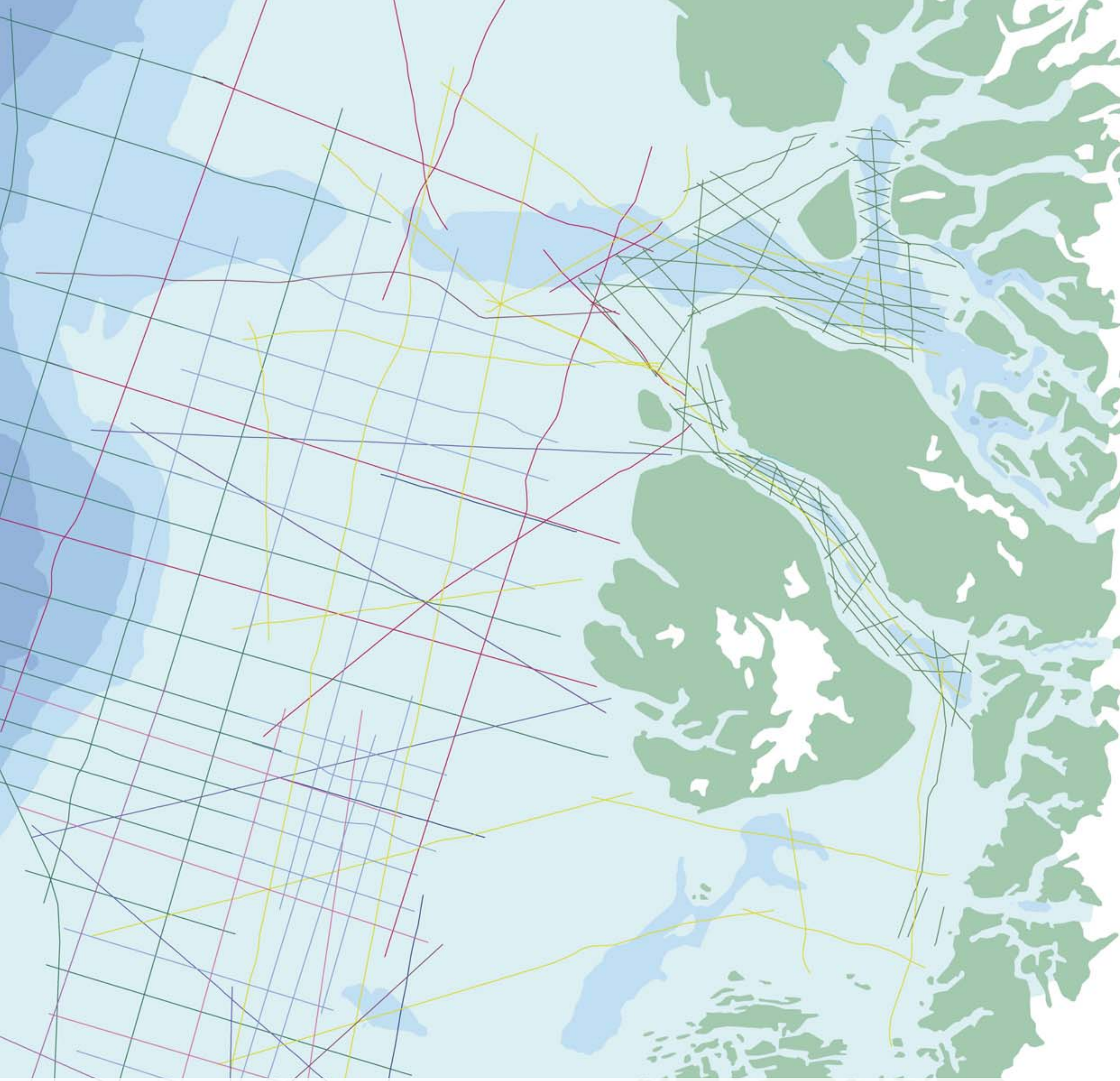

GUIDELINES TO ENVIRONMENTAL IMPACT ASSESSMENT OF SEISMIC ACTIVITIES IN GREENLAND WATERS

2nd edition

NERI Technical Report no. 785 2010

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Abstract: This report is meant as a guideline for companies preparing environmental impact assessments of seismic surveys in ice free Greenland waters. The current knowledge on impacts on marine mammals, fish and invertebrates of seismic surveys is reviewed and a set of 'best practice' actions for conducting these surveys in relation to marine mammals is given. A number of protection zones for sensitive marine mammals (walrus, narwhal and bowhead whale) are designated and maps indicating the most important offshore fishing grounds are provided.

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Summary

This report is meant as a guideline for companies preparing environmental impact assessments of seismic activities in ice free Greenland waters.

Protection zones

A number of protection zones for sensitive marine mammals (walrus, narwhal and bowhead whale) are designated and maps indicating the most important offshore fishing grounds are provided.

Best practice

The current knowledge on impacts on marine mammals, fish and invertebrates of seismic surveys is reviewed and a set of 'best practice' actions for conducting these surveys in relation to marine mammals is given.

The 'best practice' actions required in Greenland (by the Bureau of Minerals and Petroleum) are in line with the UK regulation (JNCC (2009) recommendations), which is also adopted for the regulation in many other areas.

- The airgun array should not be larger than needed for the specific survey.
- A safety zone of 500 m from the airgun array shall be applied.
- A pre-shooting search shall be conducted before commencement of any use of the airguns. If waters are less than 200 m deep, this search shall last 30 min. If waters are more that 200 m deep, it shall be extended to 60 min. If marine mammals are spotted within the safety zone, the ramp-up procedure shall be delayed 20 minutes, from the time when the animal has left the safety zone (or the ship has moved so far that the animal is outside). The pre-shooting search can be initiated before the end of a survey line, while the airguns are still firing
- The array shall not be started at full power, but individual airguns should be added one by one or if not possible, output of each airgun slowly increased by manipulation of pressure (ramp-up or soft start procedure).
- The ramp-up procedure shall occur over a period of about 20 min and can occur while the survey ship is en route to the starting point of the transect line.
- Ramp-up should not be initiated if marine mammals are inside the array or within the safety zone (500 m) of the array. If marine mammals are discovered within this safety zone during the ramp-up procedure, the airguns shall be turned off, and a new ramp-up procedure initiated when the mammal has left the safety zone - i.e. at least 20 min. after the last sighting.

- If proper ramp-up cannot be performed for technical or other reasons, other measures should be taken to assure that no animals are within the safety zone at start up.

- If the array is shut down for any reason while on the transect line it can be re-initiated at full power given that the silent break is not longer than 5 min. Otherwise a full ramp-up procedure should be followed.

- The array should be shut down completely between lines, if the transit time is longer than the time it takes to conduct a ramp-up and a full ramp-up should be initiated prior to arrival at the next line. If transit time is less than 20 min the array can be operated during transit, preferably at reduced power output.

- A Marine Mammal and Seabird Observer (MMSO) shall be posted on the source vessel (where the airguns are deployed from) and be continuously on the look-out particularly for whales during the pre-shooting search and when airguns are operated.

- Observation of marine mammals during shooting and inside the safety may not lead to shutdown.

- A log of marine mammal observations should be kept on the ship and reported as part of the cruise report.

- Passive Acoustic Monitoring (PAM) of vocalizing whales can be deployed for monitoring purposes especially in areas with bowhead whales. But it is not a demand.

- Airguns should not be used outside the transect lines, except in the cases mentioned above (ramp-up prior to arrival and on short transit lines) and for strictly necessary testing purposes. Testing the array at full power should be initiated with a ramp-up procedure as above.

Manrine mammal and seabird observers (MMSOs)

At least two Marine Mammal and Seabird Observers (MMSOs) shall be on board the seismic vessels operating in Greenland waters in order to observe continuously when operating the airguns. They shall be especially trained in observation methodology and seismic mitigation.

The MMSOs have two tasks. Firstly, they have to watch systematically for marine mammals before start-up and during seismic survey in order to mitigate and observe safety distances to whales and seals.

Secondly, the MMSOs shall collect data on abundance and distribution of seabirds and marine mammals through systematic surveys. This task shall be carried out both during times when seismic survey is conducted, and when sailing in transit.

The latter task is not secondary to the former, and considerable effort should be spent on the systematic surveys.

The purpose of the second task is to improve the knowledge on temporal and spatial distribution of marine mammals and seabirds in the West Greenland waters, which generally is low. The collected data will be included in the NERI-databases of background information. The information in these databases will constitute the basis for future EIA-work by NERI and is moreover available to the companies which shall operate in Greenland waters and prepare EIAs of their activities. Data have to be collected according to NERI standards to fit into the databases, and guidelines to observation methodology will be provided when a seismic survey is approved by BMP.

1 Introduction

Commercial seismic surveys in Greenland waters are regulated by the Bureau of Minerals and Petroleum (BMP). Requirements and documentation is described in 'Seismic survey standards for offshore West Greenland' (Link). It is stipulated that the licensee shall prepare an environmental protection plan, which shall include an Environmental Impact Assessment of the activities.

In 2000 NERI issued a report 'Preliminary Environmental Impact Assessment of Regional Offshore Seismic Surveys in Greenland' (Mosbech et al. 2000), which was meant as guidelines to companies preparing the Environmental Impact Assessment. These guidelines were updated in 2009 (NERI report 732), and are now updated again.

The major environmental concern related to seismic surveys in Greenland waters relates to marine mammals (especially whales) and fish (including the fisheries), cf. the Strategic Environmental Impact Assessment reports from the northern Davis Strait and Baffin Bay (Mosbech et al. 2007, Boertmann et al. 2009a) and western Greenland Sea (Boertmann et al. 2009b). Therefore marine mammals and fisheries will be in focus here. More detailed accounts of marine mammals and fish in Greenland waters can be found in three regional strategic environmental impacts assessment (Mosbech et al. 2007, Boertmann et al. 2009a, 2009b).

The purpose of this report is to guide companies when they prepare EIA's of their seismic activities in Greenland waters.

However these guidelines do not include the general activities and their impacts such as emissions to air, waste handling etc. They should nevertheless be considered in an EIA of a seismic survey in Greenland waters.

Only activities in the favourable season for conducting seismic surveys – that is in the summer and fall (mid-June through October) are considered. This is the time of the year when ice conditions are most suitable. Furthermore, the North Greenland region (to the north of 78° in West and to the north of 81° N in East) is not included. If seismic surveys are planned outside the indicated season or in waters to the north of 77° in West Greenland and 81° in East Greenland, these guidelines do not apply and a detailed specific assessment for each survey will have to be made.

See Figure 1 for an overview of Greenland.

Figure 1. Overview of Greenland. Major towns and the National Park in North and East Greenland (hatched line) shown.

2 Sound levels

The sound source for seismic exploration of the seabed and underlying formations usually is an array of airguns.

Airgun arrays are composed of a smaller or larger number of airguns of different volumes. When properly designed the entire airgun array, when fired simultaneously, produces a sound signal which is very short (tens of ms) and essentially monocyclic, meaning that it contains one large positive pressure peak followed by a rarefaction of similar magnitude. However, this is only true in the far field of the array, i.e. at distances roughly beyond several times the largest dimension of the array (few hundred meters for the smallest arrays). In the far field, the sound behaves as if it originated from a single point in space and thus in general obeys rules of geometric spreading loss with downward distance from the centre of the air gun array. This leads to the possibility of back-calculating a source level of the entire array, which is a fictious number, equal to the pressure 1 meter from a point sound source located at the centre of the array and capable of producing a similar sound as the one observed in the far field. The source level (SL) is a convenient way to normalize sound pressure measurements and is useful as single number to characterize the combined acoustic output of the array. However, as the array is not a point source, but an array of widely spaced sources, the actual sound pressures which can be measured inside the array (in the near field) is always considerably lower than the combined source level. This point is of particular importance when discussing the potential of the sounds to inflict damage to marine mammals.

2.1 Explosives

The above discussion of the fictious nature of the source level in relation to actual sound pressures near an airgun array does not apply to explosive sources, exactly because these are point sources. In this case the sound pressures close to the explosion can reach very high and potentially lethal levels. Thus, a different assessment of possible effects of explosive seismic sound sources is strongly recommended whenever explosive detonations are to be used in seismic surveys and the guidelines in this report cannot be used.

2.2 Transmission loss of seismic survey sounds

It is customary in many connections, including impact assessments, to assume that sound intensity falls off smoothly with distance from the source. This may be modelled as simple geometric spreading, either spherical (intensity falls off with distance squared) or cylindrical (intensity falls linearly with distance). However, for loud sound sources in deeper waters this simplification does not hold, as vertical (and sometimes horizontal) gradients in sound speed cause refraction of the sound waves. This has several consequences, of which two are highly relevant for seismic surveys in arctic waters.

One is the entrapment of sound in low velocity layers in the water column, which can lead to transmission of sounds with very little loss over extended distances (hundreds of kilometres, if not more). In tropical and temperate waters the low velocity corridor is usually located in fairly deep waters (several kilometres), but in the cold arctic waters, it may occur at or close to the surface, making long range transmission in the corridor highly relevant for all species of marine mammals.

The second consequence of refraction is the appearance of shadow zones, where received levels are significantly lower than predicted from simple geometrical spreading, and associated convergence zones where received levels are greatly increased. A complex pattern of shadow zones and convergence zones means that even under normal and simple hydrographic conditions an animal swimming straight away from a sound source may sometimes find the received level to decrease and sometimes find it to increase (Madsen et al. 2006).

3 Seismic surveys and fish in Greenland waters

3.1 Adult 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 also 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 (3D). Negative effects on fish stocks may therefore occur if adult fish are scared away from localised spawning grounds during spawning season (see below). Outside spawning grounds, fish stocks are probably not affected by the disturbance, but fish can be displaced temporarily from important feeding and fishing grounds (Engås et al. 2003, Slotte et al. 2004).

Adult fish held in cages in a shallow bay and exposed to an operating air-gun (0.33 l, source level at 1 m 222.6 dB rel. to 1 µPa peak to peak) at a distance of 5–15 m, sustained extensive ear damage, with no evidence of repair nearly 2 months after exposure (McCauley et al. 2003). It was estimated that a comparable exposure could be expected at ranges < 500 m from a large seismic array (44 l) (McCauley et al. (2003). So it appears that the fish avoidance behaviour demonstrated in the open sea protects the fish from damage. In contrast to these results, marine fish and invertebrates monitored with a video camera in an inshore reef did not move away from airgun sounds with peak pressure levels as high as 218 dB (at 5.3 m relative to 1 µPa peak to peak) (Wardle et al. 2001). The reef fish showed involuntary startle reactions, but did not swim away unless the explosion source was visible to the fish at a distance of only about 6 m. Despite a startle reaction displayed by each fish every time the gun was fired, continuous observation of fish in the vicinity of the reef using time-lapse TV and tagged individuals did not reveal any sign of disorientation, and fish in unchanged numbers continued to behave normally, before, during and after the gun firing sessions (Wardle et al. 2001). Another study during a full-scale seismic survey (2.5 days) also showed that seismic shooting had a moderate effect on the behaviour of the lesser sandeel (*Ammodytes marinus*) (Hassel et al. 2004). No immediate lethal effect on the sandeel was observed, either in cage experiments or in grab samples taken during night when sandeel were buried in the sediment, but the startle reaction was widespread (Hassel et al. 2004).

The studies quoted above indicate that behavioural and physiological reactions to seismic sounds may vary between fish species (for example, according to whether they are territorial or pelagic) and also according to the seismic equipment used. Generalisations should therefore be interpreted with caution.

3.2 Spawning areas

Fish larvae and eggs (=ichtyoplankton) cannot avoid the pressure wave from the airguns and can be killed within a distance of less than 2 m, and sublethal injuries may occur within 5 m (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 in certain periods of the year may have very high densities of spawning fish and these areas in the Lofoten-Barents Sea are closed for seismic activities during the cod and herring spawning period in spring. This is mainly to avoid scaring away the ripe adult fish from the critical spawning areas, but also to prevent the killing of larvae and eggs that can be found in very high concentrations after spawning (Anonymous 2003).

The strategic environmental assessment form the Disko West area concluded that seismic activities most likely were negligible on the recruitment to fish stocks in West Greenland waters (Mosbech et al. 2007). Because densities of fish eggs and larvae generally are low in the upper 10 m and because most fish species spawn in a dispersed manner in winter or spring, with no temporal overlap with seismic activities. Sandeel (*Ammodytes spp.*) however spawn during summer. This takes place on the shelf waters and concentration areas are not known. Experiments in the North Sea indicate that sandeel show some behavioural reactions to seismic shooting, but are not displaced (Hassel et al. 2004). Capelin (*Mallotus villosus*) spawn in dense schools along coasts just below the low tide mark. As the sound pressure waves attenuate rapidly in shallow coastal waters, it is not likely that spawning capelin will be impacted from offshore seismic activities. Spawning takes place in late May and June, which also is earlier than the usual season for offshore seismic shooting. It is therefore most likely that impacts of seismic activity (even 3D) on the recruitment to fish stocks are negligible in Greenland waters as long as the seismic surveys are carried out in summer and autumn (July-October).

As mentioned above, parts of the Lofoten-Barents Sea are closed for seismic exploration when Atlantic cod are spawning in dense concentrations. Concentrations of spawning Atlantic cod are to day known from the Southeast Greenland shelf and in the Julianehaab Bight (ICES 2008, Retzel 2008). Spawning takes place here in April and May, but recently it was suggested that spawning in the waters off South Greenland also took place much later (July). This was examined in 2008, and the results could not confirm this late spawning and concluded that also here spawning takes place in the spring (April-May) (Retzel 2008). In these years the cod stock in Greenland is increasing, and if this development continues, it must be expected that the former spawning areas on the banks off West Greenland (north to about 65° N) will be reoccupied.

3.3 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 (trawl and longline) 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 of short term and catches would return to normal after the studies. The effect was more pronounced for large fish compared to smaller fish.

A recent study of 3D seismic survey impacts on gillnet and longline fisheries showed some contradicting results (Løkkeborg et al. 2010): Gillnet catches of Greenland halibut (*Reinhardtius hippoglossoides*) and redfish (*Sebastes* sp.) increased during seismic shooting and remained higher in the period after shooting. Longline catches of Greenland halibut, on the other hand, decreased. Saithe cathes in gillnet showed a tendency to decrease (but not statistically significant) during the shooting. However also acoustic surveys of fish densities indicated that saithe left the shooting area.

An analysis of the official catch statistics from an area with seismic surveys in Norway in 2008 also showed very different results (Vold et al. 2009): Catch rates of Atlantic cod (*Gadus morhua*), ling (*Molva molva*), tusk (*Brosme brosme*) and Atlantic halibut (*Hippoglossus hippoglossus*) were not changed significantly. Catch rates of redfish and monkfisk (*Lophius piscatorius*) seemed to increase, while catch rates of saithe and haddock caught in gillnet decreased and catches with other gear was not affected. The majority of the seismic surveys included in the analysis were 2D and scattered in time and space, why major influences on the fisheries was not expected.

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.

The commercial fisheries which may overlap with the seismic surveys in Greenland waters are primarily the offshore trawling for Greenland halibut (*Reinhardtius hippoglosoides*). However, the offshore fisheries for Atlantic cod (may increase in future years) and redfish (*Sebastes* spp.) also may overlap with areas with seismic activities.

Offshore capelin (*Malotus villosus*) has been fished in the waters between Iceland and Greenland, but not in recent years.

The only studies including Greenland halibut is the Norwegian mentioned above. They concerned gill net fishery and not trawl, why the results hardly can be applied to Greenland offshore conditions.

Greenland halibut is very different from Atlantic cod and haddock with respect to anatomy, taxonomy and ecology. For example is Greenland halibut without swim bladder, which means that their hearing abilities are reduced compared to fish with swim bladder. Moreover, the fishery takes place in much deeper waters than in the Norwegian experiments with haddock and Atlantic cod fisheries.

A Norwegian review (Dalen et al. 2008) concluded that the results described of Engås et al. (1995) and mentioned above cannot be applied to other fish species and to fisheries taking place in other water depths for example the Greenland halibut fishery in Greenland.

All in all, there is a risk of reduced catches in areas with intensive seismic activity. The effect will only affect specific fisheries for a period. The trawling grounds for Greenland halibut are, however, spatially restricted; they are found at specific depths at approx. 1,500 m and on the narrow continental slope; thus alternative fishing grounds may be limited.

It should be mentioned that the Norwegian studies showed an increased catch of Greenland halibut in gillnets. There are also other examples of this trend (Hirst & Rodhouse 2000), and it most likely is the result of changed behaviour (more moving around) of the fish.

3.4 Northern shrimp and snow crab

In general there is very little knowledge on the effects of seismic shooting on invertebrates, and studies and reviews express the need for research in this field and also concern for long-term effects (Christian et al. 2003, DFO 2004a, Chadwick 2005). A Canadian review (DFO 2004a) emphasizes that there is lack in information to evaluate the effects on crustacean during their moult, as period when crustaceans are particularly vulnerable.

A study has shown that the shrimp species *Palaemon serratus*, is responsive to sounds from 100 to 3000 Hz, and that the responsive organ is the statocyst (balance organ) in the basal segment of the antennule (Lovell et al. 2005). Future research may reveal shrimp reactions to seismic sound pulses. A Canadian study (DFO 2004b) addressed impacts on snow crabs. The study was set up with short notice and did not find short term effects, but it raised questions relating to long term effects.

The few field studies on crustaceans (Norwegian lobster (La Bella et al. 1996), Australian rock lobster (Parry & Gason 2006), three shrimp species off Brazil (Andriguetto-Filho et al. 2005), snow crab (Christian et al. 2003)) did not find any short term reduction in catchability.

The Norwegian EIA of hydrocarbon activities in the Barents Sea does not assess impacts on northern shrimp or fishery on this resource, because the species is considered relatively robust to external impacts (Østby et al. 2003).

Northern shrimp (*Pandalus borealis*) is the most important species for the Greenland fishery (c. 135,000 tonnes in 2006), and today the major part is taken offshore on the edge of the fishing banks. There are no specific studies available addressing impacts of seismic surveys on northern shrimp or on effects on their behaviour or physiology.

Snow crab (*Chionoecetes opilio*) is less important to the Greenland fishery (c. 5000 tonnes in 2006) and only a smaller fraction (c. 10%) is taken in offshore waters where there could be an overlap with seismic surveys, while the major part is taken in inshore waters.

3.5 Inshore fish and fisheries

In inshore waters northern shrimp, Greenland halibut, Atlantic cod and scallop are fished on commercial basis, as a well as other species such as lumpsucker, Atlantic cod and spotted wolfish. Among non-fish species utilised in inshore waters northern shrimp, snow crab and scallop (*Pecten islandica*) are the most important.

The inshore waters are generally not included in the licence areas, and will most likely not be so in the future licence areas. However, non-exclusive prospective seismic surveys may include inshore waters, and temporary impacts on inshore fisheries could happen if they overlap with seismic surveys.

4 Seismic surveys and marine mammals

4.1 Damage by sound

Much controversy surrounds the various attempts to define safety limits for exposure of marine mammals to intense underwater sound. The main source of controversy is lack of good and relevant data. However, much progress has been made in recent years, as summarised by Southall et al. (2007).

In the USA, a sound pressure level of 180 dB re 1µPA) (RMS) or lower has hitherto been used as a mitigation standard to protect whales (NMFS 2003, Miller et al. 2005), but this level should likely be raised after the review of Southall et al. (2007).

One of the principal issues of discussions in recent years has been whether the important parameter when assessing a sounds potential to inflict damage is peak pressure (which is independent of signal duration) or signal energy (which anything else being equal increases with duration of the sound). Experimental evidence supports both approaches, which has led Southall et al. (2007) to propose a double criterion: In order for sounds to be judged safe they must both be below a specified criterion level in terms of peak pressure, and below another criterion level in terms of total signal energy.

Sounds from airgun arrays are of comparatively short duration, which means that single pulses are likely to exceed the peak pressure criterion before the energy criterion. However, if an animal is exposed to multiple pulses, as is the case for seismic surveys, the energy of the individual pulses should be summed.

4.1.1 Single pulses

For single airgun pulses, the pressure criterion levels suggested by Southall et al. (2007) are the following:

Cetaceans 230 dB re. 1 µPa peak (unweighted)

Pinnipeds 218 dB re. 1 µPa peak (unweighted).

These figures are based on experimental results from a number of pinnipeds and small odontocetes (bottlenose dolphins and belugas), where the threshold for eliciting a temporary threshold shift (TTS) has been measured. However, Southall et al (2007) defined criteria not based directly on temporary threshold shifts but instead estimated levels for inducing permanent threshold shift (PTS, equal to irreversible damage to the auditory system) by adding 6 dB to the experimental TTS-thresholds to create the criterion levels mentioned above. It is important to keep in mind that the criterion for cetaceans is based on data from small odontocetes and thus may not be valid for larger whales (beaked whales, sperm whales and baleen whales) for which no information on either TTS or

PTS thresholds is available. There is also tentative evidence that harbour porpoises may have lower TTS thresholds than dolphins and belugas (Lucke et al. 2007).

As noted above, the actual sound pressures realised in the vicinity of an airgun array are considerably smaller than predicted from the source level and geometric spreading losses. Even for the largest airgun arrays, with source levels beyond 260 dB re 1 µPa peak, pressures inside the array are unlikely to exceed 240 dB re 1 µPa peak (Caldwell & Dragoset, 2000). Nevertheless, this is still 10 dB above the recommended criterion level for cetaceans and 22 dB above the recommended criterion for seals when firing at maximum output power. However, the sound pressure is usually considered to fall of rapidly with distance, especially in the horizontal plane from the array. This would mean that animals should either be very close to the array or directly below the array in order to be exposed to sound pressures above the criterion level. However, experiments with tagged sperm whales (*Physeter macrocephalus*), indicate that this is not necessarily the case and that horizontal spreading should be considered as well (Madsen et al. 2006).

4.1.2 Multiple pulses

Each pulse should not exceed the peak pressure criterion discussed above, but in addition, the summed energy of all pulses the animal is exposed to should not exceed the limits suggested by Southall et al. (2007) These limits are:

Cetaceans 198 dB re 1 $\mu Pa^2 s$ (M-weighted, see below)

Pinnipeds 186 dB re 1 $\mu Pa^2 s$ (M-weighted, see below).

As with the pressure criteria, the energy criteria have been developed based on experimental results from seals and odontocetes (bottlenose dolphins and beluga) but there is no experimental evidence which supports their validity for larger whales and the smaller porpoises. Furthermore, the criteria depend heavily on the M-weighting of the sounds, which is a process equivalent to the C-weighting in human audiology (dB-C, a high-intensity transient sound variant of the more commonly used A-weighting, dB-A). This weighting has been proposed by Southall et al. (2007) and for most species, in particular the mysticetes whales; it relies on a number of unproven assumptions, especially in relation to the growth of the loudness function on which no experimental data exist from any marine mammal.

All this being what it is, the introduction of an exposure criterion based on energy makes good sense and makes it possible to assess the combined exposure to more than single pulses. This is done by Southall et al. (2007) by a simple summation of energy, which leads to an increase in energy equal to 10 log N for N pulses of equal energy. Thus, the combined energy for 10 pulses is 10 dB higher than the energy of the individual pulses, 100 pulses have 20 dB more total energy and etc.

A typical airgun array fires once every 10-15 seconds or less often. If, for example a whale is passed by a seismic survey at a distance of 100 m, it will be exposed to a number of pulses during the time it takes for the ship to pass. If the ship sails with a speed of about 3 knots, it will take about 4 minutes for the ship to pass the whale (the time where the whale is within 200 m from the array). During this time the whale will be exposed to 24 pulses, if firing rate is 1 per 10 seconds, which means that 14 dB should be added to the M-weighted energy of an individual airgun pulse, assuming for simplicity that all pulses are of equal intensity at the location of the whale.

4.2 Behavioural reactions to sounds

Unless dealing with species or stocks of marine mammals which are extremely vulnerable, such as northern right whales or bowhead whales of the Spitsbergen stock, the risk of injuring individual animals has little impact at a population level. The possible significant impact at population level comes instead from behavioural reactions to the sound. As animals in most cases react to sounds at much lower levels than those needed to inflict damage, these reactions can occur at much larger distance from the source and thus have the potential to affect a very large number of animals. Unfortunately, as important as these effects are, they are difficult to quantify and even more difficult to mitigate.

A number of studies have demonstrated behavioural reactions of whales to seismic surveys at distances up to tens of kilometres (reviewed by Gordon et al. 2004, Stone & Tasker 2006, Southall et al. 2007). On several occasions bowhead whales (*Balaena mysticetus*) have been shown to react to airgun sounds at distances of 20-30 km from the array (Koski & Johnson 1987, Richardson et al. 1999). Received levels were typically between 120 and 130 dB re 1 µPa peak to peak unweighted.

Humpback whales (*Megaptera novaeanglicae*) in Australian waters have been shown to react to airgun arrays within about 10 km range from the array (McCauley et al. 1998), corresponding to received levels of around 160 dB re. 1 µPa peak to peak, and they have also been reported on several occasions to remain close to or even approach active airgun arrays (McCauley 1998).

Humpback wales thus appears to be significantly more tolerant than bowhead whales. Except for gray whales (*Eschrichtius robustus*), which is not relevant for Greenland waters, little information is available on the reaction of the remaining mysticetes whales.

Sperm whales (*Physeter macrocephalus*) in Northern Norway have been shown to be tolerant to both distant seismic surveys (received levels around 140 dB re 1 µPa peak to peak) and to detonations of small amounts of explosives (received levels up to 180 dB re. 1 µPa peak to peak) (Madsen & Møhl 2000, Madsen et al. 2002).

It is clear that large differences in behavioural sensitivity to airgun pulses exists both among species and among individuals. Initial reactions have thus been reported at received levels anywhere in the range from about 110 dB re 1 µPa (RMS) to 180 dB re 1 µPa (RMS), depending on species, study and other individual circumstances (reviewed by Southall et al. 2007). It is thus not feasible to outline simple rules to follow in assessment of potential impact from individual seismic surveys. Thus, ideally, the potential impact of seismic surveys in terms of behavioural effects on marine mammals should be judged assessed individually for each survey. Alternatively, strategic assessments for regional areas and specific time windows should be conducted, outlining relevant issues and regulations pertinent to each particular area.

Important points to consider in such an assessment would be:

- Species likely to be affected. Some species apparently are more tolerant to seismic surveys.

- Natural behaviour of animals in area at time of survey. Disturbance of mating and calving is considered to have a higher impact than disturbance of feeding behaviour. Feeding behaviour is again considered of higher importance than migration, given that migration routes are not obstructed.

- Severity and duration of impact. Even a strong startle reaction to an approaching survey vessel may have only a small total impact on the animal whereas a small, but prolonged (days or weeks) disturbance to feeding behaviour could have a much larger impact.

- Total number of animals likely to be affected. It is not possible to conduct seismic surveys in the arctic without affecting marine mammals at all. The number of animals likely to be affected should be judged in relation to the size of the population, local densities and season.

- Local conditions for sound transmission. Local hydrographic and bathygraphic conditions may result in highly unusual sound transmission properties, in particular in polar waters, which may result in a very uneven sound field, with no clear relation between distance to source and received level. Potential consequences of these effects should be included in the assessment.

When planning surveys the overall exposure should be sought minimised to the degree possible in using the smallest airgun array to get the data needed. The total exposure is a complex function of number of animals exposed, the time each animal is exposed and the sound level they each are experiencing. Nevertheless, reducing any of the three parameters will also reduce the total exposure and thus the possibility of reducing one or more factors should be considered in the planning.

4.2.1 Special note on beaked whales

A number of incidents and studies indicate that beaked whales (family Ziphiidae) may be particularly vulnerable to loud impact sound. There is common consensus that a number of mass strandings of beaked whales around the world are linked to exposure to sounds from naval anti-submarine sonar (Franzis 1998, Balcomb & Claridge 2001, Jepson 2003) although the mechanism behind the strandings remains unclear. Two strandings of beaked whales on Galapagos have likewise been potentially linked to nearby seismic survey operations (Gentry 2002). Beaked whales are extreme divers (Hooker & Baird 1999, Tyack et al. 2006) and dive deeper and longer on a regular basis than any other cetacean and their vulnerability to sound may relate to this fact.

In arctic waters around Greenland the bottlenose whale (*Hyperoodon ampullatus*) is the only beaked whale commonly encountered. No mass strandings of this species has been linked to anthropogenic noise exposure, but this may be because it has a more northern distribution range than the other beaked whales and thus the risk of exposure to naval sonars and seismic surveys is smaller. Furthermore, the desolate coastlines make it possible for stranding events to go unnoticed.

However, in the light of the general vulnerability of the beaked whales particular attention also to bottlenose whales should be given in impact assessments dealing with loud seismic sound sources in areas where this species is abundant, such as the deeper parts of Davis Strait and Denmark Strait.

4.2.2 Measuring sound pressure and sound exposure level

A common standard for measuring and reporting sound levels in bioacoustics has not been adopted yet. However, some consensus principles have developed and these should be adhered to (see appendix A in Southall et al. (2007). A brief summary plus additional comments on frequency analysis is given below.

Transient pulses

The sound level of pulse type sounds (see Southall et al. (2007) for a definition of a pulse) should be reported both as µPa peak-to-peak (difference between highest and lowest pressure deflection in the pulse) and energy, the latter integrated over the entire duration of the pulse and having the unit $\mu Pa^2 s$. See Southall et al. (2007) for details of calculation of pulse energy. If a frequency weighing is performed on the signals (e.g. sensu Southall et al. 2007), then both the weighted and the un-weighted figure should be included, together with details on the weighting function.

Non-pulses

Sound level of non-pulses can be reported as energy (µPa2.s) or pressure (μPa_{RMS}; RMS = root-mean-squared). In either case the integration period should be stated and should either be the entire duration of the sound or a biologically relevant period (may be species specific, see Southall et al. 2007). As above, if frequency weighting is performed, this should be specified and also the un-weighted figure should be supplied.

Frequency weighting

In some contexts, such as calculation of signal energy to be compared with the suggested exposure criteria of Southall et al. (2007), a frequency weighting of the signal is performed. This weighting emphasises the parts of the frequency spectrum of the sound which fall into the region of best hearing of the animal and de-emphasises energy at frequencies where the animal has poor hearing. Southall et al. (2007) have suggested four standard weighting curves to be used on underwater sound: Pinnipeds, low frequency cetaceans (baleen whales), Mid-frequency cetaceans (beaked whales, sperm whale, narwhal, beluga, killer whale and most dolphins) and high-frequency cetaceans (porpoises plus a number of species irrelevant for the arctic). Southall et al. (2007) should be consulted for details on how to perform the appropriate M-weighting. If other weighting functions are used, full details of the shape of the curve should be supplied as well as justification for use of the particular weighting function over the M-weighting.

Frequency analysis

If frequency analysis (Fourier analysis) is performed, sufficient details should be supplied together with the frequency spectrum to allow an evaluation of the spectrum. This information includes FFT-size and corresponding bandwidth of individual frequency bands, type of windowing function used and if averaging over two or more spectra is performed, details on the averaging procedure.

If frequency information is displayed in the form of spectrograms, details on FFT-size, window type and window overlap should be supplied.

5 Recommendation of best practice

5.1 Marine mammals and air guns

The main concern about operating large airgun arrays in terms of inflicting damage is to make sure that the array is not fired at full power when animals are directly below or otherwise very close to the array. Particular concern surrounds start up of the array. Less concern should be given to animals approached by the survey ship while in full operation and animals who themselves actively approach the array. In those cases, the animals have the possibility to flee well in advance of levels becoming potentially dangerous, whereas an animal diving below the array at start up may be caught in a difficult situation.

Best practice to prevent damage to marine mammals during seismic surveys would be aimed at preventing animals from being exposed to dangerously high sound pressures. Although there is little experimental evidence on the efficiency of ramp-up (or soft start) procedures, these are still considered a key component of best practice.

- The airgun array should not be larger than needed for the specific survey.
- A safety zone of 500 m from the airgun array shall be applied.
- A pre-shooting search shall be conducted before commencement of any use of the airguns. If waters are less than 200 m deep, this search shall last 30 min. If waters are more that 200 m deep, it shall be extended to 60 min. If marine mammals are spotted within the safety zone, the ramp-up procedure shall be delayed 20 minutes, from the time when the animal has left the safety zone (or the ship has moved so far that the animal is outside). The pre-shooting search can be initiated before the end of a survey line, while the airguns are still firing
- The array shall not be started at full power, but individual airguns should be added one by one or if not possible, output of each airgun slowly increased by manipulation of pressure (ramp-up procedure).
- The ramp-up procedure shall occur over a period of about 20 min and can occur while the survey ship is en route to the starting point of the transect line.
- Ramp-up should not be initiated if marine mammals are inside the array or within the safety zone (500 m) of the array. If marine mammals are discovered within this safety zone during the ramp-up procedure, the airguns shall be turned off, and a new ramp-up procedure initiated when the mammal has left the safety zone - i.e. at least 20 min. after the last sighting.

- If proper ramp-up cannot be performed for technical or other reasons, other measures should be taken to assure that no animals are within the safety zone at start up.

- If the array is shut down for any reason while on the transect line it can be re-initiated at full power given that the silent break is not longer than 5 min. Otherwise a full ramp-up procedure should be followed.

- The array should be shut down completely between lines, if the transit time is longer than the time it takes to conduct a ramp-up and a full ramp-up should be initiated prior to arrival at the next line. If transit time is less than 20 min the array can be operated during transit, preferably at reduced power output.

- A Marine Mammal and Seabird Observer (MMSO) shall be posted on the source vessel (where the airguns are deployed from) and be continuously on the look out particularly for whales during the pre-shooting search and when airguns are operated.

- Observation of marine mammals during shooting and inside the safety may not lead to shutdown.

- A log of marine mammal observations should be kept on the ship and reported as part of the cruise report.

- Passive Acoustic Monitoring (PAM) of vocalizing whales can be deployed for monitoring purposes especially in areas with bowhead whales. But it is not a demand.

- Airguns should not be used outside the transect lines, except in the cases mentioned above (ramp-up prior to arrival and on short transit lines) and for strictly necessary testing purposes. Testing the array at full power should be initiated with a ramp-up procedure as above.

This practice is in line with the JNCC (2009) recommendations, which is adopted for the regulation in many other areas. However, in Canadian and US waters, the array immediately must be shut down if marine mammals are spotted within the safety zone.

Refer also to the JNCC 2009 guidelines.

5.2 Explosives

The use of explosives is not considered in these guidelines. If explosives are considered for seismic studies, detailed plans have to be submitted to the BMP for evaluation and approval.

Such plans should include estimation of safety zone, based to the best available information on actual/expected sound transmission properties of the surrounding waters, keeping in mind that transmission loss in arctic waters can sometimes deviate substantially from simple predictions based on geometrical spreading.

5.3 Marine Mammal and Seabird Observers

At least two Marine mammal and seabird observers (MMSOs) shall be on board the seismic vessels operating in Greenland waters in order to observe continuously when operating the airguns. They shall be especially trained in observation methodology and seismic mitigation.

The MMSOs have two tasks. Firstly, they have to watch systematically for marine mammals before start-up and during seismic survey in order to mitigate and observe safety distances to whales and seals.

Secondly, the MMSOs shall collect data on abundance and distribution of seabirds and marine mammals through systematic surveys. This task shall be carried out both during times when seismic survey is conducted, and when sailing in transit.

The latter task is not secondary to the former, and considerable effort should be spent on the systematic surveys.

The purpose of the second task is to improve the knowledge on temporal and spatial distribution of marine mammals and seabirds in the West Greenland waters, which generally is low. The collected data will be included in the NERI-databases of background information. The information in these databases will constitute the basis for future EIA-work by NERI and is moreover available to the companies which shall operate in Greenland waters and prepare EIAs of their activities. Data have to be collected according to NERI standards to fit into the databases, and guidelines to observation methodology will be provided when a seismic survey is approved by BMP.

6 Protection zones for marine mammals in relation to seismic surveys

The strategic environmental impacts assessments carried out in Greenland so far designate the following marine mammals as particularly sensitive to seismic surveys (Mosbech et al. 2007, Boertmann et al. 2009 a, b):

- white whale or beluga (*Delphinapterus leucas*),
- narwhal (*Monodon monoceros*)
- bowhead whale (*Balaena mysticetus*)
- walrus (*Odobenus rosmarus*).

Outside the areas covered by the impact assessments a fifth very sensitive whale occurs:

- northern right whale (*Eubalaena glacialis*).

Many other whales and seals occur in the seas surrounding Greenland. It is either not possible to designate protection zones for these or they are considered as less sensitive to seismic shooting.

The white whales arrive from Arctic Canada to Northwest Greenland in early October (Heide-Jørgensen et al. 2003) and may overlap the season for seismic surveys for a short period. It is at the moment not possible to designate any especially important areas (protection zones) for white whales because the migration corridors are poorly known, since only two white whales have been tracked by means of satellite in Greenland waters (Heide-Jørgensen et al. 2003). In addition, core wintering areas for white whales are linked to the sea ice edge and can vary widely from year to year (Heide-Jørgensen *et al*. in press).

Narwhals on the other hand occur in the seismic season in Northwest Greenland and East Greenland. They have specific summering areas where high numbers may occur, and in Northwest Greenland several whales have been traced by satellite telemetry. The results of this tracing indicate specific migration corridors and wintering areas (Dietz & Heide-Jørgensen 1995). Outside the seismic season narwhals occur in the drift ice off east Greenland and in Baffin Bay and northern Davis Strait (Heide-Jørgensen & Laidre 2005).

Bowhead whales in West Greenland occur only in the season with sea ice (Winter-May), and seismic protection zones are not necessary, because this is outside the seismic season. In East Greenland another stock of bowhead whales occur – the critically endangered Spitsbergen Stock. Surveys in 2008 and 2009 indicate that the Northeast Water Polynya and the permanent ice edge between the polynya and Île de France are important summer habitats for whales of this stock (Boertmann et al. 2009c, Boertmann & Nielsen 2010).

Northern right whale is very rare and globally Red Listed as 'critically endangered'. It occurs in summer only in offshore waters between

Southeast Greenland and Iceland, and no protection zoned can be designated due to lack of data.

Walrus occurs in the seismic season in Northwest and Northeast Greenland, where protection zones have been designated. Walruses are dependent on localised, shallow (< 100 m) banks, where they feed on bivalves and where many individuals assemble. During winter (outside the seismic season), walruses assemble in the shallow parts of Store Hellefiskebanke off central West Greenland and in polynyas of northwest and northeast Greenland.

For a few particularly sensitive marine mammals species (walrus, narwhal and bowhead whale) occurring in predictable localised and critical areas, protection zones has been designated. For the other marine mammals this is not possible, either due to lack of data or because they occur widespread without significant and predictable concentrations in the seasons covered by these guidelines.

6.1 Narwhal protection zones

6.1.1 West Greenland

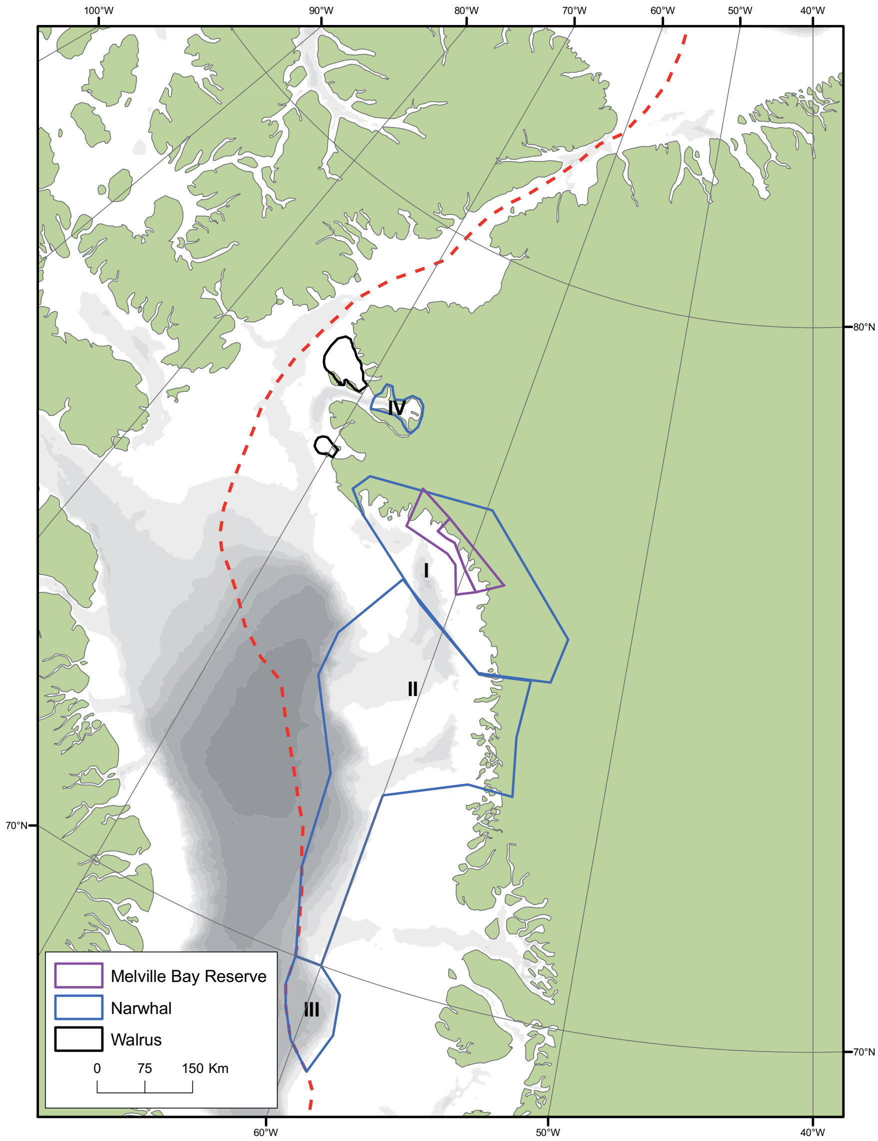
Figure 2 show the narwhal protection zones in West Greenland. The three zones in Northwest Greenland are updated from the zones designated in 2000 (Mosbech et al. 2000). They have been revised (enlarged) according to new data from satellite tracked whales (GINR unpublished). The areas in East Greenland are new and based on the available data, which in many areas is inadequate (Aastrup et al. 2005, Boertmann et al. 2009c, GINR unpublished data).

Narwhal zone I is the summer habitat, where narwhals are present when the sea ice melts in summer until fall migration (1 June to 15 Oct). The boundary is defined by a straight line (Long./Lat. projection) between Cape York and Wilcox Head on Holm Island. In zone I seismic activities shall be avoided or of limited extend (a few widely spaced (>10 km) lines). If such limited seismic surveys are planned in the protection zone a detailed shooting program is subject to approval by BMP, and if approved, impact studies on the narwhals shall be considered.

Narwhal zone II is the fall migration habitat where the narwhals are present from 15 October at least until 1 Dec. It is defined by lines connecting the points:

72° 59′ N, 56° 25′ W, Assaqutaq
72° 30′ N, 60° 00′ W
70° 00′ N, 60° 00′ W
70° 00′ N, 61° 00′ W
71° 10′ N, 62° 11′ W
72° 30′ N, 62° 35′ W
73° 40′ N, 65° 00′ W
74° 20′ N, 65° 00′ W
75° 21′ N, 63° 00′ W.

Figure 2. Narwhal and walrus protection zones in West Greenland. Protection period in narwhal zones I and IV is from 1 June to 25 Oct. and in narwhal zone II from 15 Oct. to 1 Dec. Protection period in the walrus is from 1 Oct. to 31 May. Hatched red line indicates the border of the Greenland EEZ. See text for stipulation for the three zones. Narwhal zone based on Dietz & Heide-Jørgensen (1995) and unpublished tracking results from 2008 (M.P. Heide-Jørgensen, Greenland Institute of Natural Resources pers. comm.). Walrus protection zones based on historical sources (Born et al. 1994).



Seismic activities in narwhal zone II shall be confined to a minimum in the protection period.

Narwhal zone III is the winter habitat (15 Nov. to 30 March) and was designated in the previous edition of the regulations. This is still valid and it is defined by the points:

70° 05.56′ N, 60° 01.02′ W
70° 02.05′ N, 61° 03.75′ W
69° 28.81′ N, 60° 50.51′ W
68° 57.53′ N, 60° 05.33′ W
68° 36.02′ N, 59° 09.47′ W
69° 09.19′ N, 58° 37.17′ W
69° 41.41′ N, 58° 50.40′ W.

Zone III is particularly critical to the narwhals, because individuals from the Melville Bay stock seem to be confined to the depths 500-1500 m within this area in winter (the important narwhal area stretches far into the Canadian EEZ). Seismic activities shall be avoided in the zone in the defined protection period (15 Nov. to 30 March), which is outside the usual season for seismic surveys.

Zone IV is the summer habitat in Inglefield Bay. Narwhals are present here in large numbers during the open water period from 1 June to 15 Oct., and the zone is a very important hunting area for the inhabitants of Qaanaaq town. The zone is delimited by a straight line from Qaanaq town due south to Kangeq (77° 17′ N, 69° 10′ W). In zone IV seismic activities shall be avoided or of limited extend (a few widely spaced (>10 km) lines). If such limited seismic surveys are planned within the protection zone in the sensitive period a detailed shooting program is subject to approval by BMP, and if approved, impact studies on the narwhals shall be considered.

6.1.2 East Greenland

Specific narwhal summer protection zones in East Greenland are designated in Figures 3 and 4, but as the knowledge is limited, these are preliminary and there may be more areas which could be protection zones. Narwhals occur in these areas throughout the open water season, and in the Northeast Water probably throughout the year.

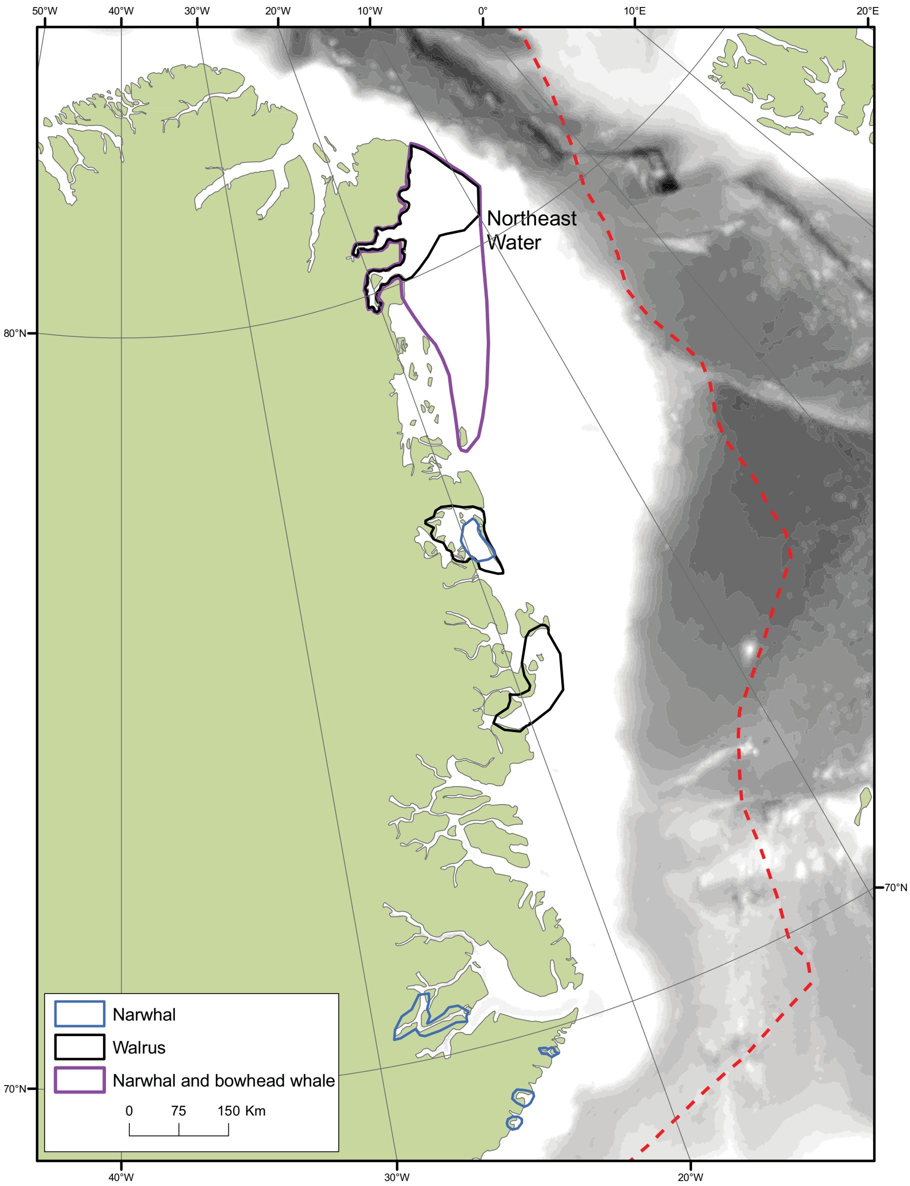
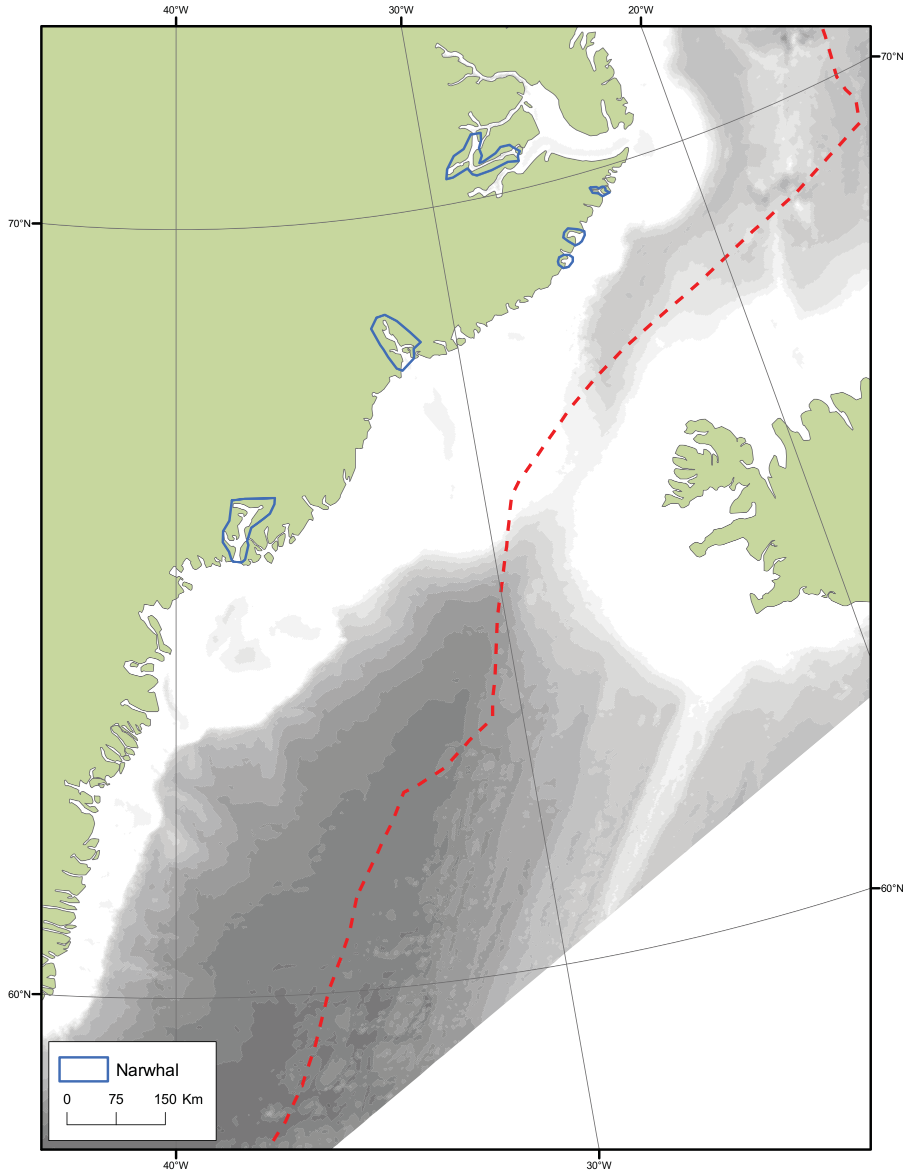


Figure 3. The protection zones for narwhal, bowhead whale and walrus in the northern part of East Greenland. Narwhal and bowhead whale protection period is from 1 July to 30 September and walrus protection period is from 1 June to 30 September. However the protection zone in the Northeast Water is an all year habitat for walruses especially females with young. Hatched red line indicates the border of the Greenland EEZ. See text for stipulations in the protection zones. Narwhal areas based on historical information (Dietz et al. 1994) and survey results from 2008 and 2009 (Boertmann et al. 2009c, Boertmann & Nielsen 2010, M.P. Heide-Jørgensen, Greenland Institute of Natural Resources pers. comm.). Walrus protection zones based on historical sources (Born et al. 1997).

Figure 4. Narwhal protection zones in the southern part of East Greenland. The protection period here is from 1 June to 30 September. Hatched red line indicates the border of the Greenland EEZ. Narwhal areas based on historical information (Dietz et al. 1994), survey reports (Boertmann et al. 2009, Boertmann & Nielsen 2010) and unpublished survey results from 2008 (M.P. Heide-Jørgensen, Greenland Institute of Natural Resources pers. comm.).



Seismic activities shall be avoided or of limited extend (a few widely spaced (>10 km) lines) in these East Greenland protection zones. If limited seismic surveys are planned within the protection zone a detailed shooting program is subject to approval by BMP, and if approved, impact studies on the narwhals shall be considered.

Seismic activities in the narwhal protection zones of East Greenland should be avoided or of limited extend (a few widely spaced (>10 km) lines). If such limited seismic surveys are planned in the protection zones a detailed shooting program is subject to approval by BMP, and if approved, impact studies on the narwhals shall be considered.

6.2 Bowhead whale protection zone

6.2.1 East Greenland

The Northeast Water Polynya and the waters off the ice edge between Île de France and Amdrup Land are important habitats for bowhead whales in summer and early autumn. The protection zone for this species is similar to the protection zone for narwhals and so are the regulations:

Seismic activities shall be avoided or of limited extend (a few widely spaced (>10 km) lines). If limited seismic surveys are planned within the protection zone a detailed shooting program is subject to approval by BMP, and if approved, impact studies on the whales shall be considered.

6.3 Walrus protection zones

6.3.1 West Greenland

The most critical areas to walruses in West Greenland are the winter habitats in the Qaanaaq area, occupied from October through May, and therefore mainly outside the seismic season. However as seismic surveys may take place in October, two areas are here designated as walrus protection zones (Figure 2). There are also winter habitats in central West Greenland (mainly Store Hellefiskebanke), but these are occupied in December to May and outside the seismic season.

Seismic activities shall be avoided or of limited extend (a few widely spaced (>10 km) lines) in the walrus protection zone in the period from 1 Oct. to 31 May. If such limited seismic surveys are planned in the protection zones a detailed shooting program is subject to approval by BMP, and if approved, impact studies on the walruses shall be considered.

6.3.2 East Greenland

Specific walrus protection zones are designated on Figure 3, and the protection period is from 1 June to 30 Sept., when open water is present at the coasts. However the Northeast Water is a year round habitat and here the protection period is the entire year.

Seismic activities in these walrus protection zones shall be avoided or of limited extend (a few widely spaced (>10 km) lines). If such limited seismic surveys are planned in the protection zones a detailed shooting program is subject to approval by BMP, and if approved, impact studies on the walruses shall be considered.

7 Areas with commercial fishery

No regulation of seismic surveys is proposed in relation to fish and fishery, except for a general recommendation of bringing a fishery liaison officer (FLO) on board when appropriate. However, maps of the most important trawling grounds are presented to give information on potential areas of overlap with seismic surveys.

The maps in Figures 5, 6, 7, 8, 9 and 10 show the areas where commercial fishery takes places in these years. Temporary effects on the fishery might happen if seismic surveys take place here in the fishing season.

Measures to protect spawning: Atlantic cod should be considered in the future, if the now depleted stock increases to the point where high concentrations again are found during the spawning season.

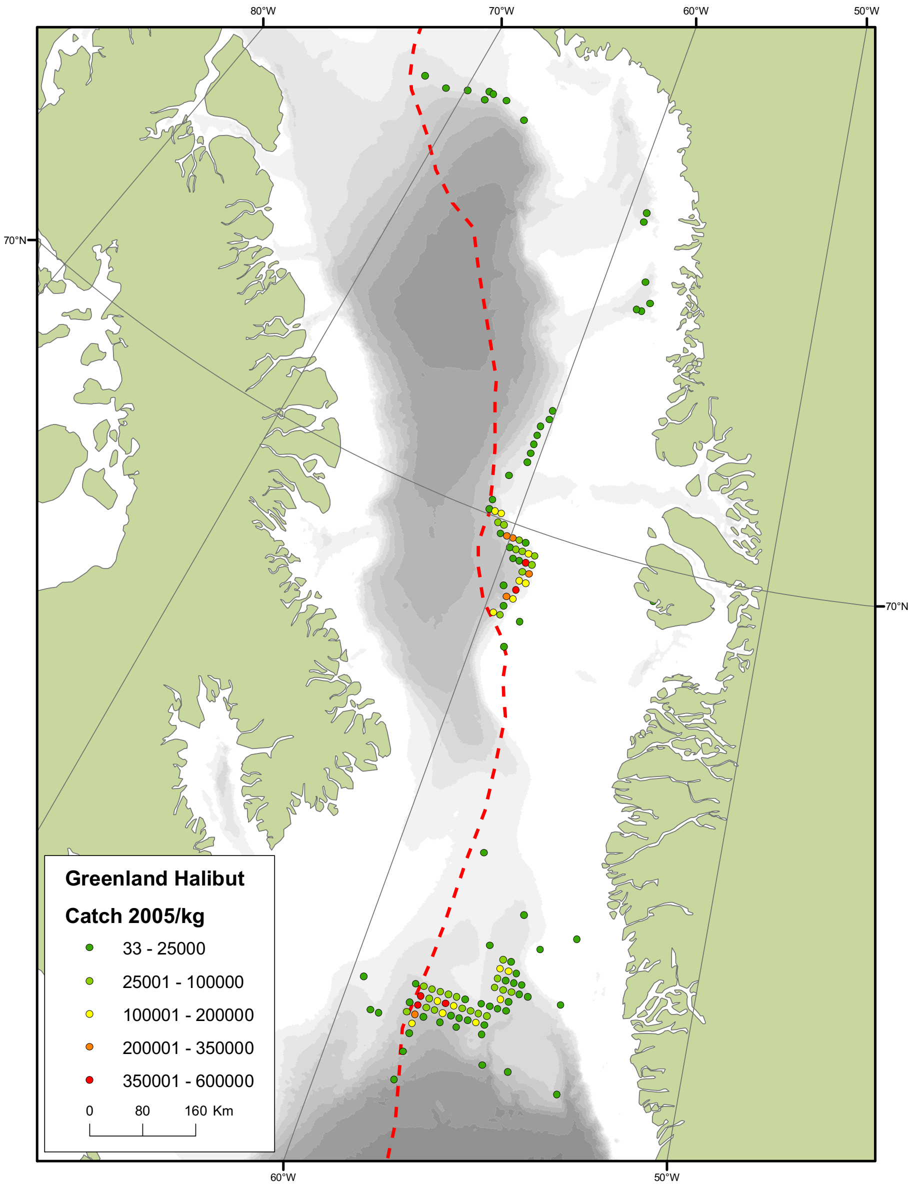


Figure 5. The trawling grounds for Greenland halibut in West Greenland. Hatched red line indicates the border of the Greenland EEZ. Data are from 2005 and provided by Greenland Institute of Natural Resources.

Figure 6. The trawling grounds for Greenland halibut in East Greenland. The colours indicate total catches 1991-2007, with yellow as the lowest and dark red as the highest. Grey line is the border of the Greenland EEZ. Blue lines are 500 m (pale blue) and 1000 m (dark blue) depth contours. Figure from ICES (2008) with permission from Greenland Institute of Natural Resources.

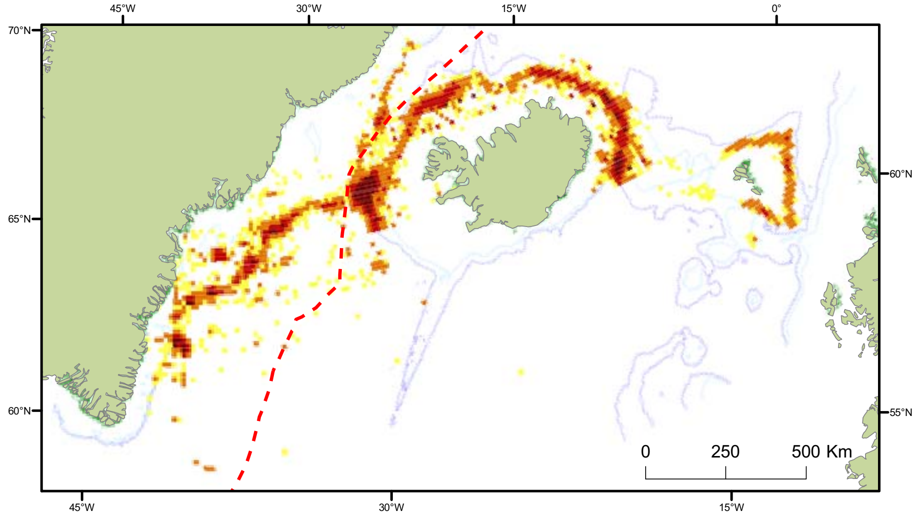


Figure 7. The fishing grounds for offshore Atlantic cod (2006 and 2007) and redfish. Hatched red line indicates the border of the Greenland EEZ. Extracted from ICES (2008).

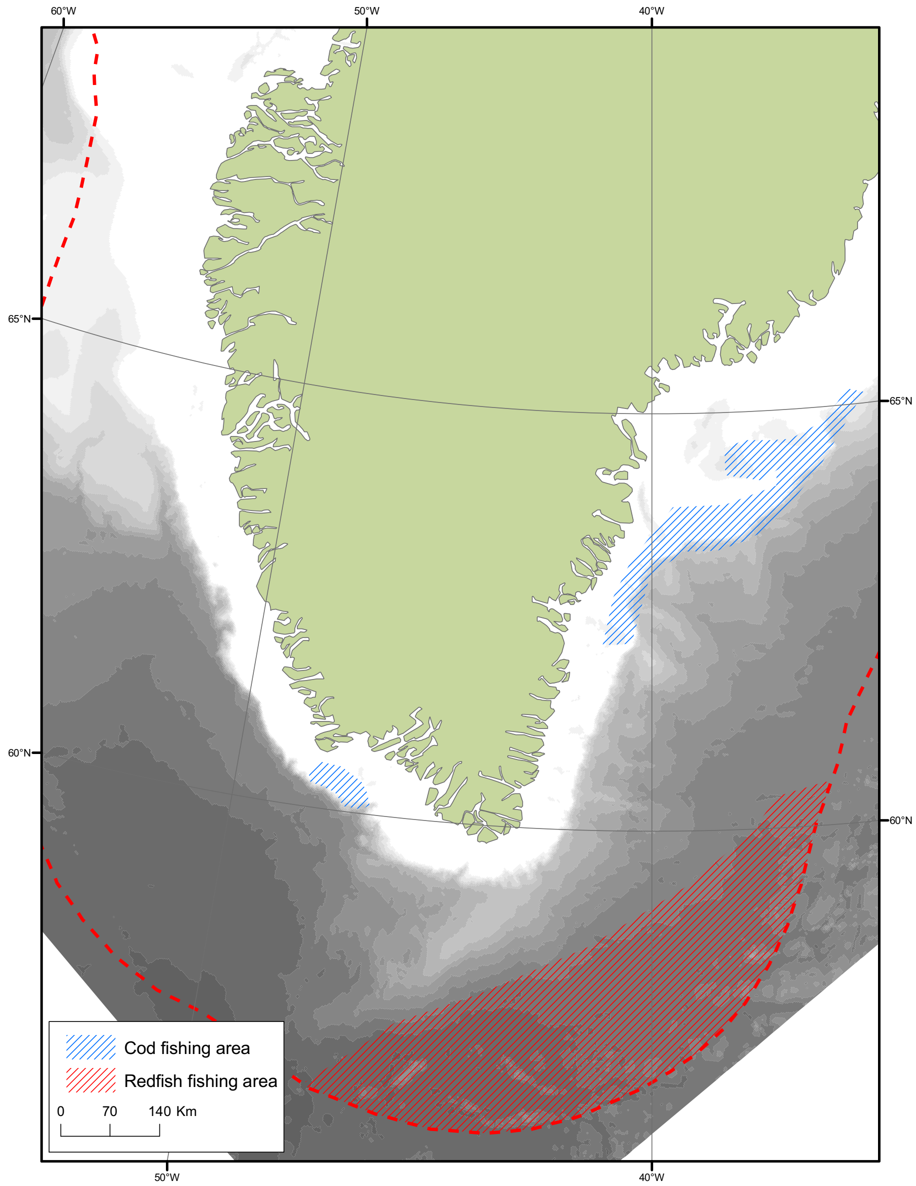


Figure 8. Distribution of northern shrimp catches in 2006. Hatched red line indicates the border of the Greenland EEZ. Data from Greenland Institute of Natural Resources.

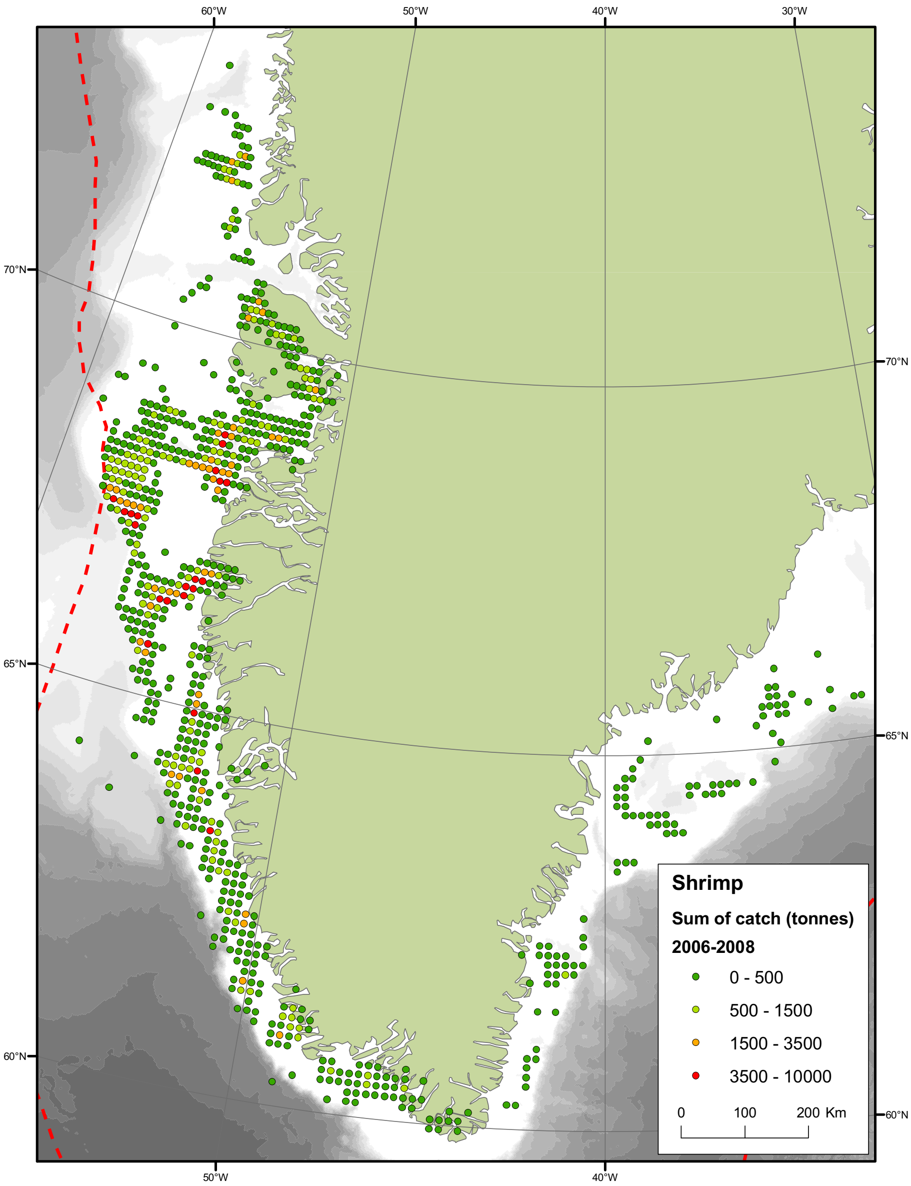


Figure 9. Distribution of snow crab catches in Greenland waters. Mean annual catches over the years 2002 to 2005. Data set not complete, and additional fishery have been carried out her and there. Hatched red line indicates the border of the Greenland EEZ. Data from Greenland Institute of Natural Resources.

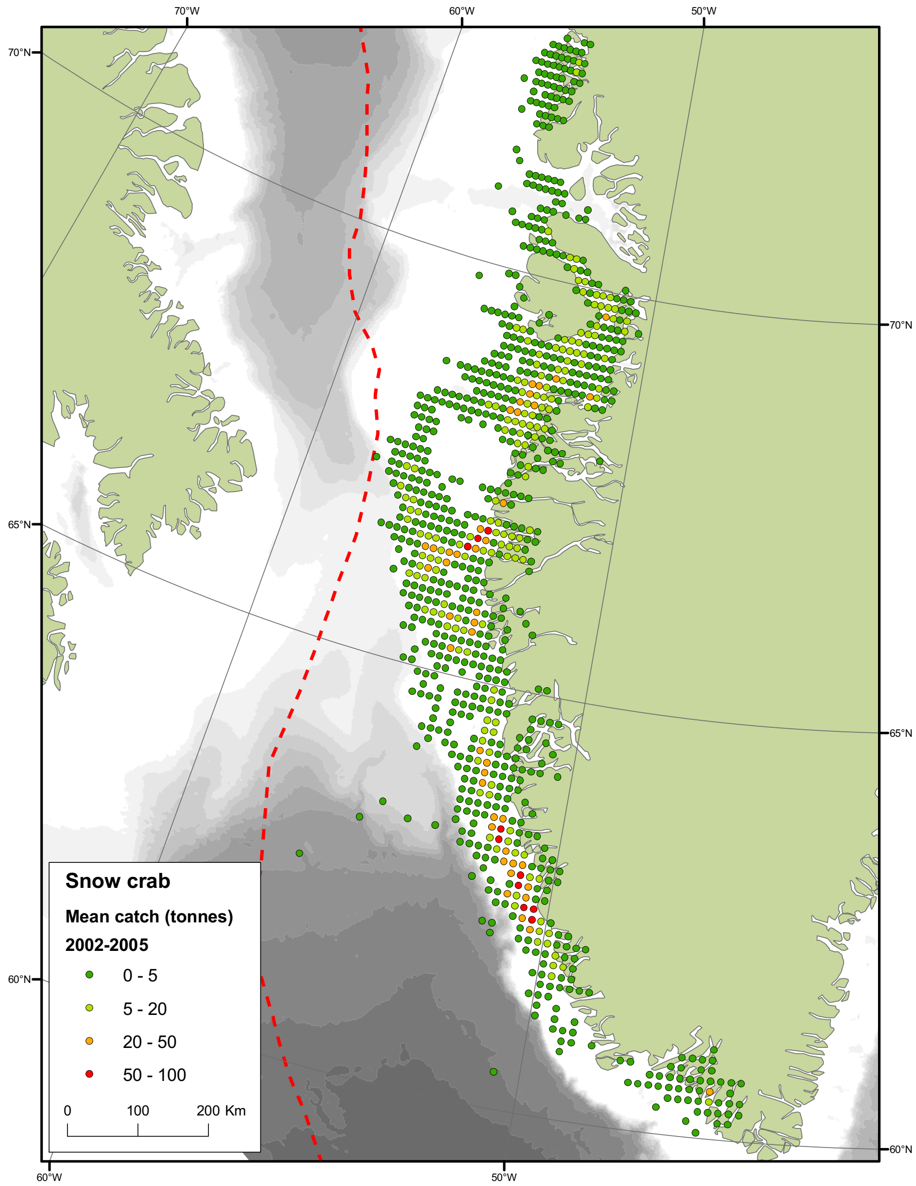
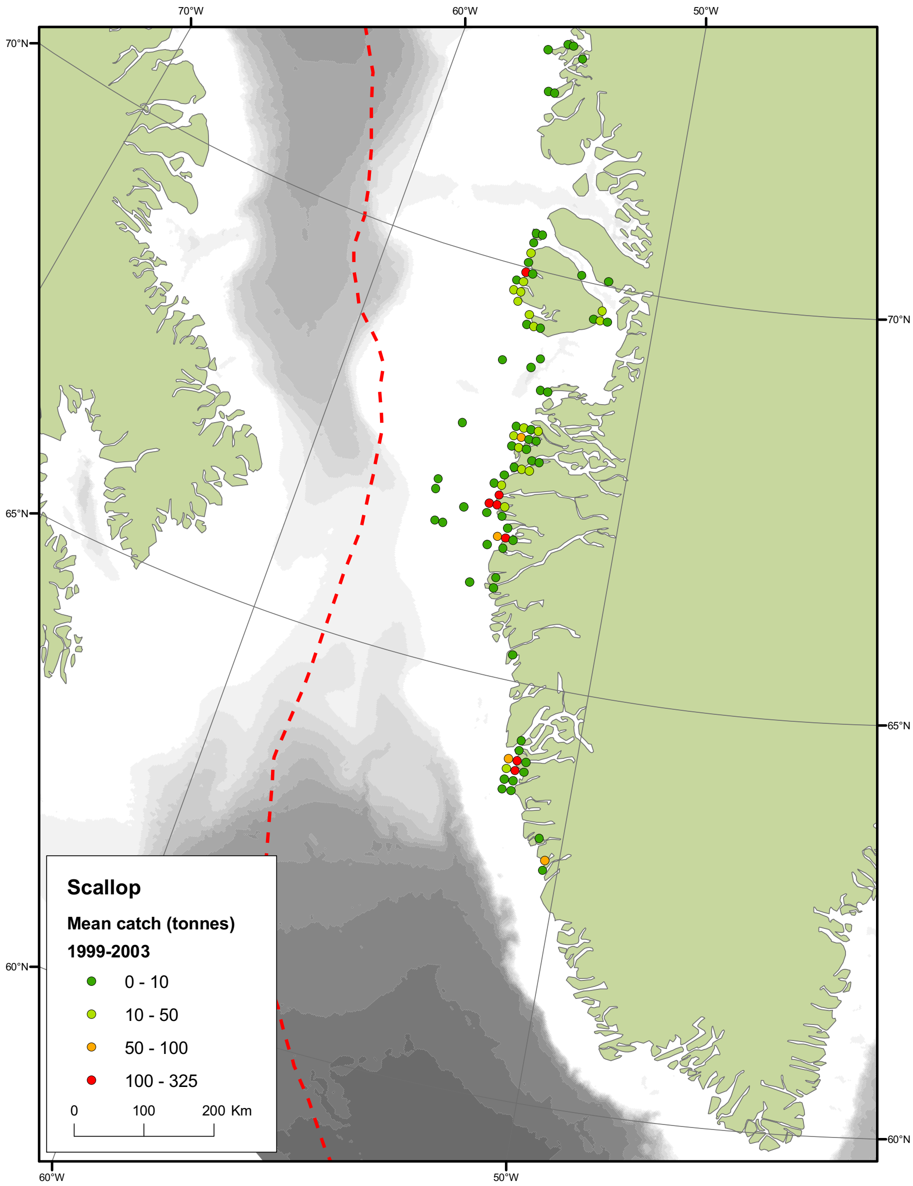


Figure 10. Distribution of scallop catches in Greenland waters. Mean annual catch over the years 1999 to 2003. Hatched red line indicates the border of the Greenland EEZ. Data from Greenland Institute of Natural Resources.



8 Future research and data gaps

In Arctic waters there are certain special conditions which should be considered when dealing with sound transmission from seismic sources. It cannot be assumed that there is a simple relationship between sound pressure levels and distance to source due to ray bending caused, for example, by 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 (> 50 km) from the sound source, and this is particularly evident in stratified Arctic waters.

Direct measurements around an operating airgun array in the arctic are missing and future research should focus on this issue.

Data on marine mammals have been collected during many seismic surveys in Greenland waters. These data should be analysed in relation to the effect of the seismic array, e.g. abundance and distance to the operating/non-operating array. These analyses should be supplemented with experiments with observers collecting distance sampling data (angle, distance, sighting conditions, etc.) while the array is functioning and during a control situation when the array is not operating.

Carefully designed experimental behaviour studies on marine mammals exposed to air gun noise are in high demand, for example to test the efficiency of the ramp-up procedure. Data loggers, satellite transmitters and PAM should be applied in such studies.

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