Research Notes from NERI No.: 80

Preliminary Environmental Impact Assessment of Regional Offshore Seismic Surveys in Greenland

Arktisk Miljø/Arctic Environment

Ministry of Environment and Energy, National Environmental Research Institute

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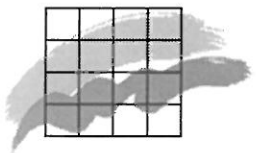
Josephine Nymand
Anders Mosbech
Rune Dietz
Department of Arctic Environment



Ministry of Environment and Energy
National Environmental Research Institute
1998

Data sheet

Title:	Preliminary Environmental Impact Assessment of Regional Offshore Seismic Surveys in Greenland. Arktisk Miljø/Arctic Environment.
Authors:	Josephine Nymand, Anders Mosbech & Rune Dietz
Department:	Department of Arctic Environment
Serial title and no.:	Research Notes from NERI No. 80
Publisher:	Ministry of Environment and Energy National Environmental Research Institute ©
URL:	http://www.dmu.dk
Date of publication:	March 1998
Referee:	Poul Johansen
Please quote:	Nymand, J., Mosbech, A. & R. Dietz (1998): Preliminary Environmental Impact Assessment of Regional Offshore Seismic Surveys in Greenland. Arktisk Miljø/Arctic Environment. National Environmental Research Institute, Denmark. 21pp. - Research Notes from NERI No. 80.
	Reproduction is permitted, provided the source is explicitly acknowledged.
Keywords:	Environmental Impact, Seismic.
ISSN:	1395-5675
Number of pages:	21
Price:	DKK 45,- (incl. 25% VAT, excl. freight)
For sale at:	National Environmental Research Institute P.O.Box 358, Frederiksborgvej 399 DK-4000 Roskilde, Denmark Tel: +45 46 30 11 00 Fax: +45 46 30 12 14
	Miljøbutikken Information and Books Læderstræde 1 DK-1201 Copenhagen K Denmark Tel.: +45 33 37 92 92 Fax: +45 33 92 76 90

Contents

Summary

The present report summarises potential environmental problems related to conducting seismic surveys offshore Greenland during summer and late 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 seismic energy source used in Greenland waters by "Thetis" consists of a four string air gun array, which is towed at a dept of 6 metres. The operating pressure ranges 12.4-13.8 Mpa. The streamer is 3 kilometres long and is towed at an average depth of 8 metres.

Fish

The effect of seismic activity on fish populations is considered to be insignificant. 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. Fish larvae and fry, which are less mobile, may get killed by the pressure waves within few metres from the energy source; this, however, is insignificant to the recruitment to the stock.

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 on land are, however, sensitive to disturbance by aircrafts so helicopter flights should 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 resumes 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.

In general, no mitigative measures are suggested for the areas shown in Fig. 1, apart from the MRA-rules.

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 Strait (Sullorsuaq) 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. Inshore areas defined as sensitive have been compiled from 'Nalunaarutit - Grønlandsk Lovsamling, Serie B og D', which is the collection of laws and regulations of Greenland, updated 1996, and from 'Rules for Field Work and Reporting Regarding Mineral Resources (Excluding Hydrocarbons) in Greenland', Anon. 1996 (unofficial translation) (below referred to as MRA-rules).

Emphasis in the report is on the effect of seismic shooting, however potential disturbance from support operations especially helicopter flights are also covered.

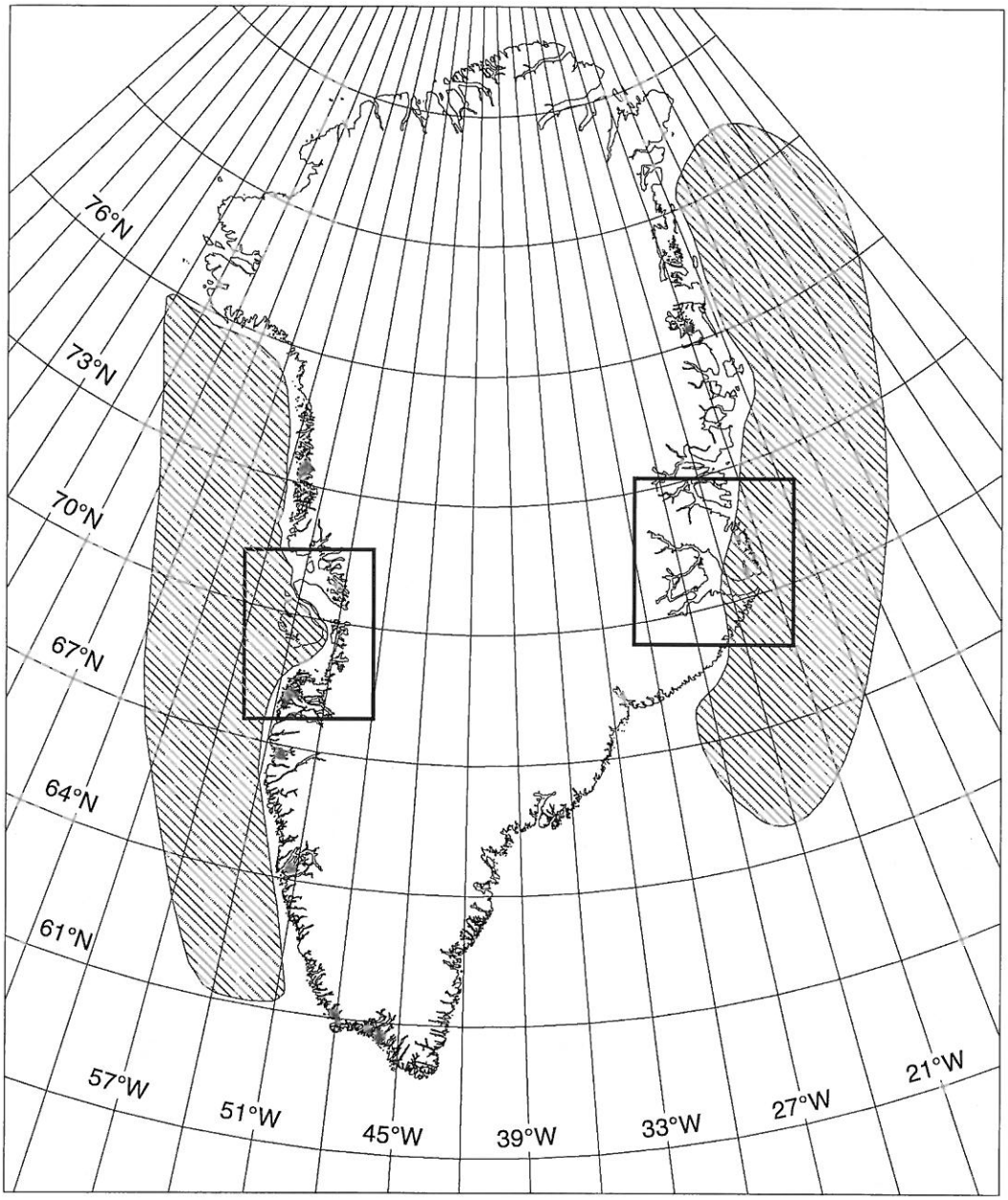


Figure 1. Map of Greenland. The hatching shows the potential areas of investigation. The rectangles show the potential areas of investigation inside the 3 nautical miles limit.

1.1.1 East Greenland

In East Greenland the potential area of investigation stretches from Ammassalik (app. 65°30'N) to Nordostrundingen (app. 81°30'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 zone of investigation covers the area from south of Fyllas Banke (app. 61°N) to Kap York (Innaanganeq) (app. 76°N). 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 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.

The type of energy source used by "Thetis" in former surveys, consists of a four string air gun array, which is towed at a depth of 6 metres. A number of air guns are attached to each string, and both the inner and the outer array length is 14.2 metres. The operating pressure ranges 12.4 - 13.8 MPa. The streamer is 3 kilometres long and it is towed at an average depth of 8 metres (Final Report Nunaoil A/S, KANUMAS - 1992).

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.

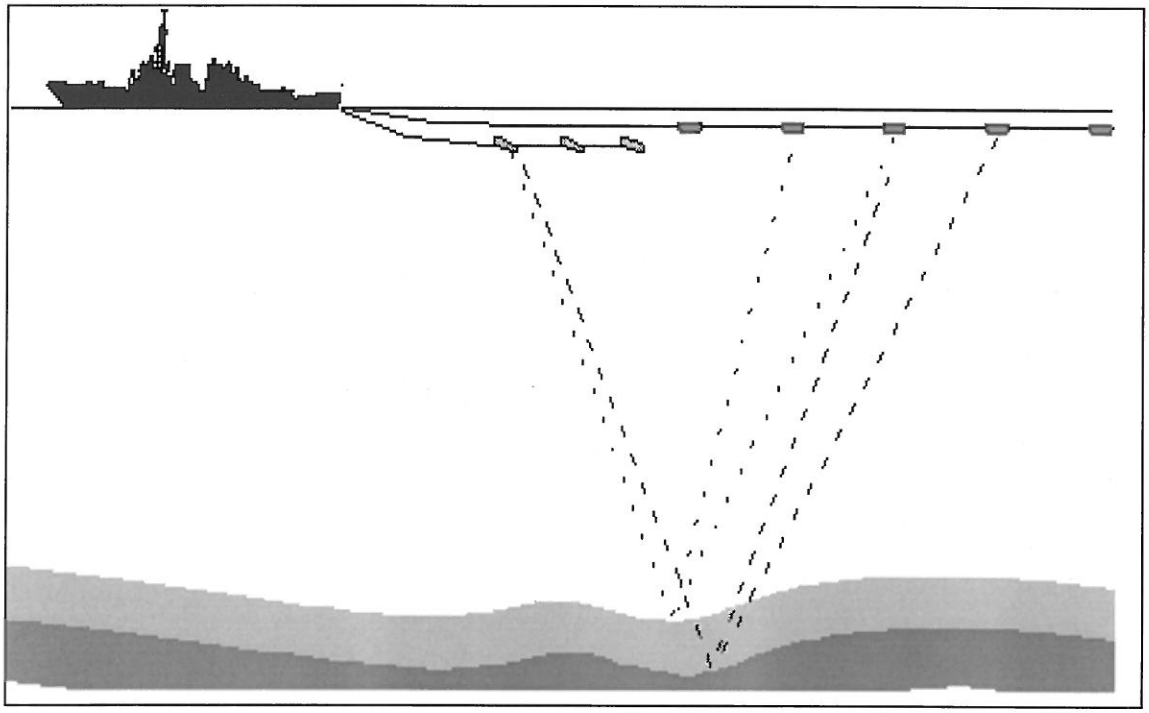


Figure 2. A seismic vessel with air guns and a single streamer. The strong sound signal can affect fish and marine mammals.

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, ice-breaking-up 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 and Ona 1995), 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 (*Gadus 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 lines 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. These results are surprising considering decades of coexistence of fishery and oil exploration, in the North Sea for example.

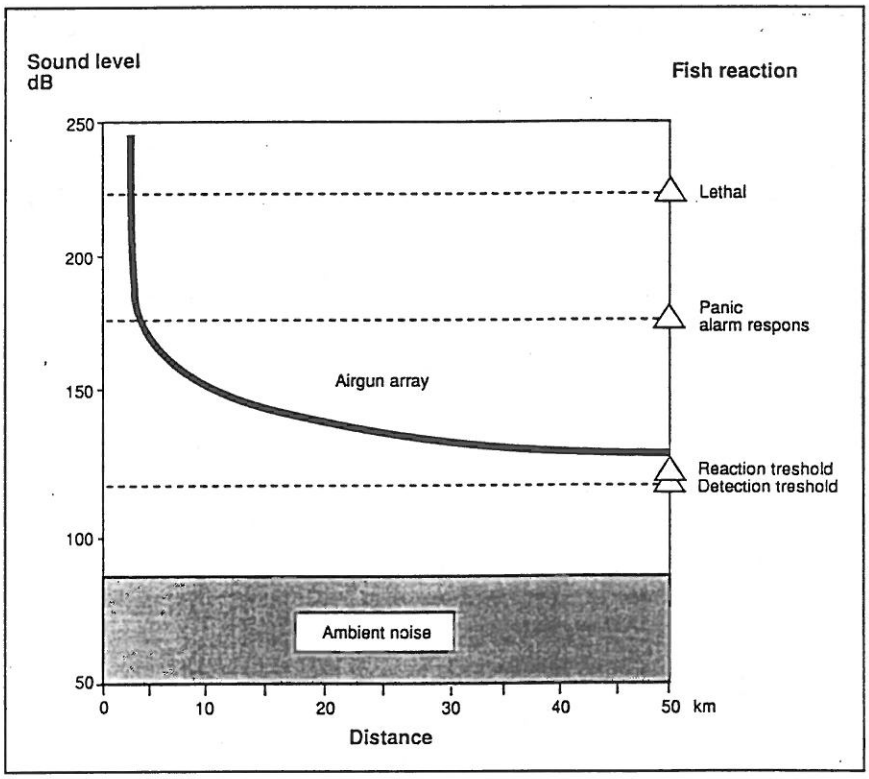


Figure 3. Generalised responsiveness of cod to sound pressure levels. The sound pressure levels versus distance of an array of air guns are given as well as the ambient noise level. The sound pressure level from the air gun is reduced to less than 200 dB within the first kilometre (modified from Nakken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

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). Gray 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 seismic noises 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 Mineral Resources Administration for Greenland, oil companies should pay attention to the environmental impact of the regional offshore seismic operations on local communities (including subsistence harvest), fish, marine mammals, and birds.

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 apparently cover a large part of the fishing banks in West Greenland (Pedersen & Smidt 1995) are not regarded as being a concentrated spawning area. 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.

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 as the study on crab larvae clearly indicates (section 3.2) there is no reason to expect significant effects on shrimp populations.

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

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) released March to May	important c
Queen crab (*Chionoecetes sp.*)	coastal and fjords, 180-400 m depth		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

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 and moulting eiders (*Somateria sp.*) are vulnerable to disturbance by helicopter flights, and attention should be paid to this by following chapter 2 of the MRA-rules.

4.1.3 Mammals

Seals

Seals seem to be quite tolerant, and given the great number 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 winters in the Northwater 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 leaves no possibilities for later alteration of decisions. A wrong decision may prove fatale. 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 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 the 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. 1992).

Other whale species which are not as strongly associated with ice, are not as vulnerable to minor delays in their migratory patterns.

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) and at Vaigat Strait (Sullorsuaq). The operator should be aware of chapter 2 of the MRA-rules when operating in coastal waters, especially regarding helicopter flights in areas with breeding seabirds and mammals, or moulting birds. Chapter 2 of the MRA-rules states, among other things, that helicopter flights should remain a minimum of 500 metres above ground or sea level, unless otherwise prompted by weather conditions or aviation regulations.

Melville Bay

Operators should be aware of the navigation and flying restrictions in this area (Bekendtgørelse fra rigsombudsmanden i Grønland om fredning af Melville-bugten af 27. juni 1980). Restrictions in this area include, among other things, all sailing.

5 Conclusion

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

Some of the fish stocks on the east coast and the west coast of Greenland will probably make temporary migrations 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, and as sand ells are only considered to have minor reaction, no mitigative measures are suggested. No effects on shrimps are expected 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 more than 50 kilometres. Toothed whales, narwhals and belugas in particular, concentrate primarily in fjords and close to land during summer outside planned survey areas. From the end of September (app. from September 20) until the beginning of October (app. October 1) the belugas migrate southwards across the Melville Bay and along the west coast of Greenland. In October, the narwhals migrate through the same area. During this period the area most vulnerable to disturbance is the area north of 75°30'N and toward the coast of Melville Bay. It is recommended that the seismic programme is planned so as to avoid the Melville Bay area north of 75°30'N from September 20 to October 15.

Helicopter traffic near seabird colonies can cause disturbance, and helicopter traffic is therefore regulated by rules of the MRA.

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Addresses:

URL: http://www.dmu.dk

National Environmental Research Institute
Frederiksborgvej 399
PO Box 358
DK-4000 Roskilde
Denmark
Tel: +45 46 30 12 00
Fax: +45 46 30 11 14

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Department of Policy Analysis
Department of Marine Ecology and Microbiology

National Environmental Research Institute
Vejlsøvej 25
PO Box 413
DK-8600 Silkeborg
Denmark
Tel: +45 89 20 14 00
Fax: +45 89 20 14 14

Department of Lake and Estuarine Ecology
Department of Terrestrial Ecology
Department of Streams and Riparian areas

National Environmental Research Institute
Grenåvej 12, Kalø
DK-8410 Rønde
Denmark
Tel: +45 89 20 17 00
Fax: +45 89 20 15 14

Department of Landscape Ecology
Department of Coastal Zone Ecology

National Environmental Research Institute
Tagensvej 135, 4
DK-2200 København N
Denmark
Tel: +45 35 82 14 15
Fax: +45 35 82 14 20

Department of Arctic Environment