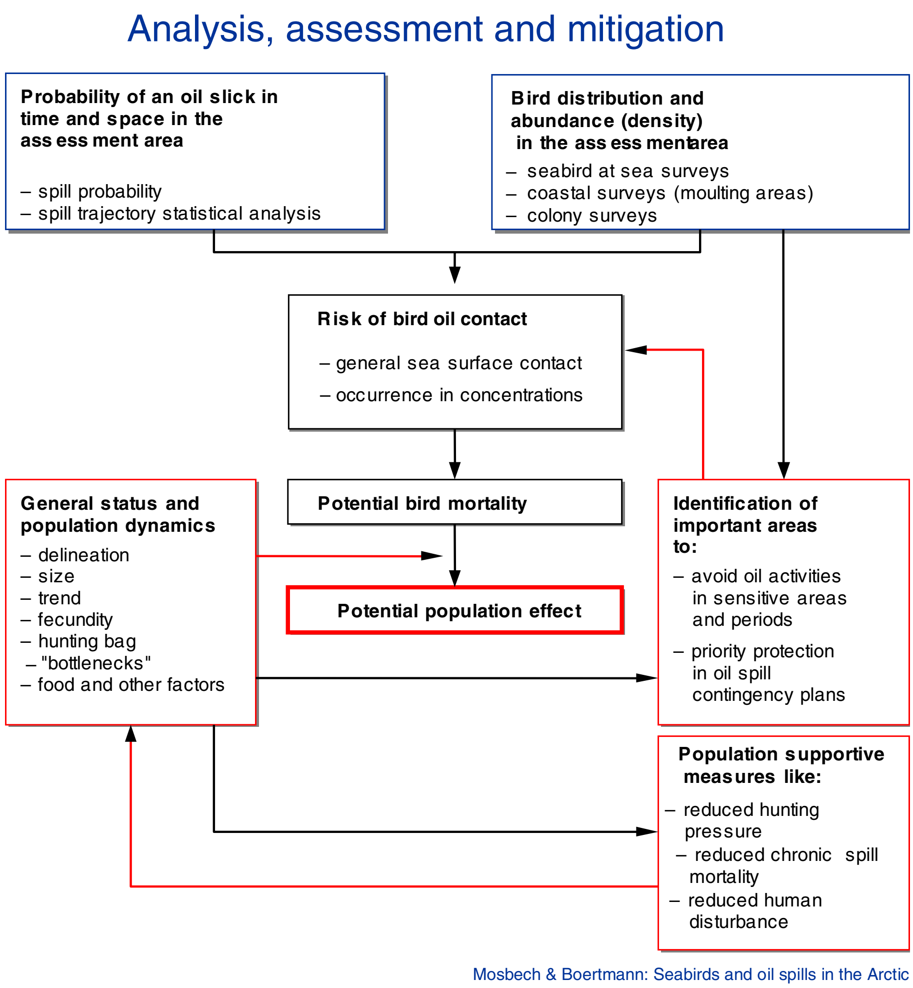



**Figure 50.** Basic principles of an analysis for assessing seabird population vulnerability to oil spills. Black lines indicate main analysis of effects on bird populations, red lines indicate analysis of possible mitigative measures (indirect effects omitted for simplicity).

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.

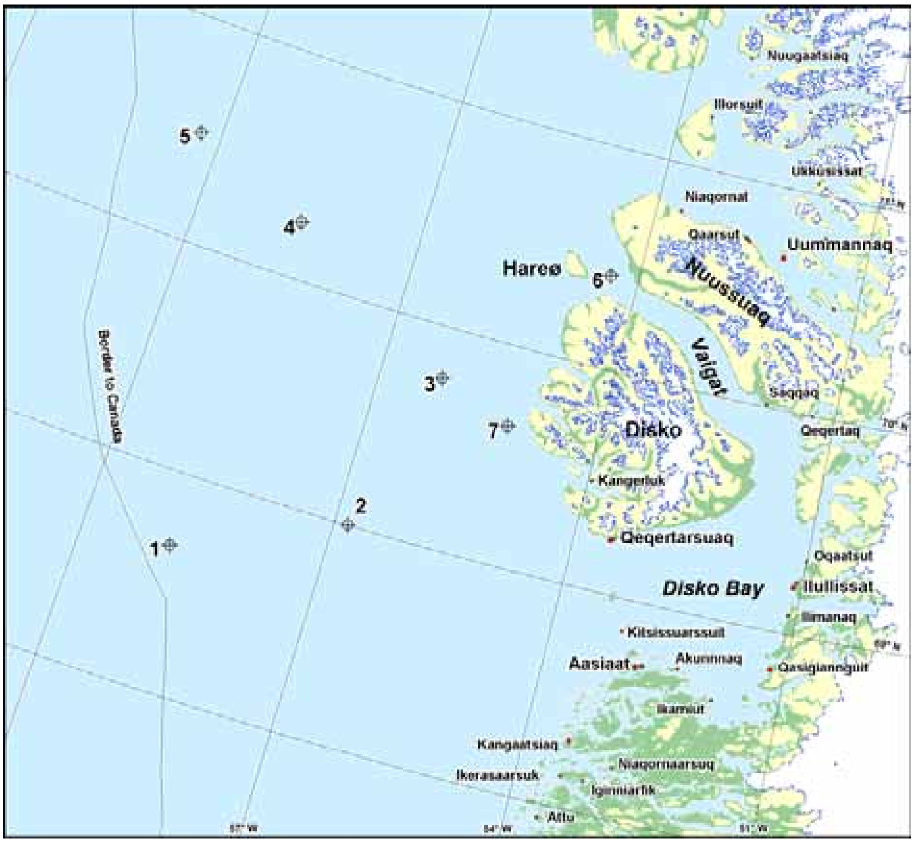



**Figure 51.** The seven spill locations and towns and settlements in the region.

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.

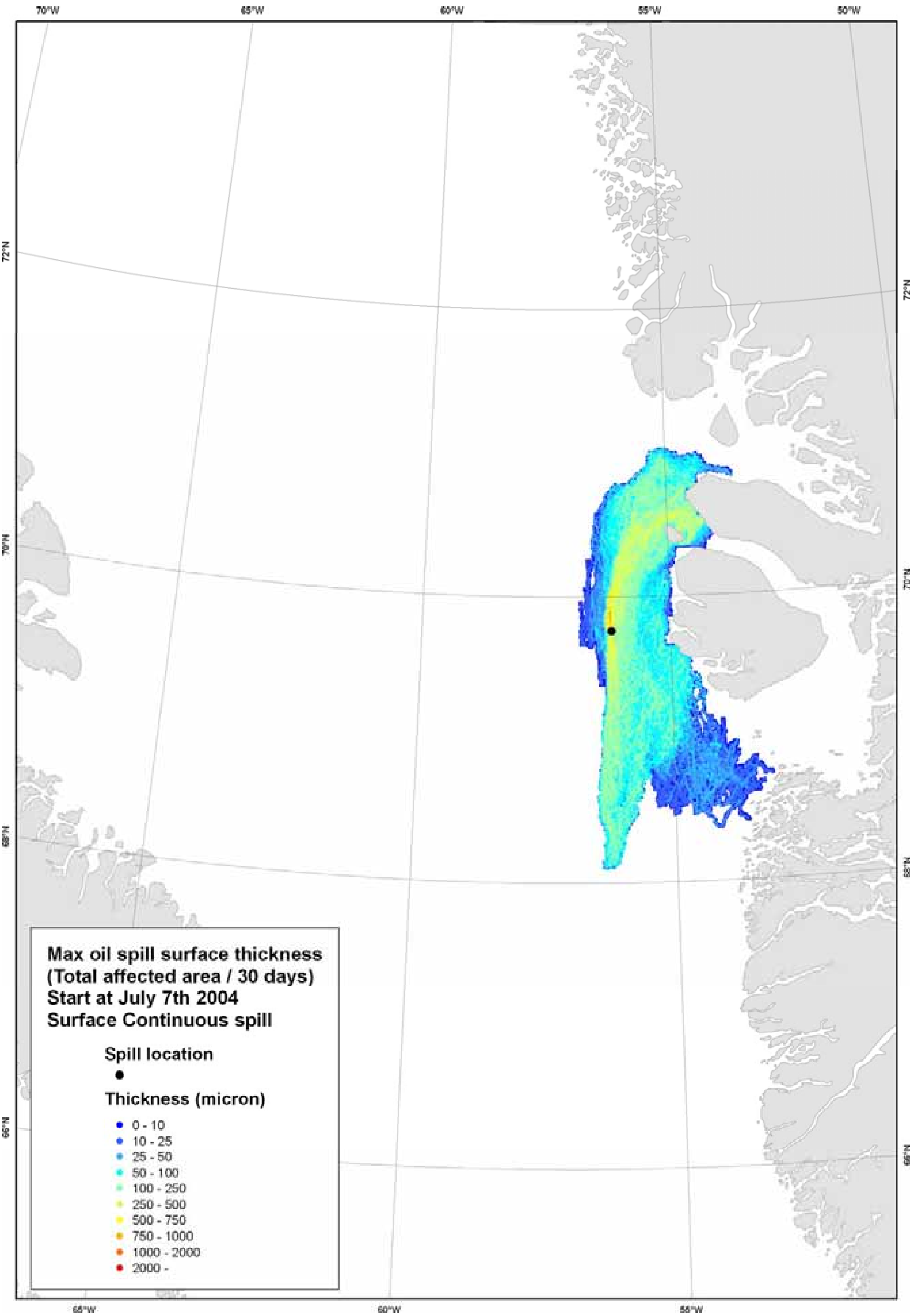



**Figure 52.** Maximum surface layer thickness and entire area swept by a continuous oil spill at location 3 for wind period 1. From Figure 39 in the DMI report (Nielsen at al. 2006).

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.

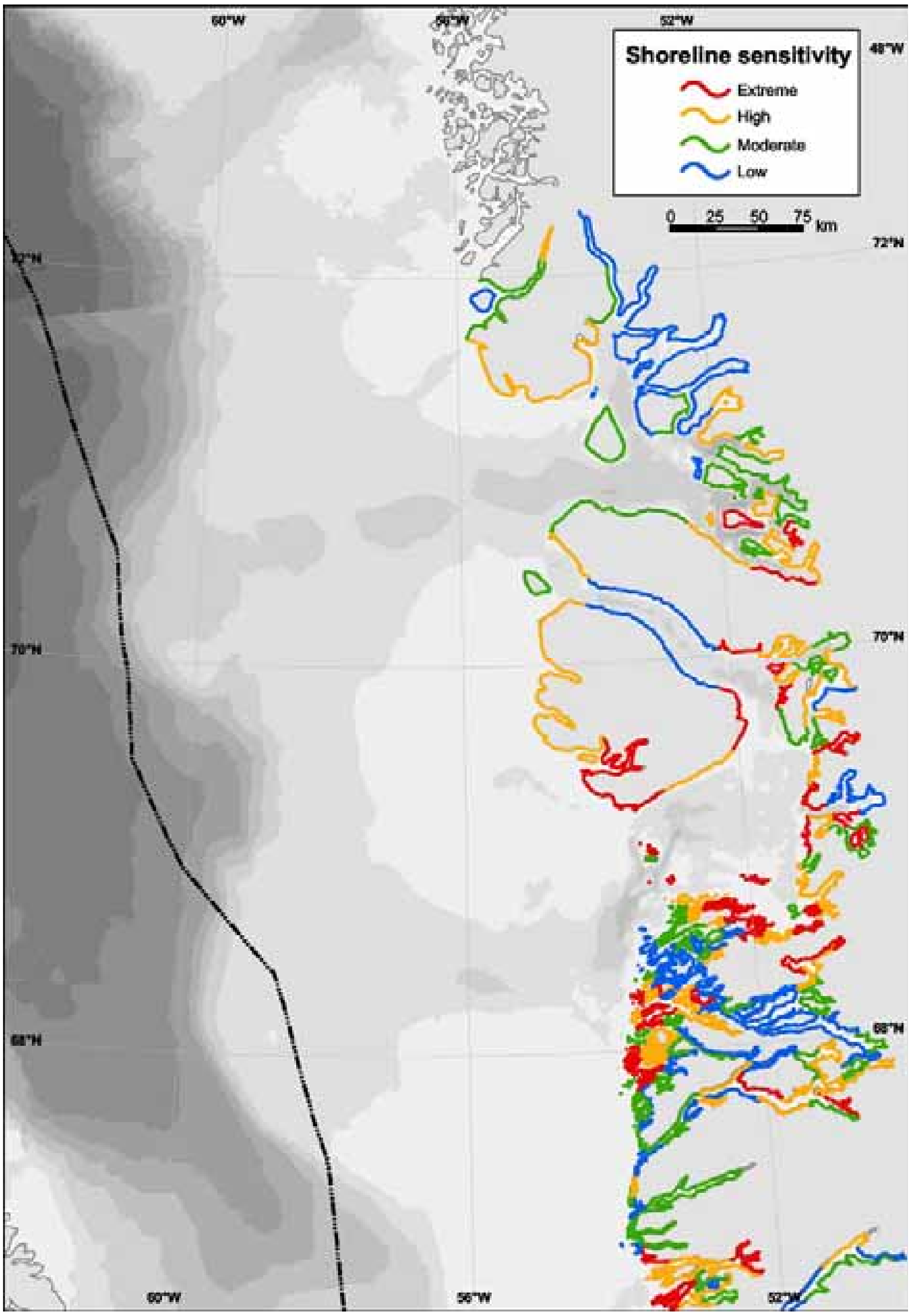



**Figure 54.** Environmental oil spill sensitivity of coast lines in the assessment area. The coasts north of 72° N have not been classified. From the oil spill sensitivity atlases issued by NERI (Mosbech et al. 2000, 2004).

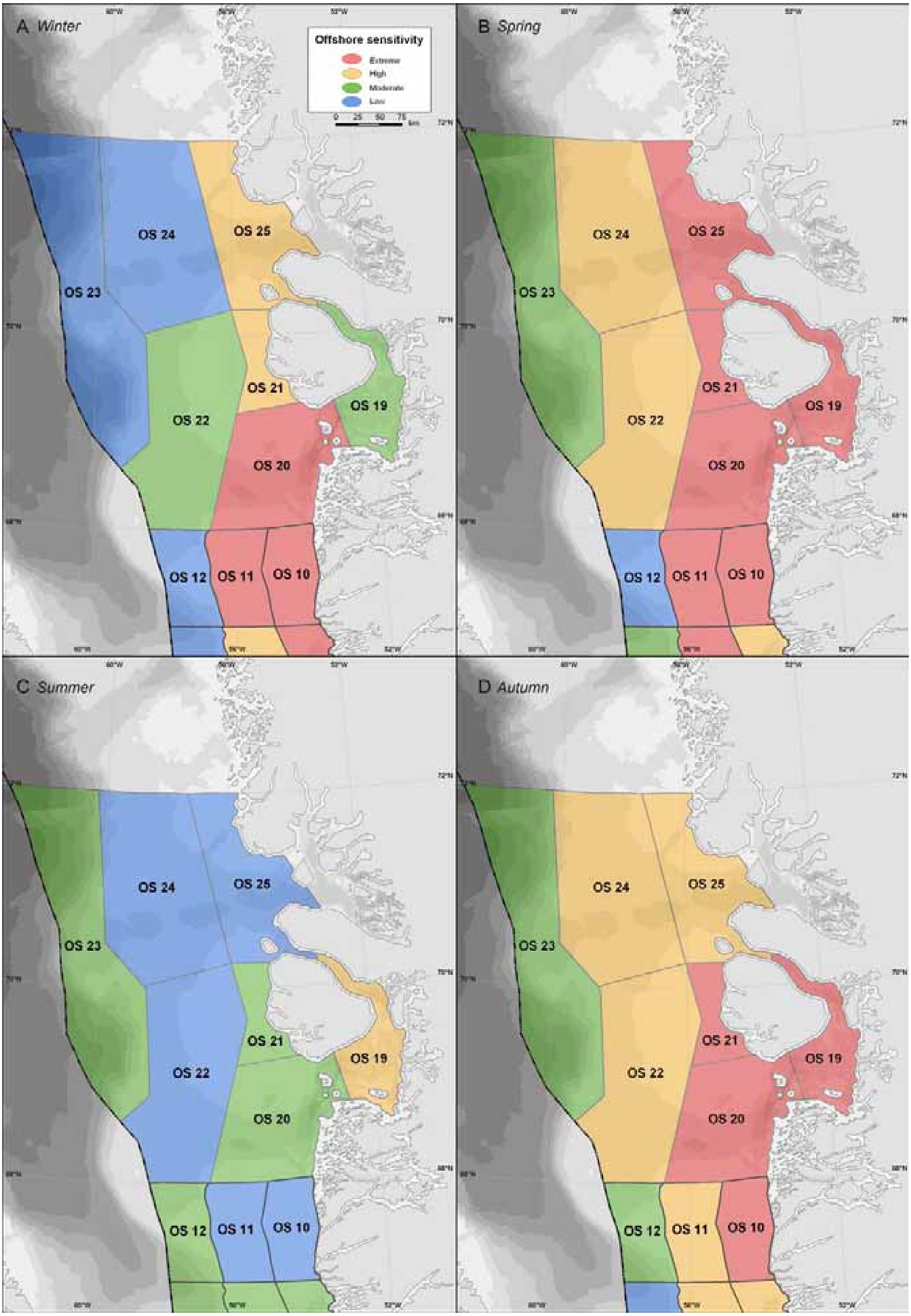



**Figure 55.** The environmental oil spill sensitivity of the offshore areas of the assessment area. The waters north of 72° N have not been classified. Updated with new information since the oil spill sensitivity atlases issued by NERI in 2000 and 2004 (Mosbech et al. 2000, 2004).

## 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.

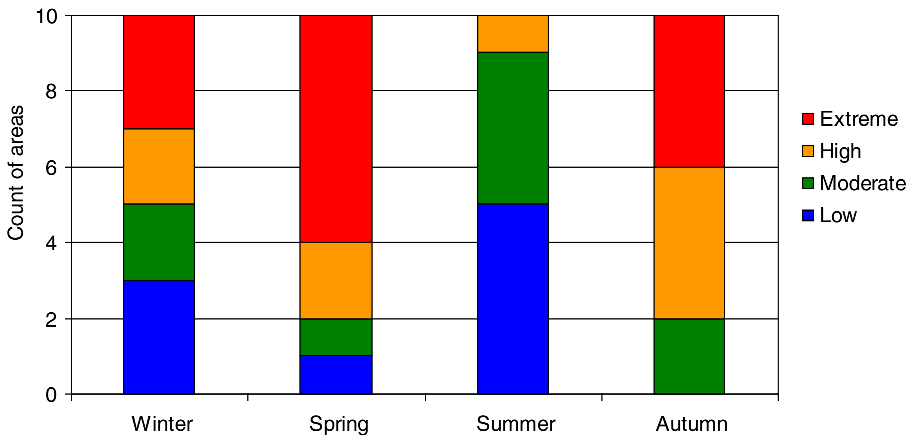



**Figure 56.** Frequency distribution of oil spill sensitivity values by season for the offshore areas. The oil spill sensitivity classes are relative and the classification levels have been defined to illustrate differences between areas and seasons during the year.

**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.

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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.

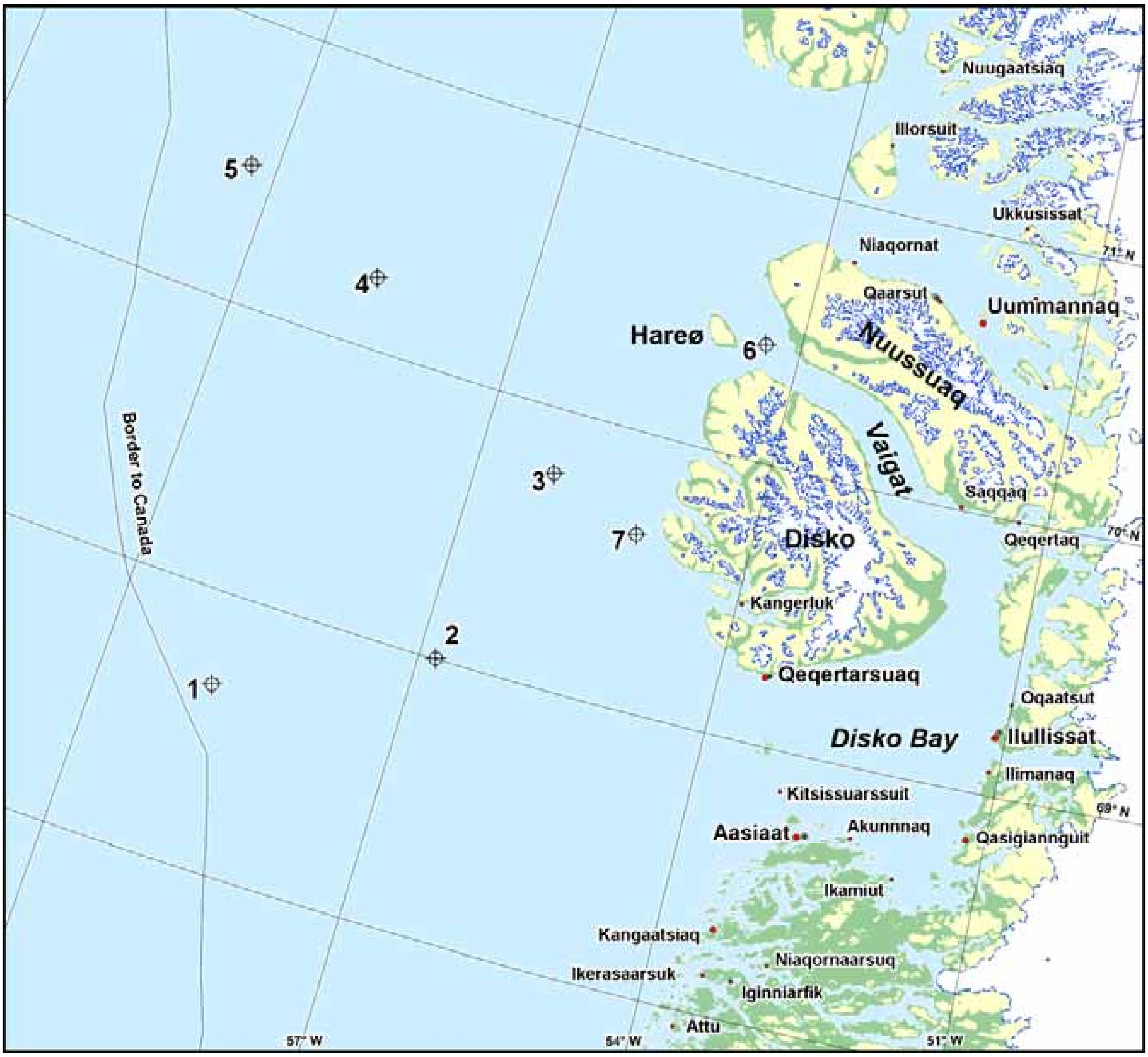


**Figure A1.** The seven spill locations and towns and settlements in the region.

**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.

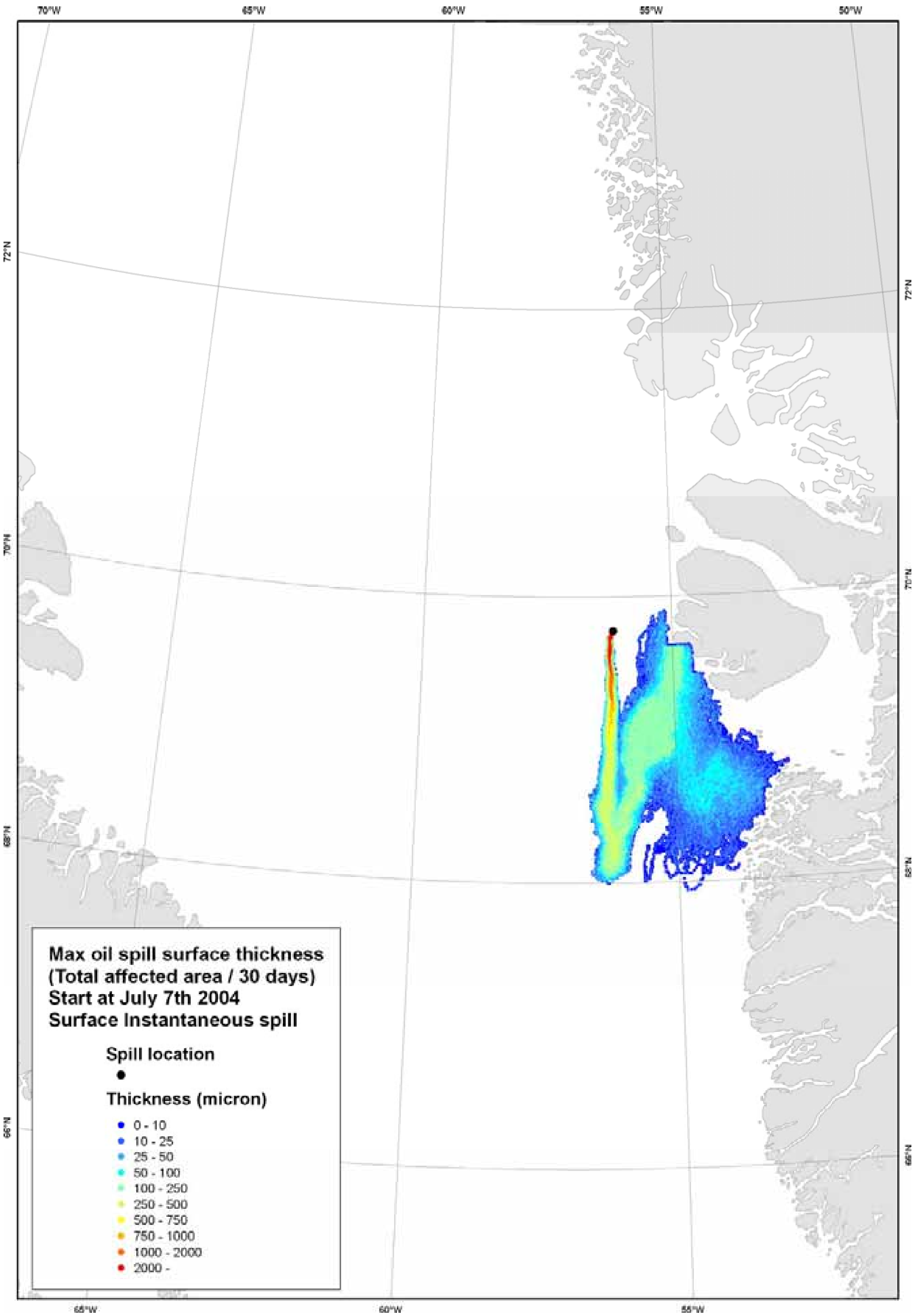


**Figure A2.** Maximum surface layer thickness and entire area swept by an instantaneous oil spill at location 3 for wind period 1 (starting on July 7th 2004). From the DMI oil spill modelling report (Nielsen at al. 2006).

#### 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.

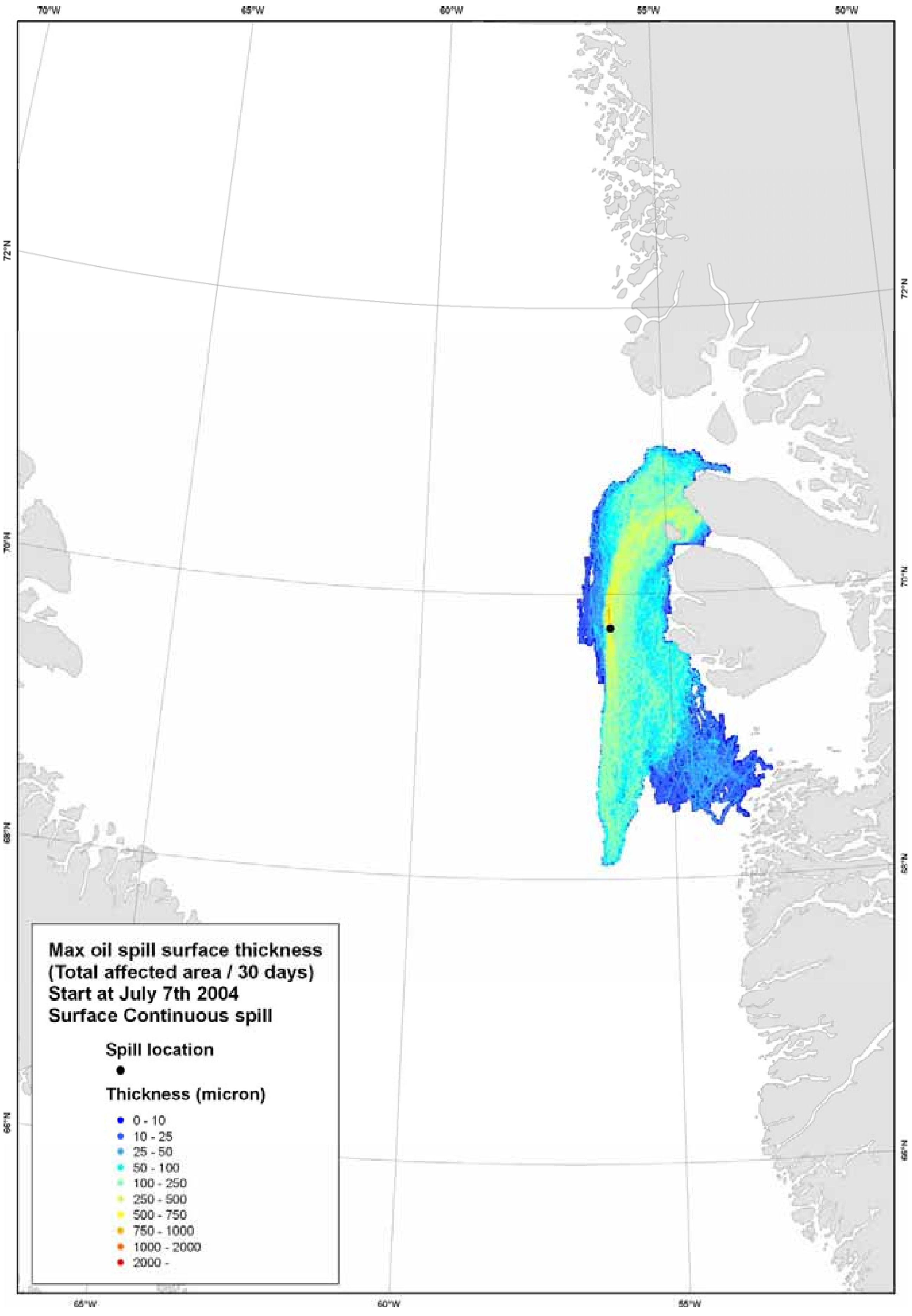


**Figure A3.** Maximum surface layer thickness and entire area swept by a continuous oil spill at location 3 for wind period 1. From the DMI oil spill modelling report (Nielsen at al. 2006).

## 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.

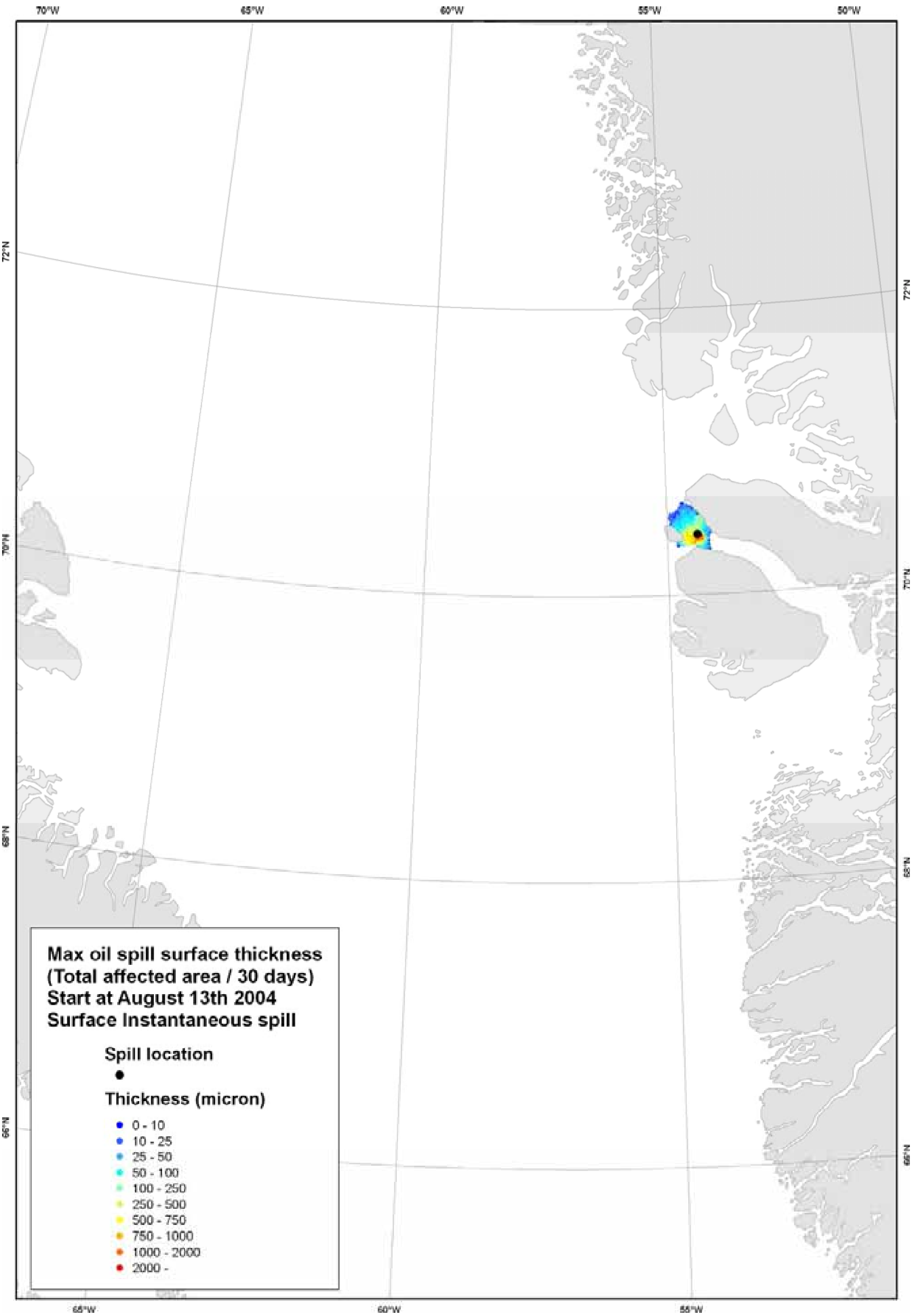


**Figure A4.** Maximum surface layer thickness for an instantaneous and entire area swept by an oil spill at location 6 for wind period 2 (starting on Aug. 13th 2004). From the DMI oil spill modelling report (Nielsen at al. 2006).

## 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.

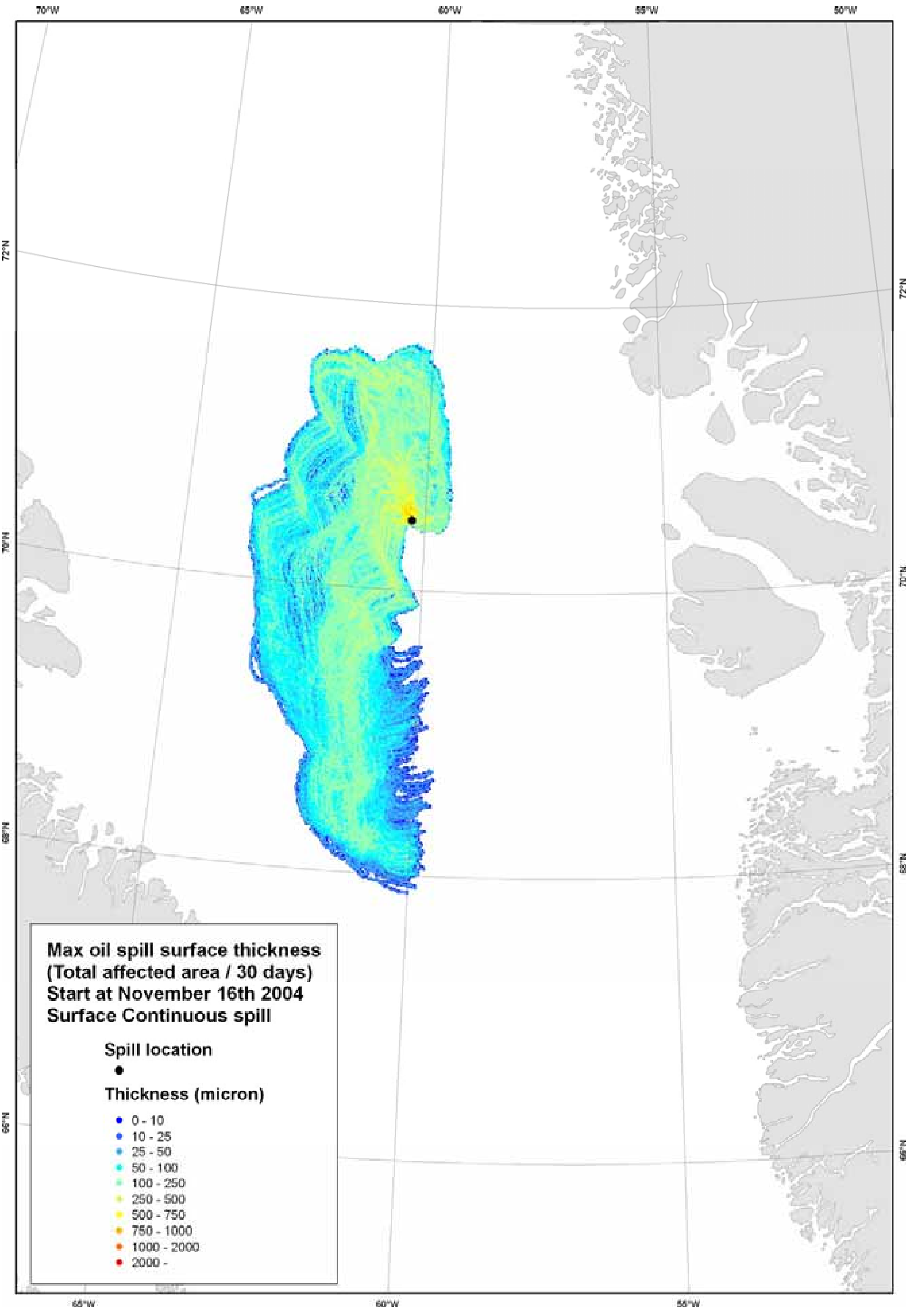


**Figure A5.** Maximum surface layer thickness and entire area swept by a continuous oil spill at location 5 for wind period 3 (starting at Nov. 16th 2004). From the DMI oil spill modelling report (Nielsen at al. 2006).

#### 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.

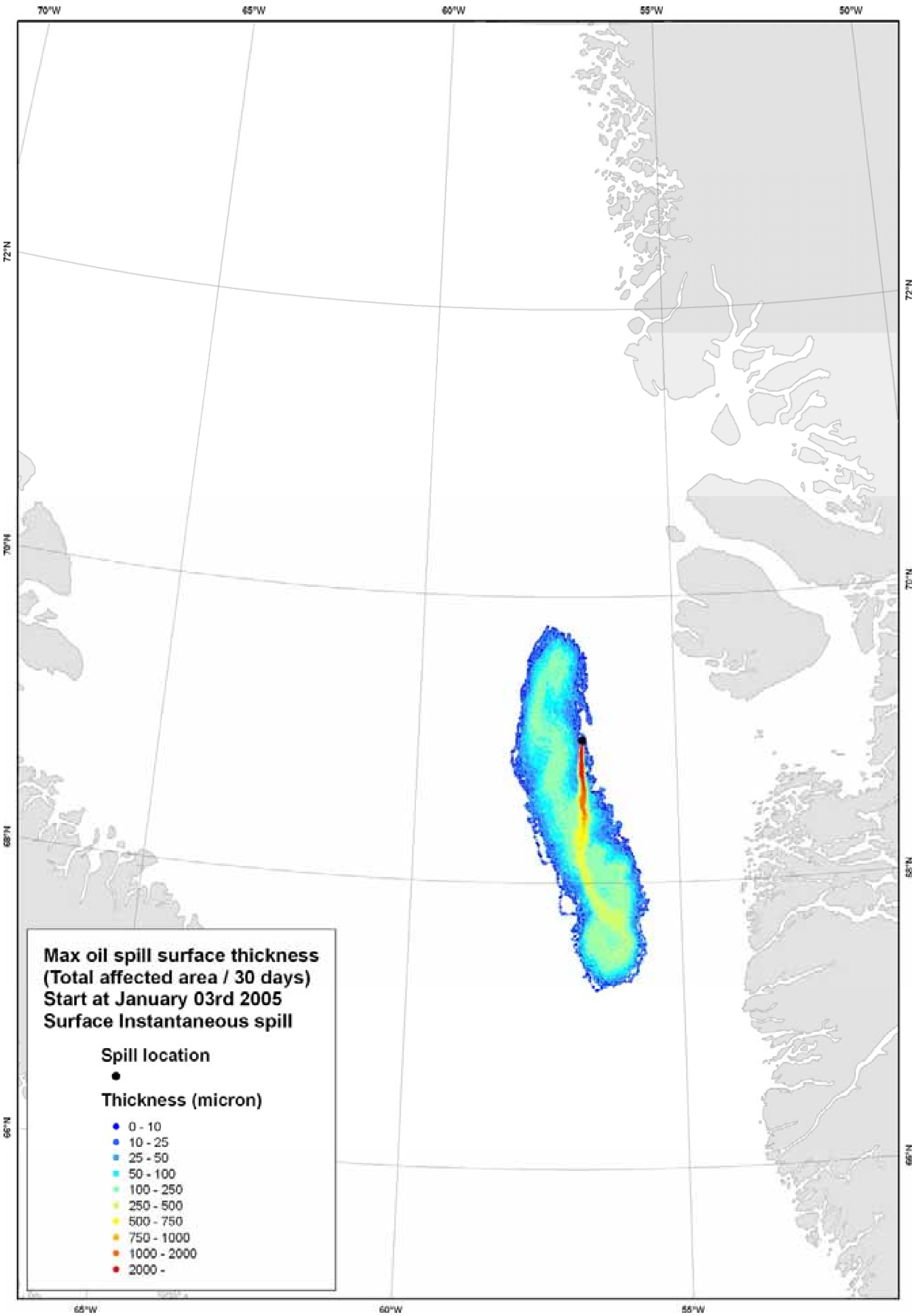


**Figure A6.** Maximum surface layer thickness and entire area swept by an instantaneous oil spill at location 2 for wind period 4 (starting at Jan. 3rd 2005). From the DMI oil spill modelling report (Nielsen at al. 2006).

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 lumpsucker 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.

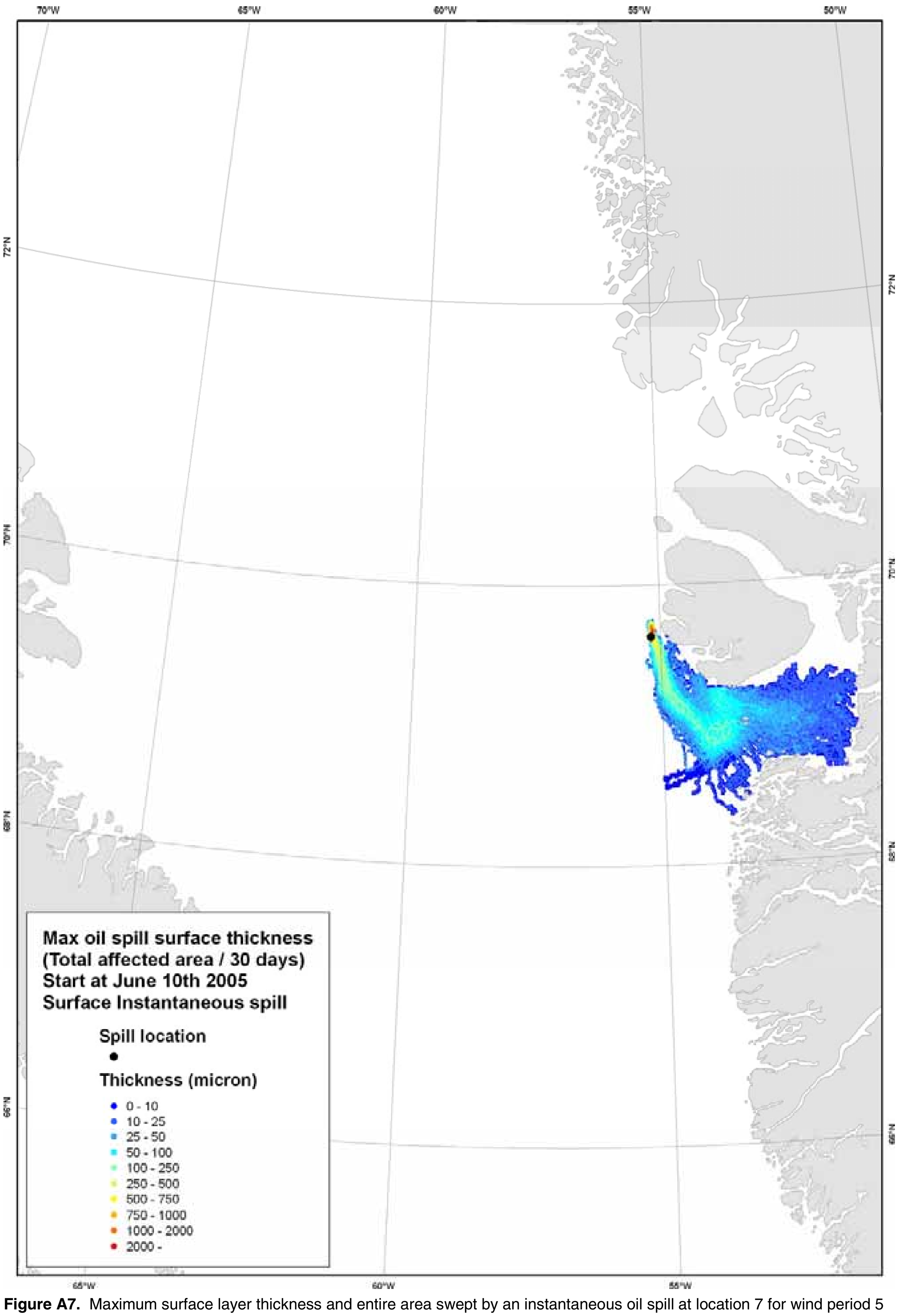


**Figure A7.** Maximum surface layer thickness and entire area swept by an instantaneous oil spill at location 7 for wind period 5 (starting at 10th June 2005). From the DMI oil spill modelling report (Nielsen at al. 2006).

#### 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.

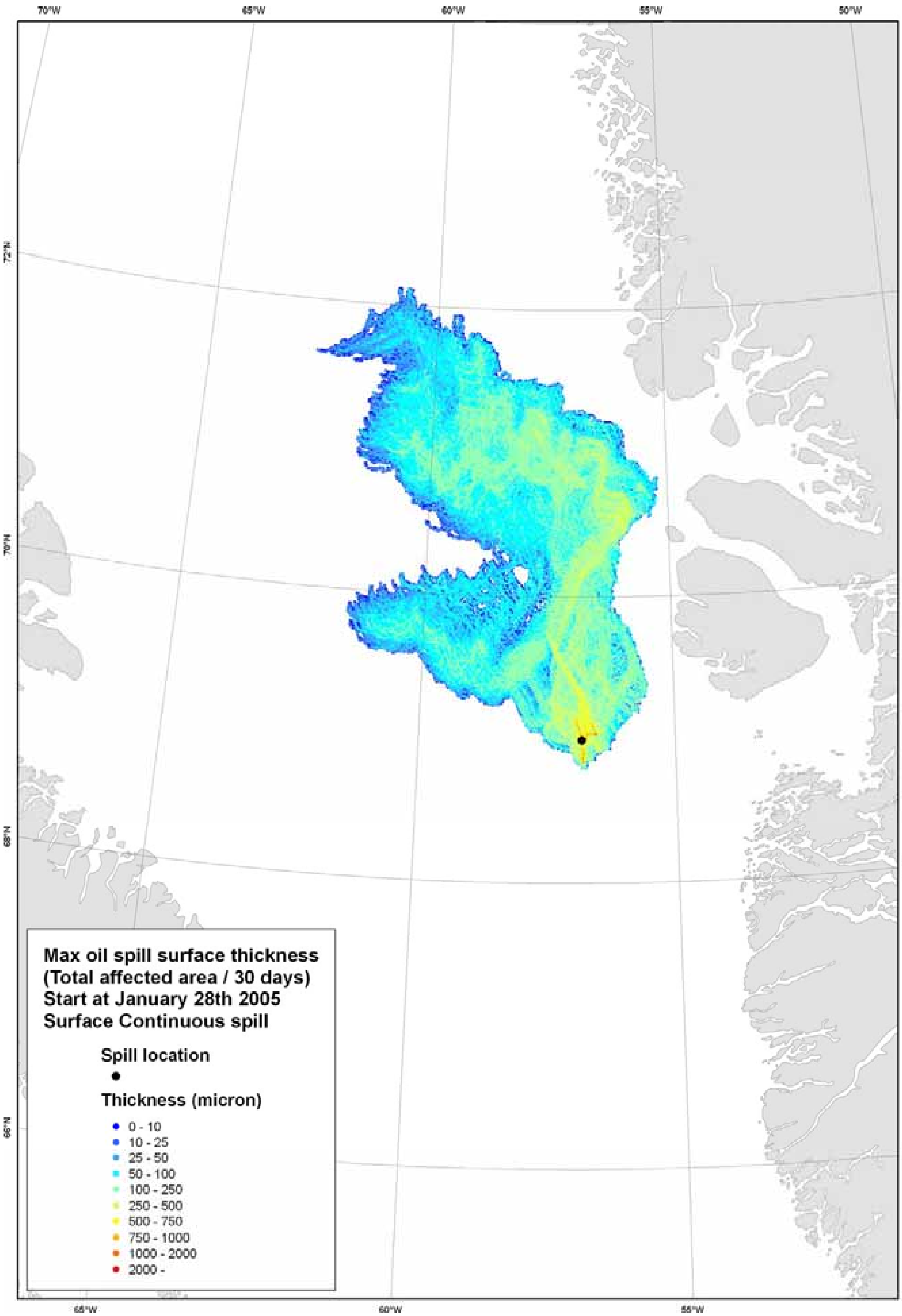


**Figure A8.** Maximum surface layer thickness and entire area swept by a continuous oil spill at location 2 in wind period 6 (starting on 28th Jan. 2005). From the DMI oil spill modelling report (Nielsen at al. 2006).

### 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.

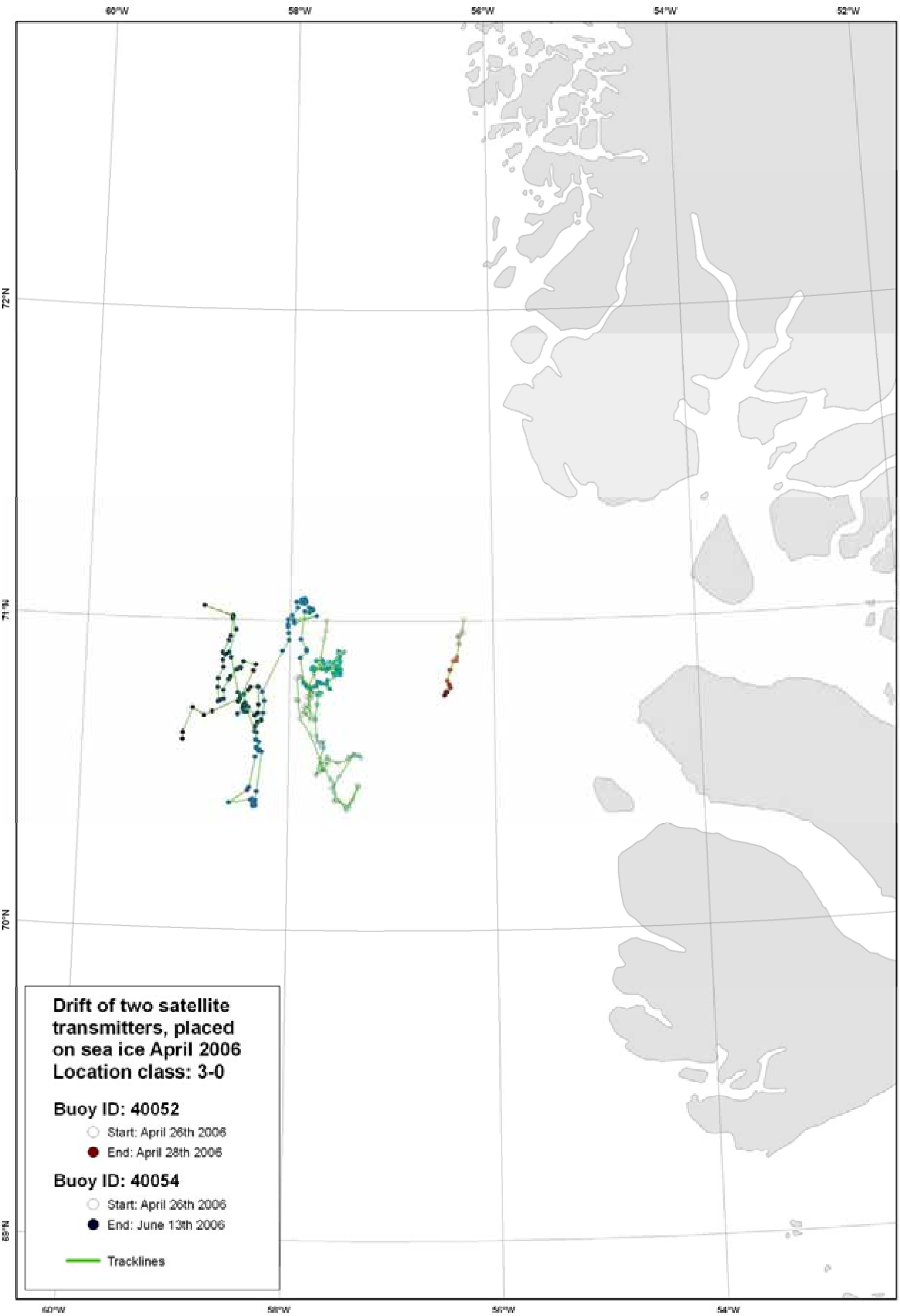


**Figure A9.** Drift pattern of two satellite transmitters placed on sea ice on 27th April 2006. One (ID 40052) stopped transmitting after 2 days when it had moved 21 km southwards. The other transmitter ID 40054)) was tracked until June $13^{th}$. The drift track is app. 500 km, but over all it moved 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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**618** Strategic Environmental Impact Assessment of hydrocarbon activities in the Disko West area

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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