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Preliminary Environmental Impact Assessment of Regional Offshore Seismic Surveys in Greenland

2nd Edition

Ministry of Environment and Energy, National Environmental Research Institute

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Arktisk Miljø/Arctic Environment

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Contents

Summary

The present report summarises potential environmental problems related to conducting regional seismic surveys offshore Greenland during summer and autumn. The report is based on available literature.

The area of investigation covers the east and west coasts of Greenland mainly outside the 3 nautical miles limit.

Seismic operations

Seismic surveys can cause disturbance, mainly from seismic shooting. Helicopter traffic to the seismic vessel can also cause some disturbance.

The most common sound source used in marine geophysical surveys is air gun arrays. Air guns function by suddenly releasing high-pressure air into the water, normally at a depth from four to eight metres. The geological structure of the sea bed is then determined by analysing the signals that, after being reflected from the underlying strata, are picked up by a number of hydrophones attached to a long cable (the streamer). Broadband source levels of 248-255 dB re 1 µPa-m are typical for a full-scale airgun array. The signals from air guns are short, sharp pulses typically emitted every 10-15 seconds. Most emitted energy lies within 10 to 120 Hz, but the pulses contain some energy up to 500 to 1000 Hz. In waters 25-50 metres deep, air guns are often audible within ranges of 50-75 kilometres. Detection ranges in deeper water, or during quiet times with efficient sound propagation can exceed 100 kilometres.

Fish

The effect of the current level of regional seismic activity is considered to be insignificant to fish populations. Fish display patterns of avoidance in response to the pressure waves, and seismic surveys can therefore affect fishery. The disturbance from a regional seismic survey will be transient though, and no significant effects on populations are expected.

The pressure waves within few metres from the energy source may kill fish larvae and fry, which are less mobile. This, however, is insignificant to the recruitment to the stock.

Disturbance and displacement of spawning fish from their spawning areas can have an effect on recruitment to the fish population. However, few species (mainly sandeel) spawn offshore during summer and autumn, and no localised spawning concentrations are known. As the frequency of seismic surveys in West Greenland increase, further studies on spawning concentrations will however be needed to secure minimal impact. Further knowledge on spawning concentrations, e.g. for cod, will also be in demand if seismic surveys are going to be conducted during spring.

As the seismic pressure waves are attenuated rapidly when they move into shallow waters capelin and lumpsucker, which spawn near the shoreline in April – June, will not be significantly affected by offshore seismic. However, inshore seismic shooting near the spawning areas should be avoided in the spawning period.

Shrimps

Shrimps are not likely to be affected by pressure waves from seismic shooting.

Seabirds and marine mammals

Seabirds in open water seem to be unaffected by seismic shooting, but only little work has been done. In inshore areas seabirds can be very vulnerable to disturbance. Especially breeding seabirds and moulting eiders are vulnerable, and precautions should be taken with e.g. helicopter flights.

There are no systematic studies on reactions of seals to seismic shooting, but casual observations indicate that seals are quite tolerant to disturbance from underwater noise. Seals and walruses on land are, however, sensitive to disturbance by aircrafts. Helicopter flights should thus be avoided close to e.g. walrus haul out localities.

Both opportunistic observations and systematic studies indicate that whales do react to seismic activities but they usually resume their normal behaviour within 48 hours after a disturbance. In West Greenland attention should be paid to the smaller whales, belugas and narwhals, and their migration routes which can be affected by heavy seismic shooting.

1 Introduction

1.1 Objective

This report evaluates potential environmental impacts of regional offshore seismic and support operations during summer and autumn in Greenland. Emphasis is placed on the environmental impact on local communities, fish, marine mammals, and birds.

This report covers areas both on the east coast and on the west coast of Greenland (Fig. 1), mainly outside the 3 nautical miles limit but including the coastal waters of Vaigat (Sullorsuaq), Disko Bugt (Qeqertarsuup Tunua) and Scoresby Sund (Kangertittivaq). This includes large areas with widely varying topographic and hydrographic characteristics.

The report is based on available literature. The sensitivity criteria related to the marine environment are based on published and unpublished information. Emphasis in the report is on the effect of seismic shooting, however, potential disturbance from support operations especially helicopter flights are also covered.

The Bureau of Minerals and Petroleum in Greenland (BMP) regulates all aspects (including environmental) of petroleum exploration in Greenland. BMP has issued “Standard Application And Requirements Concerning Offshore Seismic Operations in West Greenland” (Anon. 1999a) which includes a description of the general environmental regulation for seismic operations in West Greenland. For areas outside West Greenland the environmental rules for traffic issued by BMP in ‘Rules for field work and reporting regarding mineral resources (excluding hydrocarbons) in Greenland’, (Anon. 1999b) will generally be part of the environmental regulation of seismic surveys by BMP. The environmental regulation in these two publications is below referred to as BMP-rules.

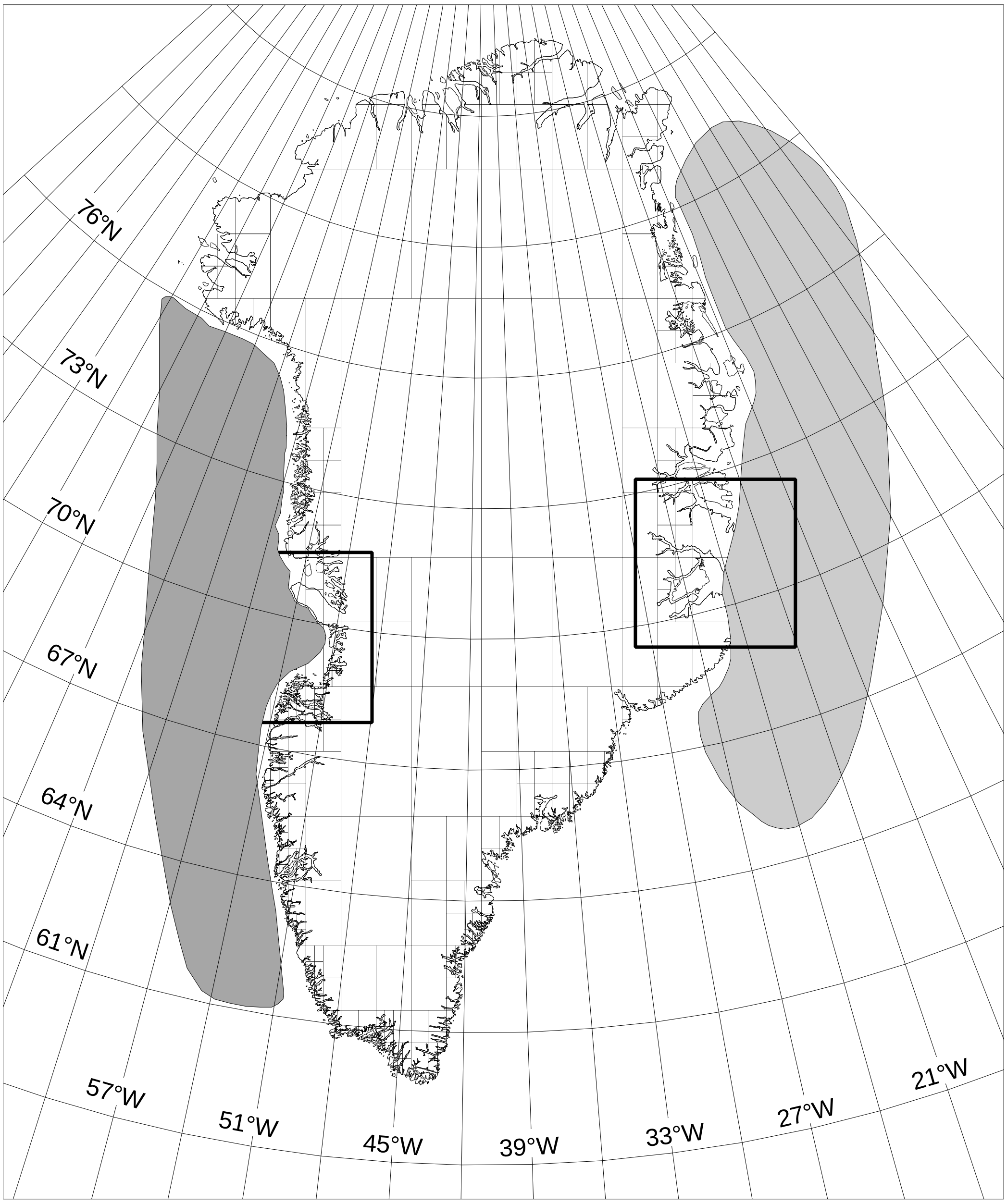

Figure 1. Map of Greenland. The hatching shows the areas of potential investigation. The rectangles show areas where investigations inside the 3 nautical miles limit have been assessed.

1.1.1 East Greenland

In East Greenland the potential area of investigation stretches from Tasiilaq (app. 65º30'N) to Nordostrundingen (approx. 81º30'N) (Fig. 1). The ice conditions on the east coast of Greenland can be severe with dense ice cover during most of the summer period.

1.1.2 West Greenland

In West Greenland the potential region of investigation covers the area from south of Danas Banke (approx. 61ºN) to Kap York (Innaanganeq) (approx. 76ºN). Most of the West Greenland area is free of ice during the summer period.

2 Marine Seismic Surveys

2.1 Seismic operations

The search for marine oil and gas deposits includes the use of seismic survey techniques, which employ high level, low frequency sounds in the analysis of sea bed structure. The most common sound source used in marine geophysical surveys is air gun arrays (Turnpenny & Nedwell 1994). Air guns function by suddenly releasing high-pressure air (typically in the range 12-14 Mpa.) into the water, normally at a depth from four to eight metres. The geological structure of the sea bed is then determined by analysing the signals that, after being reflected from the underlying strata, are picked up by a number of hydrophones attached to a long cable (the streamer) (Richardson et al. 1995) (Fig. 2). Peak levels of sound pulses from air gun arrays are much higher than the continuous sound from any ship or industrial source. Broadband source levels of 248-255 dB re 1 µPa-m are typical for a full-scale array (Richardson et al. 1995). The signals from air guns are short, sharp pulses typically emitted every 10-15 seconds, although shorter or longer intervals may be used. Most emitted energy lies within 10 to 120 Hz, but the pulses contain some energy up to 500 to 1000 Hz. In waters 25-50 metres deep, air guns are often audible within ranges of 50-75 kilometres. Detection ranges in deeper water, or during quiet times with efficient sound propagation can exceed 100 kilometres.

2.2 Types of surveys

Seismic surveys are normally carried out as 2D or 3D seismic operations. With 2D surveys, the vessel tows a seismic source and a streamer along single lines, or an open grid of lines one or more kilometres apart. 3D surveys on the other hand often involve two seismic sources and many streamers towed along parallel lines, which are closer to each other. Generally 2D surveys cover extensive areas whereas 3D surveys cover more restricted areas. Regional seismic surveys are 2D surveys with the seismic lines several kilometres apart.

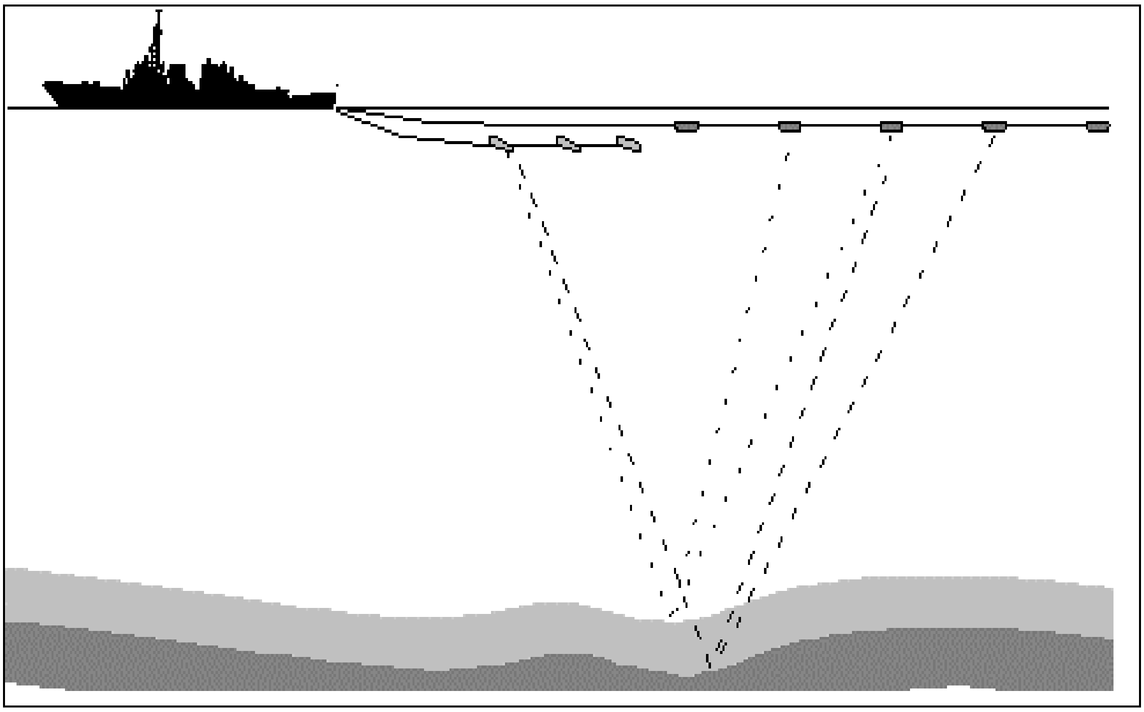

Figure 2. A seismic vessel with air guns and a single streamer.

3 Environmental Impact of Marine Seismic Surveys

3.1 Potential impact of underwater noise

Underwater noise is generated by all ships, mainly by the propellers. Seismic activities and drilling represent significant sources of noise in connection with oil exploration. This noise can disturb fish and marine mammals and can potentially mask marine mammal underwater communication and perception of important natural sounds. Birds are not likely to be affected (e.g. Dietz & Mosbech 1989, Davis et al. 1991, Richardson et al. 1995).

Ambient noise

The sea is far from being a silent environment, even without the contributions of man-made noises. The velocity of sound is four times greater in water than in air, and the transmission loss in water is much lower due to a lower attenuation. Thus, sound pressure waves can travel long distances under water. However, characteristics of sound propagation may vary considerably between locations because transmission loss is strongly dependent on local conditions such as water depth, sound velocity profile of the water column, and amount and type of ice cover. Ice cover reduces sound propagation because reflections are scattered from the rough underside of the ice. The ambient noise level under fast ice is generally low because ice reduces sound waves, however, break-up of ice and calving icebergs create considerable noise. These natural noises are characterised by a relatively constant base level with overlying periodic powerful pulses.

3.2 Fish, shrimps and seismic activity

Fish

Concern has been raised, especially in Norway, that fish populations may be negatively affected by the seismic air gun arrays usually used in offshore seismic surveys (Bjørke et al. 1991). The pressure waves from air guns can cause instant egg and larval mortality within a distance of approximately 1.5 metres, and mortal lesions within 3.0-6.5 metres. However, the ecological effect of this mortality will be marginal because the actual volume of water affected is relatively small. In a Norwegian study (Sætre & Ona 1996), larval mortality was estimated to be 0.45% in a worst case scenario. However, by applying realistic values to the distribution pattern of larvae and fry, it was concluded that only 0.3‰ of the modelled larval population was likely to be killed by a 3D survey. Such a low level of mortality is not regarded as having significant effect on the recruitment of the stock. It is therefore concluded that there is no need for restrictions on seismic investigations on the basis of injuries to egg, larvae and fry.

Fish generally display avoidance patterns in response to the seismic pressure waves. When cod (G*adus sp.*) and redfish (*Sebastes sp.*) are 30-50 mm long they are able to avoid the mortality zone in the immediate vicinity the air guns. Adult fish generally swim to the bottom and escape. On the basis of seismic source pressure, fish hearing ability, and fish behaviour in general, it has been estimated that reactions to a seismic array may be expected at distances greater than 30 kilometres, and intense avoidance behaviour can be expected within a radius of 1-5 kilometres (Fig. 3) (Nakken 1992). Norwegian studies (Engås et al. 1993, Soldal & Løkkeborg 1993) measured densities of fish around a small area (4x4 kilometres) experiencing intense seismic activity (3D). Fish densities, which were measured by trawling, long line fishery, and acoustic methods, were reduced by 50% within 10-25 kilometres from the site of seismic activity. Five days after seismic activity stopped, fish densities had not yet reached the previous levels.

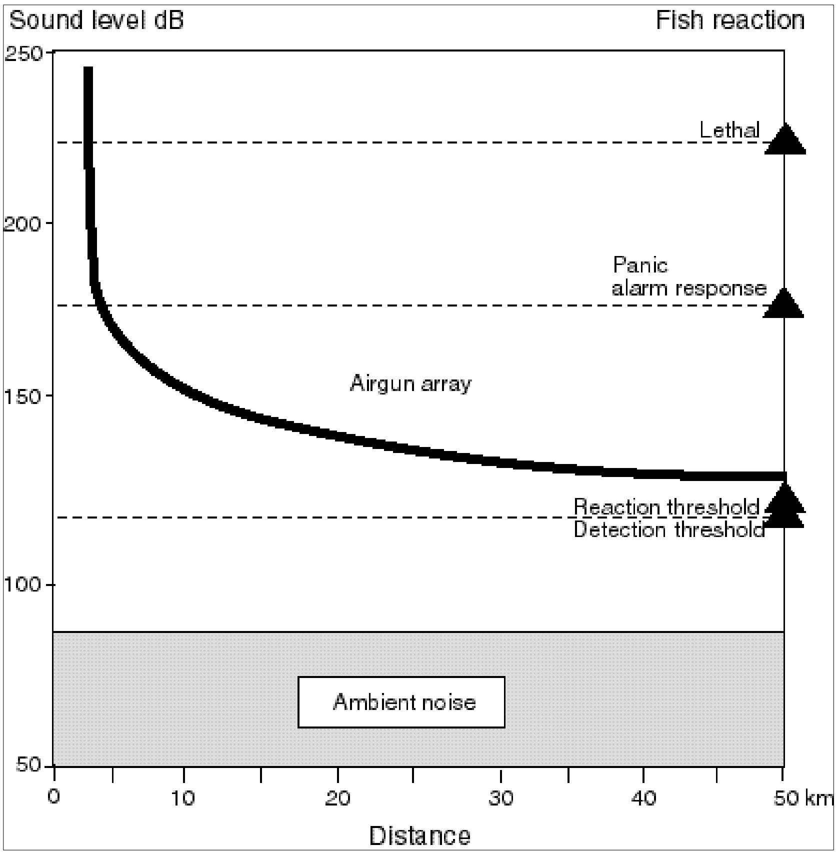

Figure 3. Generalised responsiveness of cod to sound pressure levels. The sound pressure levels versus distance of an array of air guns are given as well as the ambient noise level. The sound pressure level from the air gun is reduced to less than 200 dB within the first kilometre (modified from Nakken 1992).

Temporal displacement of fish is not necessarily harmful to either fish or fishery. However, further research is needed. Special consideration should be given to spawning because displacement of populations during spawning may affect recruitment to fish stocks. Using the precautionary principle Dalen et al. (1996) recommend that seismic shooting in areas with concentrated spawning or spawning migration should be avoided. Furthermore, it is recommended that seismic shooting in 2D- and 3D-surveys should be avoided less than 50 kilometres from these areas. At a distance of 50 kilometres, the noise levels from the seismic shooting are similar to the noise level in an area with active trawling. Site surveys and similar activities using small air gun set-ups are less noisy and may be allowed closer to but generally not in the spawning ground itself. The experimental results show that air gun shooting in areas where fishing takes place can reduce catches. Dalen et al. (1996) recommend that 2D- and 3D-surveys are avoided at distances less than 50 kilometres from the outer edges of fishing grounds, at least a week before fishing is expected to start.

Shrimps

In general, pressure waves have relatively little effect on marine invertebrates, presumably due to the lack of air containing chambers, such as a swim bladder, in these animals. In experiments with dynamite explosives, which are more damaging than air guns, shrimps were unaffected beyond 15 metres from the source (Gowanloch & McDogall 1946 as cited by Falk & Lawrence 1973). In studies with Dungeness crab (*Cancer magister*), no significant effects were detected on crab larvae exposed to high pressure levels from air guns (peak level 230 dB re 1 µPa) at a distance of 1 metre. This result suggests that crab larvae may be more resistant to effects of energy released from air guns than are fish eggs or fish larvae (Pearson et al. 1994).

3.3 Seabirds and seismic activity

Little work has been done in relation to the effects of seismic surveys on seabirds (Turnpenny & Nedwell 1994). Fulmars (*Fulmarus glacialis*), black-legged kittiwakes (*Rissa tridactyla*) and thick-billed murres (*Uria lomvia*) seem to be unaffected by noise from chemical explosives and air gun shooting in open water (Stemp 1985 *in* Turnpenny & Nedwell 1994). However, these results may not apply to inshore waters, where breeding and moulting take place.

Helicopters, can cause significant disturbance in seabird colonies and seaduck moulting areas. Research suggest that helicopter traffic should maintain a minimum distance of 3 to 6 km from thick-billed murre colonies, depending on traffic intensity (Fjeld et al. 1988, Olsson & Gabrielsen 1990).

3.4 Marine mammals and seismic activity

Seals

The information that is available regarding the reaction of seals to seismic surveys is limited (Davis et al. 1991). Grey seals (*Halichoerus grypus*) seem to be relatively tolerant to disturbance by noise from air guns, and it is expected that if seals are attracted to an area for feeding or breeding they will be rather tolerant to disturbance from underwater noise (Richardson et al. 1995). Aircrafts are known to disturb animals on land in particular (Richardson et al. 1995). Stampedes among walrus (*Odobenus rosmarus*) herds, for example, have been documented. As a result, helicopter flights should be avoided close to the walrus haul out localities in especially Northeast Greenland.

Whales

Because of the intermittent nature of the seismic noise there is no risk that this can mask marine mammal communication. Nevertheless, marine mammals may react to seismic operations anyway. Gray whales (*Eschrichtius robustus*) and bowhead whales (*Balaena mysticetus*) have been observed behaving normally in the presence of strong noise pulses from seismic vessels several kilometres away. However, most gray and bowhead whales interrupt their activities and swim away when a full-scale, pulse emitting seismic vessel approaches within a few kilometres (Richardson et al. 1995). In an experiment with humpback whales, reactions to pulses of a 1.62-L air gun were observed on a summering ground in Southeast Alaska. The whales were scared at distances of up to 3.2 kilometres when the air guns were first turned on. However, this response did not persist (Malme et al. 1985, cited in Richardson et al. 1995). Opportunistic observations of different whale species during seismic activities are equivocal with observations of bowheads swimming rapidly away from a seismic vessel at a distance of 24 kilometres (Koski and Johnson 1987 in Davis et al. 1991), and minke whales (*Balaenoptera acutorostrata*) apparently approaching a seismic vessel to a distance of 100 metres during shooting (J. Durinck pers. comm.). Sonars and similar pulsed sources may elicit quieting or avoidance behaviour by sperm and humpback whales, as documented by Richardson et al. (1995). Even though toothed whales have poor hearing sensitivity at low frequencies, they are quite sensitive to noise. Sperm whales have been observed reacting to seismic pulses at distances of more than 50 kilometres (Mate et al. 1994). Smaller toothed whales such as belugas (*Delphinapterus leucas*) and narwhals (*Monodon monocerus*) are also known to be sensitive, and reactions of alarm calls from belugas have been recorded at distances of up to 105 kilometres from a ship approaching in ice covered waters of the Canadian High Arctic (Finley et al. 1983 cited in Davis et al. 1991). However, the whales usually resume their normal behaviour within 48 hours after a disturbance.

4 Environmental Impact in the Area of Investigation

According to the regulations by BMP all activities that relates to petroleum exploration can only be carried out if an environmental impact assessment including effects on local communities (incorporating subsistence harvest), fish, marine mammals, and birds has been accomplished.

4.1 Areas outside the 3 nautical miles limit

4.1.1 Fish and fishery

Fish

Seismic activity may cause fish populations to leave an area temporarily. This can be harmful in spawning areas and it may have an effect on fishery.

The sand eel (*Ammodytes sp.*) is the only important fish species spawning in the offshore area during the summer period when seismic activity is expected to take place (Table 1). Sand eels are an important prey item to commercially important fish species, e.g. cod and salmon. How sand eels react to seismic activity is unknown. However, small fish in general seem to be less sensitive than larger fish. Furthermore, fish without a swim bladder, such as sand eels, are also less sensitive than fish with a swim bladder. It is therefore likely that any response to seismic activity by the sand eels will be minor. Some displacement is possible during spawning. However, the spawning areas which cover a large part of the fishing banks in West Greenland (Pedersen & Smidt 1995) does apparently not contain spawning concentrations. The disturbance from a regional seismic survey will be transient because the seismic vessel will pass through the area quickly, and no significant effects are expected.

As the frequency of seismic surveys in West Greenland increase further studies on spawning concentrations will however be needed to secure minimal impact. Further knowledge on spawning concentrations, e.g. for cod, will also be in demand if seismic surveys are going to be conducted during spring.

As the seismic pressure waves are attenuated rapidly when they move into shallow waters capelin and lumpsucker, which spawn near the shoreline in April – June, will not be significantly affected by offshore seismic.

Regional seismic surveys can cause temporary migration of fish and changes in behaviour, which can have both a positive and a negative effect on catchability. However, the noise impact in a regional seismic survey will be so transient that the impact on fisheries is expected to be insignificant.

Shrimps

Information on the effect of seismic pressure waves on shrimp (*Pandalus borealis*) is limited, but the study on crab larvae (section 3.2) indicates that there is no reason to expect significant effects on shrimp populations.

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Species	Main habitat	Spawning area	Spawning period	Exploitation
Deep sea shrimp (*Pandalus borealis*)	mainly offshore, 100 -600 m depth	larvae released at relatively shallow water (100-200 m), larvae in middle of water-column	(July -September) larvae released March to May	important c
Snow crab (*Chionoecetes sp.*)	coastal and fjords, 180-400 m depth		larvae released April-May	c
Atlantic cod (*Gadus morhua*) (offshore stock)	on banks north to 64°	(former) western slope of banks, pelagic eggs and larvae in upper water column	March-April,	See text
Greenland cod (*Gadus ogac*)	inshore / fjords	inshore / fjords, demersal eggs	February-March	c & s
Arctic cod (*Boreogadus saida*)	pelagic	mainly north of 68°N		no
Sand eel (*Ammodytes sp.*)	on the banks at depths between 10 and 80 m	on the banks, demersal eggs, larvae in the water column	June - July to 66° N later in the north	no, important prey item
Wolffish (*Anarhicas minor*)	inshore and offshore	hard bottom, one area known outside Maniitsoq, demersal eggs	peaks in September	c & s
Atlantic salmon (*Salmo salar*)	offshore and coastal	freshwater	-	c & s
Arctic char (*Salvelinus alpinus*)	coastal, fjords	freshwater	-	c & s
Capelin (*Mallotus villosus*)	coastal*	beach, demersal eggs	April-June	c & s, important prey item
Atlantic halibut (*Hippoglossus hippoglossus*)	offshore and inshore, deep water,	? western slope of banks south of 66° N , pelagic eggs and larvae, deep water	winter	c& s
Greenland halibut (*Reinhardtius hippoglossoides*)	offshore and inshore, deep water,	offshore south of 66° N, deep water, pelagic eggs and larvae	spring	important c & s
Redfish (*Sebastes spp.*)	offshore and in fjords, 150-600 m depth	main spawning south-west of Iceland, larvae drift to West Greenland banks	-	mainly bycatch & s
Lumpsucker (*Cyclopterus lumpus*)	pelagic	coastal, demersal eggs	May-June	c & s

Table 1. Important fish and large invertebrate species in the West Greenland area.

Exploitation of the species is categorised in c: commercial and s: subsistence fishery.

* There is also a spawning area of capelin off the south-east coast of Iceland.

4.1.2 Seabirds

Seabirds appear to be unaffected by air gun emissions (Turnpenny & Nedwell 1994), although the number of systematic studies is low. Breeding seabirds (especially Brünnichs guillemots / thick-billed murre) and moulting eiders (Somateria sp.) are vulnerable to disturbance by helicopter flights, and attention should be paid to this. (cf the BMP-rules (Anon. 1999a and b).

4.1.3 Mammals

Seals

Seals seem to be quite tolerant, and given the large numbers and even distribution of most Greenland seal species, seals are not regarded as vulnerable to 2D seismic operations.

Whales

Belugas and narwhals are known to migrate seasonally between their summer and winter habitats. Little information is available on what determines the whales' migration routes or their habitat preference. Current knowledge indicates that not all of the marine environment is explored by the whales, and that various genetically distinct stocks are specialised to occupy different ecological niches. Hence, the narwhals from the Melville Bay population seem to follow well-defined migration routes on the continental shelf on their southward migration in October - November. Such "corridors" may in certain areas be as narrow as 20 kilometres wide (Dietz & Heide-Jørgensen 1995). Other species such as belugas may have to choose where they prefer to winter. Individuals of the West Greenland stock which winter in the "Northwater" (year-round open water polynia in the mouth of Smith Sound) or off Central West Greenland have to make a choice between the two areas in September (Heide-Jørgensen & Dietz 1996). The considerable distance and the formation of ice leave no possibilities for later alteration of decisions. A wrong decision may prove fatal. Freeze up of the open water may cause the well known "sassats", where hundreds of whales may be caught in the ice and eventually die (Siegstad & Heide-Jørgensen 1994). An alteration due to disturbance of such natural migration routes can therefore be of great importance to the hunting communities which are heavily dependant on seasonal catches of whale species such as belugas and narwhals.

Heavy shipping and seismic activity have the potential of affecting the migratory routes selected by the whales. The duration, timing, and area in question may be critical. Seismic activity should be avoided in areas where populations are migrating in large herds. For the belugas, the critical areas are the "Northwater" and Melville Bay in September. The same areas are critical for narwhals in October. The bowhead whale may have similar vulnerability during its southward migration. However, available information on this rare species is limited, and the majority of the whales probably follow the Canadian shore (Boertmann et al. 1998, Mosbech et al. 1998).

Other whale species that are not as strongly associated with ice are not as vulnerable to disturbance of their migratory patterns. However, to minimise disturbance of marine mammals in general it is good code of conduct that the array of air guns shall be started gradually over a period of 20 minutes and that the array of air guns shall not be started within 500 m of a group of large whales (two or more individuals of e.g. humpback whales). This code of conduct is included in the BMP rules (Anon 1999a).

4.1.3.1 Zonation in relation to narwhal distribution

As previously outlined toothed whales and in particular white whales and narwhals are believed to be very sensitive to disturbances. Due to this fact the seasonal distribution of narwhals have been studied by use of satellite transmitters. The distribution of Greenlandic and Canadian narwhals is shown in Fig. 4. The distribution within Greenland waters has been divided into three areas based on the knowledge on the summer, autumn and winter distribution.

The three geographical areas reflect the main habitats in different periods and are defined as follows:

Area I:
The Melville Bay summering population has its main distribution area within a region defined by the following co-ordinates (see Fig. 4):

No.	longitude	latitude
1	58°26.24'W	75°18.53'N
2	58°52.70'W	75°39.24'N
3	59°35.20'W	75°45.16'N
4	60°29.09'W	75°56.91'N
5	62°29.59'W	76°10.30'N
6	63°40.44'W	76°2.36'N
7	65°3.19'W	75°58.22'N
8	64°54.56'W	75°38.09'N
9	61°28.30'W	75°4.80'N
10	59°24.41'W	75°10.43'N

A substantial part of this area is already covered by the Melville Bay Nature Reserve, where sailing, flying and hunting is prohibited. The narwhals are present in Area I from 15 July to 25 October, where seismic operations should be minimised or avoided.

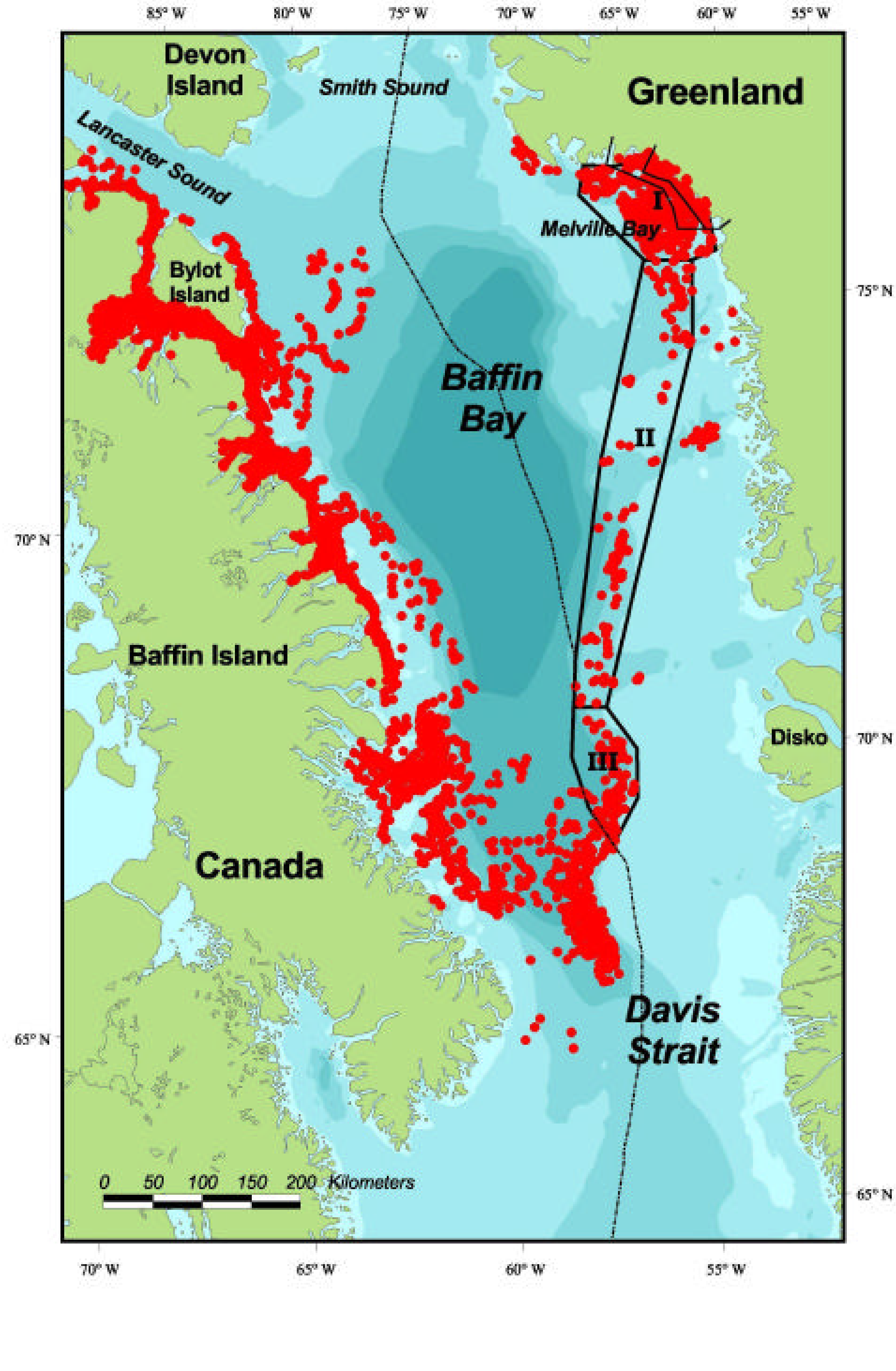

Figure 4. Map showing narwhal distribution and the three main Areas within the Greenland part of the sea between Greenland and Canada. In addition the Melville Bay Nature Reserve is shown. (Source: Dietz & Heide-Jørgensen unpublished).

Area II:
From 15 October to 1 December narwhal will be migrating through this region which is defined by the following approximate co-ordinates:

9	61°28.30'W	75°4.80'N
10	59°24.41'W	75°10.43'N
11	58°52.70'W	74°15.25'N
12	60°1.02'W	70°5.56'N
13	61°3.75'W	70°2.05'N
14	61°17.10'W	70°32.61'N
15	61°42.99'W	72°46.08'N

The area between 75°10'N and 70°00'N is well defined by the continental slope with depths between 500 to 1500 m as this passage is transient and based on relatively few tagged individuals. No regulations are proposed for this area at the moment.

Area III:
In the period between 15 November and 30 March the narwhals stay in their wintering area which is also defined by the continental slope with depths between 500 to 1500 m. More than half of the wintering area is in Canadian waters. The Greenland part of this area is defined by the co-ordinates:

12	60°1.02'W	70°5.56'N
13	61°3.75'W	70°2.05'N
16	60°50.51'W	69°28.81'N
17	60°5.33'W	68°57.53'N
18	59°9.47'W	68°36.02'N
19	58°37.17'W	69°9.19'N
20	58°50.40'W	69°41.41'N

This region is particularly critical to the narwhals, and therefore any seismic activities should be avoided during this period. The narwhal distribution is also limited by the extensive ice coverage, which may reduce the area available for the narwhals with more than 90% of the surface area. Furthermore, the region houses a substantial part of both the Canadian and Greenlandic narwhal population. The social structure and exchange between these two populations have so far not been elucidated.

4.2 Areas inside the 3 nautical miles limit

Some seismic operations may take place within the 3 nautical miles limit, e.g. at Scoresby Sund (Kangertittivaq), Disko Bugt (Qeqertarsuup Tunua) and in Vaigat (Sullorsuaq).

As the seismic pressure waves generally are attenuated rapidly in shallow waters capelin and lumpsucker, which spawn near the shoreline in April – June will not be significantly affected by seismic unless it is quite close. NERI (Nielsen et al. 2000, Mosbech et al. 2000) has mapped the spawning areas for capelin and lumpsucker between Paamiut and Aasiaat, and seismic operations close to these spawning areas should be avoided in the spawning period.

In coastal waters disturbance, especially helicopter flights, can have a negative impact in areas with breeding seabirds and mammals, or moulting birds. To mitigate this impact BMP has developed rules for traffic (aviation and navigation) in areas and periods of particular significance to wildlife (Anon. 1999a and b).

5 Conclusion

Seismic surveys, not employing explosive charges, rarely cause physical injuries to animals. Accordingly, disturbance of behavioural patterns is the focus of concern.

Some of the fish stocks on the east and west coasts of Greenland could probably be displaced temporarily during seismic surveys. Part of the spawning area of sand eel on the west coast may be disturbed. However, as these areas are not regarded as high concentration areas no mitigative measures are suggested for the current level of seismic activity.

Capelin and lumpsucker spawn in April – June at shallow water near the shoreline. Seismic surveys should be avoided close to these spawning areas during spawning. However, seismic operations outside the 3 nautical miles limit will not impact these spawning areas.

Effects on shrimp populations are not expected from seismic shooting nor are any effects on seabirds.

Seals seem to be quite tolerant to seismic activity and no regulations are recommended for these species. Whales, especially toothed whales, may react to noise at distances of up to more than 50 kilometres. Toothed whales, narwhals and belugas in particular, concentrate primarily in fiords and close to land during summer outside likely survey areas. So far an important summering area has been identified in Melville Bay, where narwhals are present from 15 July to 25 October. Seismic operations should be minimised or avoided in area I (Figure 4) in the period mentioned.

Traffic, especially helicopter flights, can cause disturbance in important wildlife areas (e.g. seabird colonies, moulting areas and marine mammal haul-out sites). Traffic should therefore be minimised in these areas as stipulated in the BMP-rules (Anon 1999a and b).

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