A Review of the Impact of Seismic Survey Noise on Narwhal & other Arctic Cetaceans

Report prepared for Greenpeace Nordic by Marine Conservation Research Ltd.

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Executive Summary

Baffin Bay has recently experienced an increase in the number of planned and operational seismic surveys for oil and gas exploration. This report examines the effects of noise and disturbance from seismic surveys on vulnerable Arctic spcies, specifically the narwhal. The population status of narwhals is very poorly understood; however, for narwhal subpopulations in Baffin Bay that have been the subject of research and monitoring efforts, there are clear indications of declines in numbers. It is important therefore to adopt a precautionary approach and to protect critical habitats for this species, including breeding/nursery areas, migratory routes and feeding areas, from disturbance when individuals are present. Various threats to narwhals are discussed in this briefing, particularly in the context of cumulative impacts from human activities; however, a detailed analysis of hunting and its impacts were not included within the scope of this review.

Baffin Bay is a marginal sea of the North Atlantic Ocean, located between Baffin Island, Canada and the southwest coast of Greenland. The Bay is a unique and sensitive ecosystem which has been assessed to be of particular significance in terms of the high levels of species richness for Arctic marine mammals. Baffin Bay has been subject to very little human perturbation until the last 100 years, being an essentially undisturbed habitat, with few adjacent human settlements due to the inhospitable climate and difficulties in navigating the icy waters.

With the reductions in sea ice cover resulting from climate change, increasingly the land adjacent to, and the waters of Baffin Bay have become affected by a range of human activities including mining, shipping, commercial hunting and more recently oil and gas exploration and drilling. Offshore petroleum exploration off West Greenland started during the 1970s. Since this time there has been very little exploration activity until 2010, when ten licence blocks for exploration and exploitation of oil and gas in Baffin Bay were distributed to seven companies. Offshore exploration for oil and gas deposits is undertaken using seismic surveying; a method which utilises intense blasts of sound from powerful airguns. The blasts penetrate the ocean floor and relay data about the underlying geology beneath the seabed.

Since the issuance of new licenses for exploration blocks within Baffin Bay in 2010, it is evident that the levels of anthropogenic noise from shipping, seismic surveys and potentially drilling and production activities are increasing. It is widely recognised by regulatory authorities in many countries that there is a risk of injury to whales from loud sound sources and particularly seismic surveys. Efforts to develop sound exposure criteria relating to hearing damage in marine mammals estimated that hearing damage would be expected at exposure to impulsive sound levels of greater than 180 dB, behavioural impacts would be expected at exposure to lower sound levels.

For marine mammals, especially cetaceans, the use of sound is fundamental to their ability to navigate, communicate and find prey. The exact hearing range and auditory sensitivities of most cetacean species are unknown. Noise pollution is known to have harmful impacts on marine mammals; loud anthropogenic sound sources such as military sonar, piling (in construction) and shipping noise have been linked to whale strandings, changes in behaviour and vocalisations, and displacement and avoidance reactions in cetaceans around the globe. The research that has been undertaken specifically on the impacts of seismic noise on cetaceans is somewhat limited (and especially so for Arctic species); however, there is a growing body of evidence demonstrating a link between seismic testing and detrimental effects on cetaceans.

As marine species living in Baffin Bay have not been exposed over generations to increasing levels of background noise, the effects of noise pollution are likely to be more severe than for similar species in noisier areas. Arctic species face multiple challenges caused by a rapidly changing climate including altered critical habitats, changes in food webs, increased competition for prey with both migrant species that remain in Arctic waters for longer periods and fisheries, and increased levels of predation, thus additional stressors such as noise and disturbance may have more extreme effects than otherwise predicted; cumulative impacts must also be considered.

Arctic species, and especially the narwhal, exhibit a number of specific, unique characteristics which result in particular concerns; thus aspects of their ecology and life histories should be taken into account when assessing the potential risks to the species. Narwhals have been described by experts as the most specialised of the ice whales, living exclusively in the Arctic environment, with a close association with sea ice being fundamental to their ecology and survival, in terms of both feeding and shelter/protection from predators and other threats (natural and human).

There have been no direct studies of the reactions of narwhal to seismic noise; however, it is essential to note, that in all cases, a lack of documented response does not imply a lack of impact. Many studies on the effects of geophysical surveys have been conducted in those areas that have historically been exposed to high levels of seismic activity. Therefore, these studies do not represent a true baseline and when considering seismic activity in new habitats, such as this part of the Arctic; thus, research specific to the area should be conducted to understand the impacts of noise on this specific habitat and its wildlife.

Hearing damage and loss from seismic activity has not been documented in narwhals. However, beluga whales, a close relative of the narwhal, have been found to develop temporary hearing loss at distances of 260 metres from a single airgun pulse, and at a range of 1 km from multiple pulses. Although hearing loss is amongst the most extreme and immediate physiological harm which can occur to individual marine mammals as a result of exposure to noise at close proximity, a range of longer term impacts are also likely, including decreased foraging efficiency, increased energetic demands, reduced group cohesion, reduced ability to communicate, increased risk of predation and decreased reproductive success. Some or all of these could cause serious impacts at the population level, resulting in population decline or lack of recovery in depleted populations.

It is well known from Inuit Traditional Knowledge and from reports of narwhals' reactions to the presence of icebreakers that this species is extremely sensitive to noise and disturbance. Further, it is well documented that narwhals are extremely difficult to observe at sea, due to their highly skittish, shy nature, which confounds research activities and marine mammal observation for mitigation purposes. Narwhals have displayed obvious avoidance behaviour at distances of over 80 km and anti-predator responses (freezing and cessation of vocalising) at 50 km from icebreakers, indicating an extreme sensitivity to disturbance. In fact, this long-distance displacement of narwhals is exceptional in the literature on the effects of disturbance on marine mammals. Additionally, the tendency of narwhal to 'freeze and sink' rather than flee in response to disturbance makes them even more susceptible to injury than other species, as they do not typically remove themselves from a zone of impact. This was described in a recent paper by an eminent narwhal expert linking significant changes in narwhal behaviour to seismic activities, determining that disturbance from seismic noise delayed the migration of narwhals at the usual time, causing thousands of narwhal to become fatally entrapped in ice, in an area and at a time when ice entrapments had never previously been recorded. If seismic noise and the entrapment are indeed correlated, the fact that the seismic surveys ceased a month before the ice entrapment occurred demonstrates the far reaching impacts seismic surveys can have on the species and habitat both temporarily and spatially. *Furthermore, there are serious implications for the proposed 2D survey being planned in Canadian waters for summer-autumn 2015, between July and November, which overlaps with a narwhal wintering area, as such disturbance has the potential to severely impact their migration to their winter feeding area. It would appear that there is a significant risk to narwhals from the planned increase in seismic survey noise and ongoing development of oil and gas exploration and production activities in Baffin Bay over the next few decades.*

Demonstrating harm, by linking cause and effect, is difficult, but from the growing literature on the subject, it is clear that the research question should no longer be whether there is an impact from seismic noise on cetaceans, as this is indisputable, but instead, which species, subpopulations, and critical habitats are likely to be at most risk.

For many Arctic species, perhaps most notably the narwhal, very limited data exist on population trends, migration patterns, and population status. As seismic testing has already been implicated in changes in narwhal migrations, it is recommended that future seismic surveys in Baffin Bay are not permitted during narwhal migration periods. Mitigation activities have been developed and implemented with the objective of minimising injury to marine mammals from seismic noise; these include the use of marine mammal observers to locate cetaceans that may be present within a 500 m safety zone around the airguns, a situation which would initiate shut down of the airguns. However, recent modelling suggests the reduction in risk of injury from loud sound sources provided by MMOs is minimal, with few instances where mitigation using visual observers can achieve a greater risk reduction than would be achieved by a 3 dB reduction in source level. Indeed, the uncertainty about the effectiveness of measures to reduce impacts is also noted by New Zealand's Code of Conduct for minimising disturbance to marine mammals from seismic survey operations (DOC 2013) which notes that the best course of action may simply be to avoid conducting seismic surveys in "sensitive areas" until less disturbing technologies are in regular use. The High Arctic may be defined as one such sensitive area.

Glossary of terms relating to seismic testing

2D seismic survey: In 2D reflection seismic surveying both the sound source and the sound detectors are moved along a straight line i.e. just one streamer is used. The resultant product can be thought of as a linear cross-section of the subsurface beneath the survey line.

3D seismic survey: In 3D reflection seismic surveying the sound detectors are spread out over an area, i.e. there are several streamers (up to 12 or more). The resultant product can be thought of as a cube of common depth point stacked reflections. Advantages over 2D include the additional dimension, the fact that many more reflections are available for stacking at each point, which provides greatly improved resolution of subsurface features, and elimination of the "ghost" or "side swipe" reflections from nearby offline features that 2D surveys are prone to.

4D seismic survey: 4D reflection seismic surveying is the exact repetition of a 3D survey at two or more time intervals. The primary application of 4D is mapping the movement of fluid interfaces in producing oil and gas reservoirs.

Airgun: used for marine reflection and refraction surveys (seismic surveys). The air gun array is submerged below the water surface, and is towed behind a ship. When the air gun is fired, air escapes and produces a pulse of acoustic energy. The echo of the airgun refracting off the seabed provides data on the bathymetry and density of the seabed, which helps locate oil and gas deposits. Air gun arrays are built up of up to 48 individual air guns with different size chambers, the aim being to create the optimum initial shock wave with minimum reverberation of the bubble after the first shot.

Continuous noise: sound sources which produce continuous noise such as shipping traffic; generally low intensity and considered as chronic.

Decibel (dB): the unit used to measure sound level. The dB is a logarithmic description of the ratio between two values of a physical quantity, often power or intensity. As decibels are on a logarithmic scale, care must be taken when interpreting values; for example, a doubling of sound pressure adds 6 dB.

Impulsive noise: noise sources which have short, distinct sounds such as seismic blasts or piling noise; generally high intensity and considered as acute.

Noise: is a sound, especially one that is loud or unpleasant or that causes disturbance.

Noise underwater versus noise in air: confusion arises because sound levels given in dB in water are not the same as sound levels given in dB in air. This is because different reference intensities are used to compute sound levels in dB and because the intensity of a sound wave depends not only on the pressure of the wave, but also on the density and sound speed of the medium through which the sound is traveling. Sounds in water and sounds in air that have the same pressures have very different intensities because the density of water is much greater than the density of air and because the speed of sound in water is much greater than the speed of sound in air.

Sound: composed of vibrations that travel through the air or another medium and can be heard when they reach a person's or animal's ear.

Streamer: also called an array; a long line of multiple hydrophones (often thousands), towed behind the survey vessel, which are used during seismic surveys to listen for the echoes of the noise produced from the airguns.

1. Introduction

Baffin Bay is located between Baffin Island, Canada, and the southwest coast of Greenland. It is a marginal sea of the North Atlantic Ocean and is connected to the Atlantic Ocean via the Davis Strait and the Labrador Sea (Figure 1.1). The narrower Nares Strait connects Baffin Bay with the Arctic Ocean. The bay is less than 1,000 m deep near the coast and up to 2,000 m in Baffin Hollow, in the centre of the Bay. Currents form a cyclonic circulation. On the eastern periphery, in summer, the West Greenland Current transports water from the Atlantic Ocean to the North. In its western part, the Baffin Island Current brings the Arctic waters to the south. The bay is not navigable most of the year because of ice cover and the high density of floating ice and icebergs in open areas. However, a polynya (an area of highly productive open water amid the sea ice) of about 80,000 km^2, known as the North Water, opens in summer on the north side near Smith Sound. The bay is a unique and sensitive ecosystem with much of the aquatic life of the bay concentrated near the North Water.

The North Water provides air to ice algae and zooplankton and is characterized by abundant fauna. The Atlantic region of Baffin Bay and the Davis Strait has been assessed to be of particular significance in terms of the high levels of species richness for Arctic marine mammals (Laidre *et al*. 2015). Marine mammals present in the region include walrus, narwhal, beluga, harp seal, bearded seal, ringed seal, bowhead whale, blue whale, fin whale and polar bear. All aquatic mammals crucially depend on the availability of open water; they have very limited ability to maintain breathing holes in ice and are all vulnerable to attacks by polar bears when breathing at the holes. Most large animals of the bay are subject to traditional hunting, but the hunting has been restricted since the 20^{th} century to preserve wildlife populations.

Arctic species face multiple challenges, in addition to impacts from human disturbance, caused by a rapidly changing climate. They will have to adapt to altered critical habitats, especially those species that are closely associated with the ice edge, and changing food webs, while potentially dealing with increased competition for prey with seasonally migrant species that remain in Arctic waters for longer periods, and in some areas cope with increased levels of predation (Watt *et al*. 2013).

Figure 1.1: Map showing the location of Baffin Bay in relation to the Atlantic Ocean, Labrador Sea, Greenland and Baffin Island (map source: By Kmusser (self-made, based on DCW data.) [CC BY-SA 2.5 (http://creativecommons.org/licenses/by-sa/2.5)], via Wikimedia Commons)

There are few settlements around Baffin Bay, due to the inhospitable climate and difficulties in navigating the ice filled waters; the bay has experienced very little human pressure until the last 100 years or so. However, increasingly the land adjacent to and the waters of, Baffin Bay have become affected by human activities including mining, shipping, commercial hunting and more recently oil and gas exploration and drilling. Petroleum exploration in offshore areas off West Greenland started during the 1970s; during which time 21,000 km of 2D seismic survey line data were acquired and five exploration wells were drilled. These wells were declared dry in 1978, but in 1997 a geological survey of Denmark and Greenland re-investigated the well data and found that many areas had been abandoned prematurely. Following this discovery there were several rounds of applications between 2002 and today resulting in companies being given exploration licenses around Greenland; however it wasn't until late 2009 that the application round for Baffin Bay was started. The area currently available for tender covers 151,000 km^2 and is split into 14 blocks, varying in size between 8,000 km^2 and 15,000 km^2. On 26th November 2010, Naalakkersuisut approved the distribution of the different licence blocks in Baffin Bay. A total of seven exclusive licences for exploration and exploitation of oil and gas have been granted to the following oil companies: Qamut (ConocoPhillips, DONG, NUNAOIL); Anu and Napu (Shell, Statoil, GDF SUEZ, NUNAOIL); Pito, Napariaq and Ingoraq (Cairn Energy, NUNAOIL); and Tooq (Mærsk Oil, NUNAOIL) (MinesOnline, 2015) (see Figure 1.2).

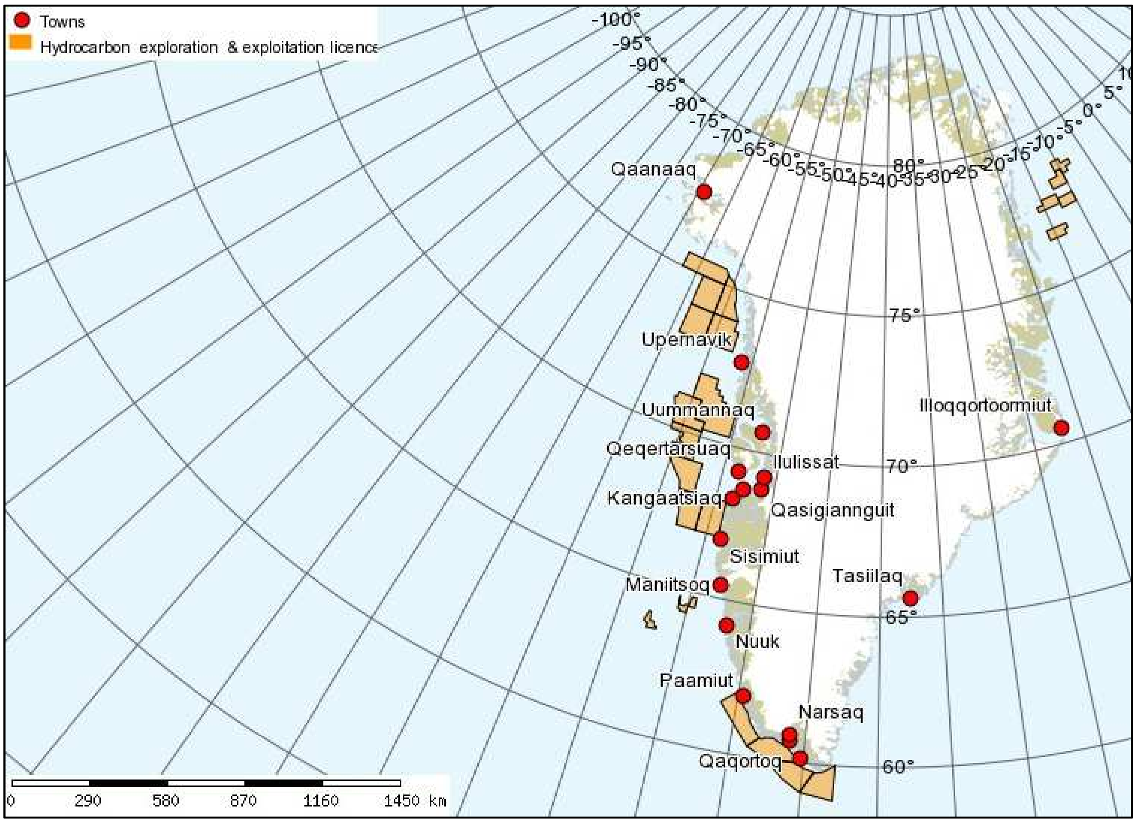

Figure 1.2: A map showing the hydrocarbon exploration and exploitation license blocks (marked in brown) around Greenland.

In the Canadian waters of Baffin Bay, a five year 2D seismic survey proposed to begin in 2015 is the first seismic survey approved in the region for six years. The National Energy Board of Canada has approved nine seismic programs in the last 13 years in the Davis Strait / Baffin Bay / North Labrador Sea region. No drilling activity has ever been authorized.

The offshore exploration for oil and gas deposits is carried out using reflection seismology (seismic surveying); a method which uses blasts of sound from powerful airguns. The blasts are able to penetrate the ocean floor, relaying data back about what lies beneath the seabed.

According to the Oxford English Dictionary, 'sound' is composed of vibrations that travel through the air or another medium and can be heard when they reach a person's or animal's ear. 'Noise' is a sound, especially one that is loud or unpleasant or that causes disturbance. For the purposes of this review, 'sound' shall be considered a signal designed to transfer information (be it biological or geophysical); 'noise' shall refer to an undesirable component that obscures a wanted signal. Specifically with regard to seismic airgun output there is the intended low frequency component sound of the airgun used for the geophysical survey; however there is also much extraneous higher frequency noise. From a biological view point, the entire output from seismic airguns is considered to be noise.

Marine mammals, especially cetaceans, use sound to navigate, communicate and find prey (through echolocation). Loud anthropogenic sound sources such as military sonar, piling and noise from shipping has been linked to strandings, behavioural and vocalisation changes and avoidance reactions in cetaceans around the globe. The research that has been undertaken on the impact of seismic noise on cetaceans is limited, although it has been linked to similar reactions; as such, research on the reactions of Arctic species to seismic noise is extremely limited. However, it is important to note that if there is no observed effect on an individual, a species or population; it does not mean that there is no impact. Certain species have received more research effort due to their ease of study, for example, spending a lot of time at the surface, being maintained in captivity, etc. However, other species, such as beaked whales, and species found exclusively in the Arctic, may be more difficult to study due to their typical behaviour, ecology or habitat.

As the marine species living in Baffin Bay have not been exposed over generations to increasing background noise, the effects of noise pollution are likely to be more severe than in other similar species in noisier areas. Severe reactions of up to 80 km away have been noted for beluga and narwhal to ice-breaking ships, and narwhal have been documented by Traditional Knowledge built up by Arctic Indigenous Peoples to be sensitive to noise from snowmobiles and even people walking on the ice. The long-distance displacement of narwhals is exceptional in the literature on marine mammals (Heide-Jørgensen *et al*. 2013). Thus it may be assumed that narwhals will likely face serious impacts from the planned increase in seismic survey noise in Baffin Bay over the next few decades. This report reviews available data on the impact of noise, and specifically, where information is available, the impact of seismic noise on Arctic species, and particularly on narwhals. It provides some background context on seismic activity in Baffin Bay, how and why marine mammals use sound and then reviews the information available on the ranges at which seismic airgun noise might cause physiological injury, increase the risk of stranding, affect their behaviour, cause displacement and avoidance, affect their young and impact their prey.

2. Seismic testing that will be conducted in Canadian waters of Baffin Bay in 2015

Summary

- In the summer of 2015 a 2D seismic survey covering a linear distance of 16,173 km, utilising an airgun array of 4135 in^3, is planned in the Canadian waters of Baffin Bay.
- After assessing any potential adverse socio-economic and environmental effects likely to occur as a result of a project, the National Energy Board of Canada ruled that collectively, the mitigation measures proposed for this project in the environmental impact assessment would minimise the possibility of marine mammals occurring in close enough proximity to the airgun discharges such that they would suffer permanent or temporary hearing damage or behavioural changes and that the proposed project's residual effects would likely be of short-term duration. However, this ruling by the NEB may overlook the the highly sensitive nature of narwhals and the problems with detecting/locating them visually. Mitigation methods based on use of Marine Mammal Observers (MMOs) may have limited effectiveness in terms of detecting narwhals within the zone of injury with an animal that is so elusive and inconspicuous, and whose typical response to loud noise is to sink and freeze (see chapter 8).
- The project has been proposed to run between July and November. Although the proposed survey lines overlap with a narwhal over-wintering area, the project was considered unlikely to affect narwhals as the survey is scheduled to take place before November.
- The data available on the airgun specifications, source levels and modelled impact zones are lacking; as such, a similar proposed project has been used to examine the sound propagation ranges.
- Furthermore, a table displaying the available information for other surveys which have been conducted or were proposed has been compiled for comparison.
- Appendix 1 provides further information on the mitigation requirements for marine mammals during seismic testing in Baffin Bay, and compares these with the requirements for minimising acoustic disturbance to marine mammals in New Zealand (widely considered to be one of the most precautionary Codes of Conduct). There is also some additional information about the efficacy and effectiveness of mitigation (use of MMOs etc.) in the Conclusions section. New Zealand adopted a new Code of Conduct in 2013 which notes the uncertainty in the effectiveness of measures to reduce impacts and that 'the best course of action is simply to avoid conducting seismic surveys in sensitive areas' (DOC 2013). Recent simulation modelling undertaken by Leaper *et al*. (*in press*) indicates that there will be very few instances where mitigation using visual observers can achieve a greater risk reduction than would be achieved by a 3 dB reduction in source level.

2.1 General background and information

On 16 April 2010, TGS-NOPEC Geophysical Company ASA (TGS) filed a project description with the National Energy Board (NEB) of Canada, for the purpose of conducting a two dimensional (2D) offshore seismic program in the Baffin Bay and Davis Strait area. The project was originally scheduled to commence in July 2010, however the project was delayed until 2011. In January 2011, TGS-NOPEC submitted a revised project description that includes the original project area in addition to an area extending further south. The proposal covers an area within Baffin Bay and Davis Strait that is seaward of Canada's 12 nautical mile Territorial Sea Limit, away from land fast ice and bounded to the east by the Canada/Greenland International Boundary. The northern extent of the seismic survey is approximately 180 km from the mouth of the proposed Lancaster Sound National Marine Conservation Area extending south to the 61°N parallel. The majority of the project will be conducted in deep waters covering an area of approximately 16,173 linear kilometres (NEB 2014). Subsequently, the National Energy Board (NEB) of Canada received a Geophysical Operations Authorization application in May 2011 from TGS, Petroleum GeoServices (PGS) and Multi Klient Invest AS (MKI) to conduct a 2D offshore seismic survey program in Baffin Bay and Davis Strait over five years during the open water season. The NEB was required to undertake an environmental assessment (EA) under the Canadian Environmental Assessment Act (CEA Act).

In 2013, the NEB conducted public meetings in Pond Inlet, Clyde River, Qikiqtarjuaq and Iqaluit, and in response to unprecedented numbers of written and oral comments, written comments from the public and information gathered from community meetings informed NEB's Environmental Assessment process. In June 2014, the NEB approved a Geophysical Operations Authorization (GOA) application for the project with MKI designated as the Project Operator; the Environmental Assessment report concluded that the project is "not likely to result in significant adverse environmental effect". The GOA issued by the Board is subject to 15 conditions including the requirement for MKI to make status updates of environmental commitments and marine mammal observer reports accessible to the public.

2.2 Brief description of the seismic program

The survey is proposed to be conducted in the open water season (from July through to November), depending on weather and ice conditions, for up to 5 years starting in 2015. The seismic survey would involve a seismic survey ship travelling back and forth across the area shown in the map below (Figure 2.1) towing an array of airguns that produce pulses of sound waves under the water. The sound waves pass through the water and into the rock below the seabed. The reflected sound waves from the rock layers are detected and recorded by listening devices on the streamers called hydrophones, which are also towed by the seismic survey ship. The loudness of the airguns is estimated to be 230 decibels at a distance of 1 metre, and will be repeated every 13 to 15 seconds, 24 hours a day while operating. The Project would collect up to approximately 16,173 km of 2D seismic data (NEB 2014). The program will include the use of a seismic array, support vessel and associated re-supply activities.

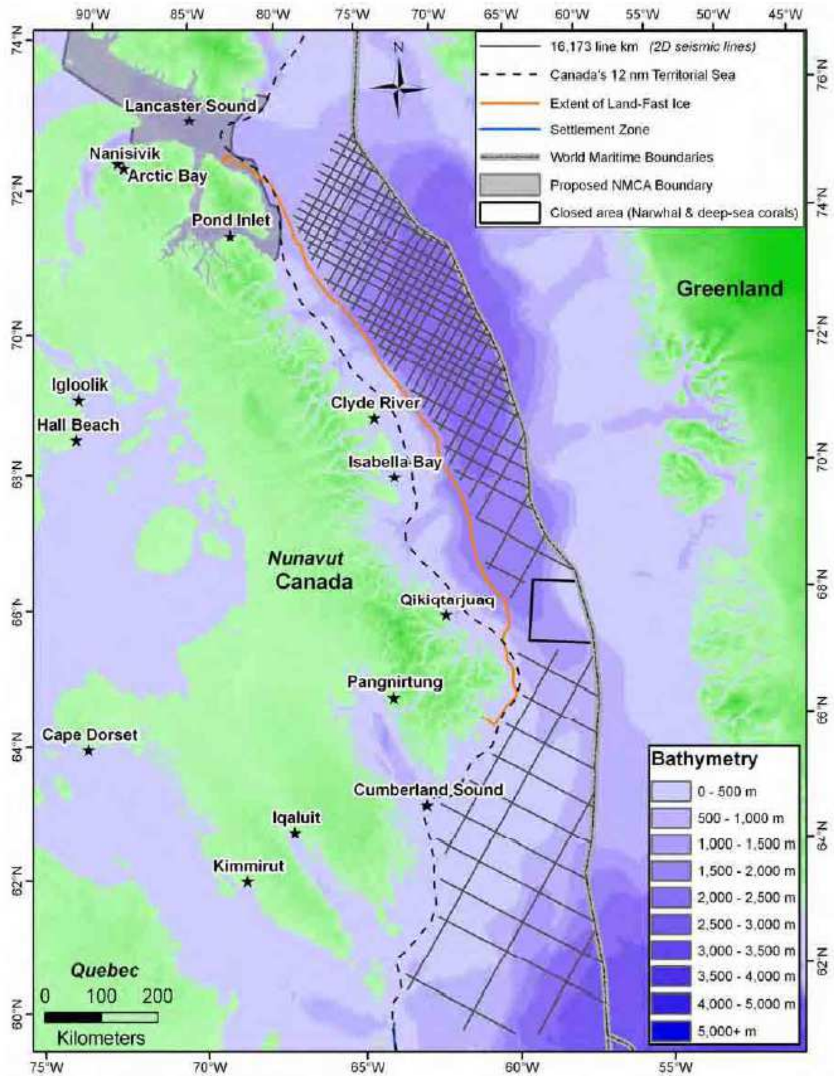

Figure 2.1: Location of the proposed 2D seismic project (NEB 2014).

2.3 Seismic data acquisition:

A source (airgun) array, containing up to 34 active airguns in total (in three sub-arrays) would be towed behind a seismic vessel to generate sound energy (Table 2.1). The airgun array has a total volume of 4135 in^3 and would discharge alternately every 13 to 15 seconds, and would operate 24 hr/ day. The airguns would produce sound energy that can be measured in decibels (dB). The peak sound pressure level from the company's seismic array would be approximately 230 dB at a distance of 1 m from the array (Note this is a theoretical level and may not be reached as the array is not a point source). Sound levels from the arrays would decrease with distance away from the array and at a distance of about 1 kilometre from the sound source the received sound is in the order of 170 dB re 1 µPa (RPS 2011a). The sound generating source will be adapted to reduce received sound levels to 180 dB within a 500 metre safety radius. A solid streamer would be towed behind the seismic vessel, which contains positioning transceivers and hydrophones that would receive and record the sound data. Streamers are filled with solid polyurethane foam and towed at a depth of 4 m to 10 m below the ocean surface. Streamers would extend approximately 10,050 m behind the seismic vessel.

Table 2.1: Specification of energy source for the proposed project.

Array parameter	Description
Manufacturer and type	Sercel – G Gun 2
Effective volume of standard array(s)	4135 in^3
Maximum number of sub-arrays	6
Standard array depth(s)	7 M
Position of depth transducers	Front and tail of sub-array
Working pressure	2000 psi
Type of firing sensors	Pressure activated
Position of firing sensors	Mounted directly on the gun
Type of firing synchroniser unit	RTS BigShot
Timing resolution	0.1 ms
Timing accuracy	+/- 1.0 ms
Position of near field phones	1 mounted on each gun hang frame
Air compressors capacity	Neuman & Esser, 2200 cfm each
Number of air compressors	2

2.4 Seismic and support vessel operations:

The proposed seismic vessel is a heli-deck equipped, ICE-C class vessel that measures 86 m long and 16 m wide, has a draft of 5.8 m, and would accommodate a crew of 47 persons (NEB 2014). The seismic vessel would operate at a cruising speed of 13 knots when transiting to and demobilising from the area of operations, and would operate at an average speed of 5 knots when acquiring seismic information. The seismic vessel would mobilize to the Baffin Bay/Davis Strait via St. Johns Newfoundland. The supply vessel will provide supplies to the seismic vessel and assist in emergency situations. The supply vessel may also be used to survey the way ahead for hazards and will be staffed by a Marine Mammal Observer (MMO) and a Fisheries Liaison Officer; passive acoustic monitoring of marine mammals would be initiated on a trial basis to monitor the presence of cetaceans. The program will not require refuelling at sea.

2.5 NEB's Environmental Assessment Report

The latest Environmental Assessment report by NEB (2014) lists the following potential adverse effects of the proposed survey on all marine mammals under the environmental effects analysis:

- Sensory disturbance including avoidance behaviour.
- Increased mortality risk (whale strikes).
- Sensory and physical disturbance causing:
    - Temporary reduction in hearing sensitivity.
    - Permanent hearing impairment.
    - Masked communication.
    - Changes in behaviour and distribution including avoidance of seismic ship and alteration of migration routes.

In its Environmental Impact Assessment and responses to information requests, MKI committed to routine design and best practice mitigation measures to reduce each of the potential adverse environmental effects categorised above. Proposed mitigation measures listed for marine mammals are (NEB 2014):

- Vessels would maintain a constant speed of approximately 5 knots while surveying.
- Vessel speed/course will be altered in response to weather, traffic, fishing activity and mechanical concerns.
- Mitigation measures set out in the Statement of Canadian Practice with Respect to the Mitigation of Seismic Sound in the Marine Environment (The Statement of Canadian Practice) will be adhered to.
- Four MMOs will be contracted for the duration of the Project, for each rotation, two of whom will be Inuit Observers and two will be experienced MMOs. MKI taught Marine Mammal Observation training to the students in the Arctic College Environmental program.
- A safety radius or shut down zone of 500 metres from the airgun array will be maintained. Airguns will be shut down if any marine mammal enters or is anticipated to enter the 500 metre safety zone through observations by the MMOs. Safety zones for marine mammals are commonly defined by the areas within which specific sound level thresholds are exceeded. These have been quantified by the US National Marine Fisheries Service (NMFS 2000). NMFS policy regarding exposure of marine mammals to high-level sounds is that whales should not be exposed to impulse sounds exceeding 180 dB re 1µPa (rms). These sound levels are the received levels above which one cannot be certain that there will be no injurious effects, auditory or otherwise, to marine mammals.
- Airgun start-up procedures will include a “ramping up” period where a single low volume airgun will fire singly, followed gradually by other airgun units in the array. If a marine mammal is sighted within 500 metres of the array during ramp-up the array will be shut down. About 30 minutes prior to arriving at the start of a line, the airgun array is slowly brought up to a specified power, a ramp-up procedure referred to as a “soft start”. This procedure is an environmental protection measure to permit marine animals opportunity to temporarily vacate that area if the sound levels are perceived as a disturbance. A soft start approach would occur at the beginning of a new line within the perimeter or at the start of operations anywhere within the program area.
- The airgun array will be “powered down” during transit from one seismic line to another. All guns will be turned off except for one, which will function as a signal intended to alert marine mammals of the presence of the vessel. Vessels towing streamers have reduced manoeuvrability when the equipment is deployed. MKI propose a 10 km vessel turn-around perimeter around the survey area. MKI, TGS, and PGS propose a 500 m safety zone monitoring program for whale species at risk during survey data acquisition. The airguns will be shut down every time an endangered whale enters the defined safety zone
- Passive Acoustic Monitoring will be used on a trial basis to monitor the presence of vocalising whales and porpoises and will be used prior to ramp-up during periods of low visibility in accordance with The Statement of Canadian Practice.
- The project will not take place in the vicinity of the Nunavut Settlement Area.
- Sound modelling will be conducted for the first year of survey lines.

In summary, NEB identified the potential for adverse effects to marine mammals, traditional harvesting of marine mammals and fish, and commercial fish harvesting as the main concerns associated with the proposed project. The NEB ruled that collectively, the mitigation measures above would minimise the possibility of marine mammals occurring in close enough proximity to the airgun discharges such that they would suffer permanent or temporary hearing damage or behavioural changes. The NEB decided that the proposed project's residual effects would likely be of short-term duration, in which individual receptors such as marine mammals would be exposed to effects during the seasonal survey, but the effects would be reversible during the life of the project. The effects would occur at a local to regional scale and would be of low magnitude. Although the proposed survey lines overlap narwhal over-wintering area (Figure 2.2), the project was considered unlikely to affect narwhals as the survey is scheduled to take place before November. In conclusion, the NEB stated that if MKI follows the above-mentioned mitigation measures, the commitments made within its application and additional submissions to the NEB, the project is not likely to cause significant adverse environmental effects (NEB 2014).

In terms of cumulative effects, the NEB identified the temporary displacement of marine mammals due to exposure to anthropogenic sound input and vessel traffic had the potential to interact cumulatively. Mitigation measures to reduce the exposure of marine mammals to simultaneous and overlapping noise sources include MKI sending a daily email to AFA (Arctic Fisheries Alliance LP) and BFC (Baffin Fisheries Coalition), daily communication with the fishing fleets in Baffin Bay and Davis Strait via a Fisheries Liaison Officer and MKI posting notices to mariners indicating where and when surveying will occur. The NEB found that any potential cumulative environmental effects would be minimal due to the proposed mitigation measures. The NEB noted that displacement of marine mammals would be temporary and reversible (NEB 2014). Therefore, the NEB has determined that it is not likely that there would be any significant cumulative environmental effects resulting from the proposed project.

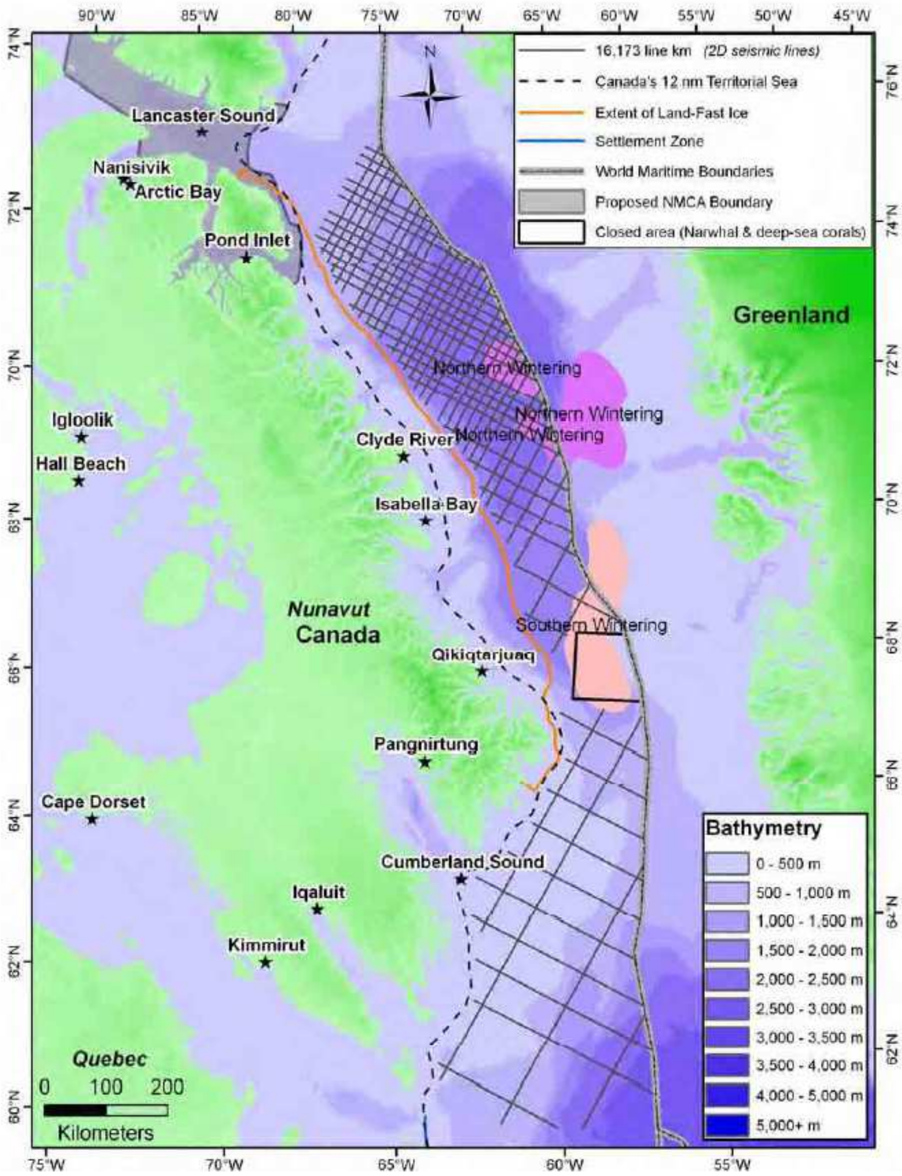

Figure 2.2: Location of narwhal over-wintering areas relative to the proposed survey (NEB 2014).

2.6 Assumed airgun specifications and noise propagation

As publicly available technical details for the proposed survey by MKI/TGS/PGS are limited, details are presented for a similar survey proposed by MKI for the Labrador Sea and Davis Strait (RPS 2011a), which we are in doubt if it ever took place.

The Labrador Sea survey was scheduled to use the same seismic vessel with the same airgun array characteristics (Sercel G Gun 2 with an effective array volume of 4135 in^3). The guns have a working pressure of 2000 psi and the typical array is a single source array made up of 6 sub-arrays. The individual source unit volumes range from 45 in^3 to 250 in^3. The energy source would be a dual air source array system. The produced broadband source level for a typical array is about 252 dB re 1 µPa @ 1m, with the highest energies falling between 10 and 100 Hz.

An air source unit is essentially a stainless steel cylinder charged with high-pressure air. The firing of an air source generates an oscillating bubble in the surrounding water. At the time of firing, the pressure of the air inside the cylinder far exceeds the outside pressure in the surrounding water. This difference in pressure causes a bubble to rapidly expand in the water around the air source. The seismic signal is a popping sound created when air is released forcefully into the water column. It is this initial bubble expansion that generates the relatively broadband seismic pulse. The array is configured in such a way as to maximize the amount of seismic energy projected vertically into the geologic formation being surveyed. Although the direction of the greatest sound intensity is directed vertically downwards from the array, some energy is radiated in directions away from the beam axis and into the surrounding environment. Because of the pattern of air source placement in an array, the signature changes as a function of direction (azimuth) and emission angle (angle from the vertical). The firing times for all the air sources in the array are synchronised to ensure that the primary pulses from each gun align exactly with one another along the vertical axis of the array. These differences in the array signature with respect to direction and angle from the vertical are referred to as the array response; thus the frequency content and sound pressure level of the array signature will be different at different locations in the water. These differences are known as the acoustic radiation pattern and can be mapped in three dimensions. Figure 2.3 shows the acoustic radiation emitted from a 4135 in^3 array for frequencies from 0 to 100 Hz.

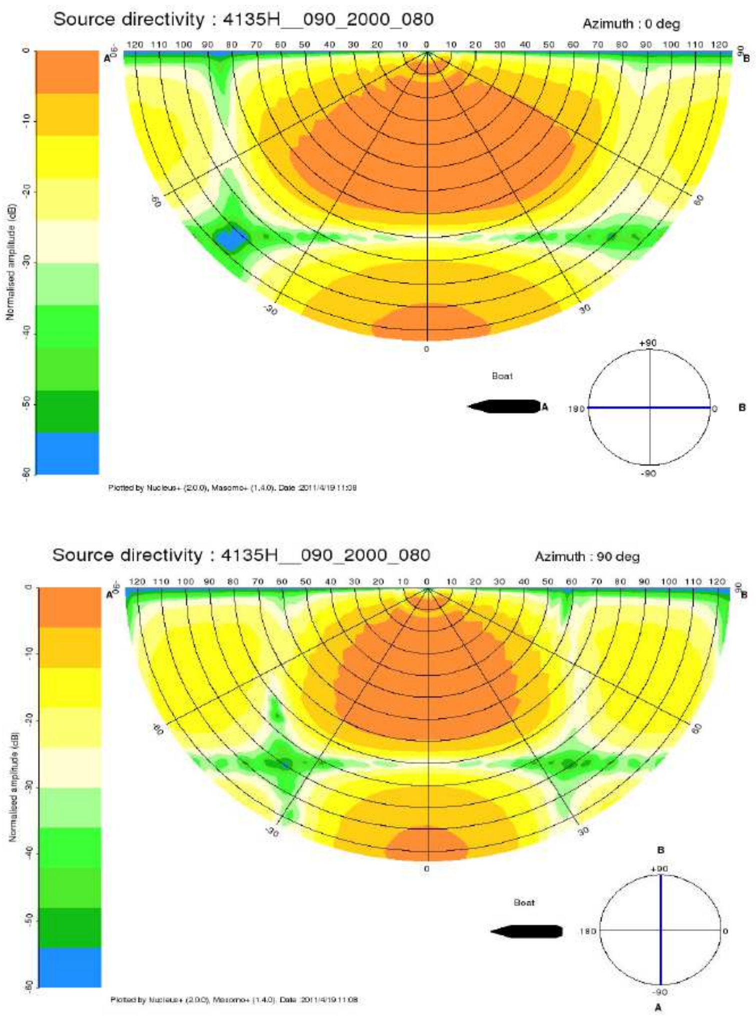

Figure 2.3: Directivity plots in the vertical plane for a 4135 in^3 array source with an azimuth of (a) 0 degrees (inline; front to back of vessel) and (b) 90 degrees (crossline; port to starboard of vessel) at frequencies 0-100 Hz.

Most of the broadband energy from an airgun array is concentrated close to the vertical. Emissions at frequencies above 300 Hz are highly attenuated along radiation paths away from the vertical. Radiation plots suggest more high frequency energy is emitted side-ways from the array than from front-to-back. When the peak pressure amplitude and frequency emission plots are reviewed together, the following summary statements can be made about the direct air source pressure pulses propagating through the water column:

- Most of the broadband energy emitted from the air source array is concentrated close to the vertical emission angle.
- In the array's near-field, pressure amplitudes will be significantly less than predicted from point source extrapolation (by as much as –20 dB) as the array is not a point source.
- The pressure amplitude rapidly diminishes at emission angles greater than 45 degrees.
- Coherent high frequency energy generated by air source arrays is generally less than 300 Hz.

Sound decreases with distance from the source. This is referred to as transmission loss and it is influenced by geometric spreading loss and attenuation. The projected transmission loss at source for the 4135 in^3 array for 100 Hz from 0° to 90° off vertical and azimuth 90° are provided in Table 2.2.

Table 2.2: Transmission losses (TL) at source presented as peak amplitude (0-p), root mean square pressure (RMS) and sound exposure level (SEL) at 90° azimuth and 0-90° from vertical.

Degree from vertical	TL (dB)	0-p	RMS	SEL
0	0	255	243	233
30	12	243	231	221
45	24-36	231-219	219-207	209-185
90	36-48	219-207	207-195	197-185

Tables 2.3 show the predicted sound levels over the proposed study area in the Labrador Sea in water depths of 300 to 3000 m at varying distances from a typical array. Lawson (2009) reviewed seismic studies on the accuracy of model predictions for cases where monitoring was undertaken. He highlighted that discrepancies existed between modelled and measured sound propagation; with received sound levels varying by 10 to 30 dB, which equates to a change in amplitude of 3 to 31 times, respectively. As the distances to a given safety radius, of for example 180 dB, varied considerably, there is a need to be conservative when planning mitigation during Environmental Impact Assessments based on the data from models.

Table 2.3: Predicted sound levels (rms dB) presented as 45° off vertical (or horizontal) based on spherical and cylindrical spreading transmission losses. (The values are based on crossline levels at 45° and 90° off vertical (i.e. horizontal) of a source of 243 dB re 1 µPa @ 1 m (rms) with the array towed at 6 m depth)

	Depth of water being surveyed (m)						
Distance from array (m)	**300**	**500**	**1000**	**1500**	**2000**	**2500**	**3000**
1	213	213	213	213	213	213	213
2	207	207	207	207	207	207	207
4	201	201	201	201	201	201	201
8	195	195	195	195	195	195	195
16	189	189	189	189	189	189	189
32	183	183	183	183	183	183	183
64	177	177	177	177	177	177	177
128	171	171	171	171	171	171	171
256	165	165	165	165	165	165	165
521	162	159	159	159	159	159	159
1,024	159	156	156	153	153	153	153
2,048	156	153	153	150	150	147	147
4,096	153	150	150	147	147	144	144
8,192	150	147	147	144	144	141	141
16,384	147	144	144	141	141	138	138
32,768	144	141	141	138	138	135	135

2.7 Comparison of the proposed 2015 survey with other surveys in the region

Since the first round of licensing for hydrocarbon exploration in Greenland in 2006 there have been hydrocarbon-related offshore activities in western Greenland every summer. Baffin Bay was opened to hydrocarbon exploration in 2010 when five licenses were awarded for the blocks Qamut (ConocoPhillips), Anu (Shell), Pitu (Cairn), Napu (Shell) and Tooq (Maersk). The first large-scale activities took place in autumn 2011, when Cairn conducted a 2D seismic survey in the Pitu block (Perry *et al*. 2011). This was followed by a very large programme in the summer/autumn 2012, where seismic surveys were conducted simultaneously in the four remaining blocks (LGL & Grontmij 2012; Inuplan A/S & Golder Associates 2012; NunaOil 2012).

As publicly available technical details for the proposed survey by MKI/TGS/PGS are limited, details are presented for similar surveys that have been planned and/or conducted in the Canadian High Arctic and/or Greenland. Appropriate caution should be taken in comparing these outputs as the sound exposure level any marine mammals may experience in the vicinity will vary not only with airgun size but also bathymetry, sea-bed substrate, local availability of key habitats, season and length of survey and local environmental variables including degree of ice cover. Additionally, surveys vary in the density of survey lines, the ramp up/down procedures used and other mitigation practices.

It should be noted that planned seismic surveys for 2015-2019 cover a large area with relatively high volume airguns, over a long duration (4 months), compared to previous surveys (see below). Consideration should also be given to the cumulative impacts of a 5 year programme that may overlap with other planned seismic surveys or other O&G related activities that may occur in the region.

Survey	Cairn 20102D seismic survey South Greenland	TGS-NOPEC 2010 2D seismic survey in Baffin Bay	Cairn 2011 3D seismic survey for Saqqamiut block, Southern Greenland	Capricorn Greenland 2011 3D seismic survey for Pitu, West Greenland	MKI A/S 2011 2D seismic survey for Labrador Sea & Davis Strait
Planned or completed	Completed	Completed	Completed	Completed	Completed?
Location	Southern Greenland	West Greenland	Southern Greenland	West Greenland	Labrador Shelf
Firing timeframe	August – October 2010	July – October 2010	June – August 2011	August 2011 onwards	July 2011 – November 2013
Duration (days)			~45	35	120-180
Block area (km^2)	15,000	15,078	1,500	1,500	561,423
Total survey length	8,095		3,183	3,178	9,200 (1st year)
Survey type	2D	2D	3D	3D	2D
Duty cycle		24 hrs/day, 7 days/week	24 hrs/day, 7 days/week	24 hrs/day, 7 days/week	24 hrs/day, 7 days/week
Airgun make			Sodera G-Gun II	Sodera G-Gun II	Sercel – G gun 2
Total airgun volume (in^3)	4,130	4,100	4,135 (2 arrays)	4,135 (2 arrays)	4,135 (34 guns)
Array type	1 array plus streamer (7km)	1 array plus streamer (6km)	2 arrays firing alternatively plus 10 streamers (7km)	2 arrays firing alternatively plus 10 streamers (7km)	6 sub-arrays firing continuously plus 1 streamer (10km)
Working pressure (psi)			2000	2000	2000
Array SL dB re 1 µPa 0-p (broadband)			259	259	255
Array SL dB re 1 µPa pp (broadband)			265	265	
Array SL dB re 1 µPa rms (over 90% pulse duration)					243
Array SEL dB re 1 $µPa^2s$ (per pulse)					233
Signal duration (ms)					
Modelling conducted			No	No	Limited
Firing rate (shots/min)					3-9
Line spacing			500m	500m	120km
Depth below seabed					
Vessel speed (kts)		5			4.5
MMSO/PAM			MMSO	MMSO	
Vessels	1 seismic (SV Nordic Explorer), 1 support	1 seismic (MV Bergen Surveyor), 1 support	1 seismic (M/V Ramform Challenger), 3 support	1 seismic (M/V Ramform Challenger), 3 support	1 seismic (M/V Sanco Spirit), 1 support
Icebreaker required					
Reference			Shtepenko *et al*. 2011	Perry *et al*. 2011	RPS 2011a

Survey	Shell Kanumas A/S 2012 3D seismic survey in Baffin Bay blocks 5 (Anu) & 8 (Napu)	ConocoPhilips 2012 2D seismic survey in Baffin Bay block 2 (Qamut)	Maersk Oil 2012 3D seismic survey of block 9 (Tooq)	TGS/MKI 2015 Northeastern Canada 2D seismic survey (Baffin Bay/Davis Strait)
Planned or completed	Completed	Completed	Completed	Planned
Location	Northwest Greenland	Northwest Greenland	Northwest Greenland	Canadian Baffin Bay/Davis Strait
Firing timeframe	August – October 2012	August – September 2012	August – October 2012	End July 2015 – mid November 2019
Duration (days)	~75	28-42	~60	~125
Block area (km^2)	9,188	9,392	1,900	
Total survey length	14,388	~3,000		16,173
Survey type	3D	2D	3D	2D
Duty cycle	24 hrs/day, 7 days/week	24 hrs/day, 7 days/week	24 hrs/day, 7 days/week	24 hrs/day, 7 days/week
Airgun make			Bolt 1500-LL/1900-LLXT	Sercel – G gun 2
Total airgun volume (in^3)	3,480 (33 guns)	3,940	3,480	4,135 (34 guns)
Array type	2 arrays (of 3 sub-arrays) firing alternately plus 6 streamers (7km)	1 arrays (of 3 sub-arrays) firing continuously plus 1 streamer (10km)	2 arrays (of 3 sub-arrays) plus 10 streamers (?km)	3 sub-arrays plus streamer (10km)
Working pressure (psi)	2000	2000	2000	2000
Array SL dB re 1 µPa 0-p (broadband)	247.3			~230
Array SL dB re 1 µPa pp (broadband)		262.4	262.6 (for 4,240 ci array)	
Array SL dB re 1 µPa rms (over 90% pulse duration)		247.1	240.9 (for 4,240 ci array)	
Array SEL dB re 1 µPa^{2}s (per pulse)	227.8	232.8	233.2 (for 4,240 ci array)	
Signal duration (ms)		33.5ms	151	
Modelling conducted	No	Yes	Yes (for 4,240 ci array)	
Firing rate (shots/min)	6 (3 each source)	6	6	4-5
Line spacing	600m			
Depth below seabed	5-6km		3-4.5km	
Vessel speed (kts)	4.3	4.0	4-5	
MMSO/PAM	MMSO & PAM	MMSO & PAM	MMSO & PAM	
Vessels	2 seismic (M/V Polarcus Samur & M/V Polarcus Amani), 5 support	1 seismic (M/V Princess), 2 support	1 seismic (MV Polarcus Asima), 4 support	1 seismic (M/V Sanco Spirit), 1 support
Icebreaker required	No	No	No	
Reference	LGL & Grontmij 2012	Inuplan A/S & Golder Associates 2012	NunaOil 2012	RPS 2011b, NEB 2014

3. An introduction to the whales & dolphins of Baffin Bay

Summary

- Baffin Bay and Davis Strait are two large basins between Baffin Island, Canada and Greenland that connect the Arctic and Atlantic Ocean; these waters are highly productive in terms of phytoplankton and, in turn, lower-trophic level fish and zooplankton.
- This attracts large numbers of top marine predators.
- Many species of cetacean use the waters of Baffin Bay at some point through the year, although the three main species of interest for this briefing are the 'true Arctic' species, narwhal, beluga and bowhead whales.
- Narwhals, a species listed by the IUCN Red List as Near Threatened, are year-around residents of Baffin Bay and are distributed primarily in deep waters.
- Beluga whales are listed as Near Threatened on the IUCN Red List; their distribution is very dependent on ice-cover and they have been increasingly reported in the waters of West Greenland.
- Bowhead whale numbers were severely depleted by whaling in the 1600-1800s. Although globally the species is now listed as of Least Concern on the IUCN Red List, the Baffin Bay/Davis Strait population is listed as Near Threatened on the Greenland Red List. They are only found in Arctic and subarctic regions, spending their lives in and near the pack ice, migrating to the high Arctic in summer, and retreating southward in winter with the advancing ice edge.
- Other cetacean species that are routinely found in Baffin Bay include humpback, sei, minke, fin, blue, pilot, bottlenose and sperm whales.

3.1 General background and information

The coast of West Greenland is the longest continuous stretch of subarctic to Arctic coastline in the world. Baffin Bay and Davis Strait are two large basins between Baffin Island and Greenland that connect the Arctic and Atlantic Oceans. Covering over 1.1 million square kilometres, the region includes the North Water Polynya, one of the Arctic's largest open-water areas and one of the most biologically productive volumes of water in any polar region. When the annual winter sea-ice cover retreats, the dissolution of salts in the water and the warming effect of southerly currents in Baffin Bay trigger a large bloom of primary production on the continental shelf. This principally involves numerous single-cell algae and small invertebrates, most notably euphausiids (small shrimp-like crustaceans). Smaller organisms such as these attract high densities of lower-trophic-level foraging fish and zooplankton (Laidre *et al*. 2008) and in turn large numbers of top marine predators. The icy habitat of Baffin Bay and Davis Strait is home to globally important populations of cold water corals, fish, seabirds and more than ten species of baleen (mysticete) and toothed (odontocete) whales. Variations in the extent of the sea-ice cover influence the timing of the diatom-dominated spring bloom (Hansen *et al*. 2006, Heide-Jørgensen *et al*. 2007a), a phenomena closely coupled to the appearance of *Calanus* copepods which form the basis of the marine food chain in the region (Madsen *et al*. 2001). Thus local foodwebs are strongly susceptible to thermal perturbation.

3.2 Cetaceans in Baffin Bay

This introduction provides a summary of the three Arctic cetacean species, i.e. those that occur north of the Arctic Circle (66° 33′ N) for most of the year and depend on the Arctic marine ecosystem for all aspects of life: the narwhal, beluga and bowhead whale. Other species of cetacean known to visit the waters of Baffin Bay regularly are also briefly discussed.

3.2.1 Narwhal (*Monodon monoceros*)

Narwhals are medium sized, gregarious, highly vocal whales. Narwhals have grey mottled backs and sides, small rounded heads, short flippers with upturned tips, and an uneven dorsal ridge along the spine rather than a dorsal fin. In males, usually the left one of two elongated maxillary teeth grows and protrudes through the maxillary bones and skin of the rostrum to form a tusk. Some males lack this helical tusk whereas others may develop two tusks. Average body length is 4.0 m and 5.5 m and body mass 1000 kg and 1600 kg, in adult females and males respectively (Heide-Jørgensen 2009).

Distribution

Narwhals primarily inhabit the Atlantic sector of the Arctic and are year-round residents of Baffin Bay. The principal distribution is from the central Canadian Arctic (Peel Sound – Prince Regent Inlet and northern Hudson Bay) eastward to Greenland and into the eastern Russian Arctic (around 180°E). In summer, narwhals spend approximately two months in ice-free shallow bays and fjords of the high Arctic; they overwinter in offshore, deep, ice-covered habitats along the continental slope (Heide-Jørgensen & Dietz 1995). The whales migrate annually between these disjunct seasonal areas of concentration, with the migratory periods lasting approximately two months (Koski & Davis 1994, Innes *et al*. 2002, Heide-Jørgensen *et al*. 2002, Dietz *et al*. 2001, Heide-Jørgensen *et al*. 2003).

Tracking studies of narwhals in Baffin Bay have been conducted since 1997 with projects conducted in Tremblay Sound, Baffin Island, in 1998 and 1999; Creswell Bay, Somerset Island, in 2000 and 2001; and in Admiralty Inlet, Baffin Island, in 2003 and 2004 (Dietz *et al*. 2008). It has been observed that narwhals from Admiralty Inlet as well as from Melville Bay and Tremblay Sound over-winter in northern Davis Strait and southern Baffin Bay, identified as the “southern narwhal over-wintering area” (Dietz *et al*. 2001, Heide-Jørgensen *et al*. 2002) but narwhals from Somerset Island (Creswell Bay) over-wintered further north in central Baffin Bay, identified as the “northern narwhal over-wintering area” (Heide-Jørgensen *et al*. 2003). The northern over-wintering area lies largely within Greenland waters, while the southern area lies primarily within Canadian waters (Figure 3.1).

Breeding

The breeding habits of narwhal are largely unknown. Narwhals mate during the spring season from February to June (Best & Fisher 1974, Hay 1984, Heide-Jørgensen & Garde 2011). The average narwhal has a gestation period of 13 to 15 months and will bear its calf between June and August (Best & Fisher 1974, Heide-Jørgensen & Teilmann 1994). The narwhal only bears one calf at a time and calves nurse for ~ 20 months. This lengthy period of nursing gives the calf time to learn how to hunt independently. At birth the calves are about 1.6 metres in length, weigh about 80 kg and have 25 mm thick blubber. After the calf is born, it stays very close to the mother’s back as it may need assistance swimming. The narwhal normally has a birthing interval of three years.

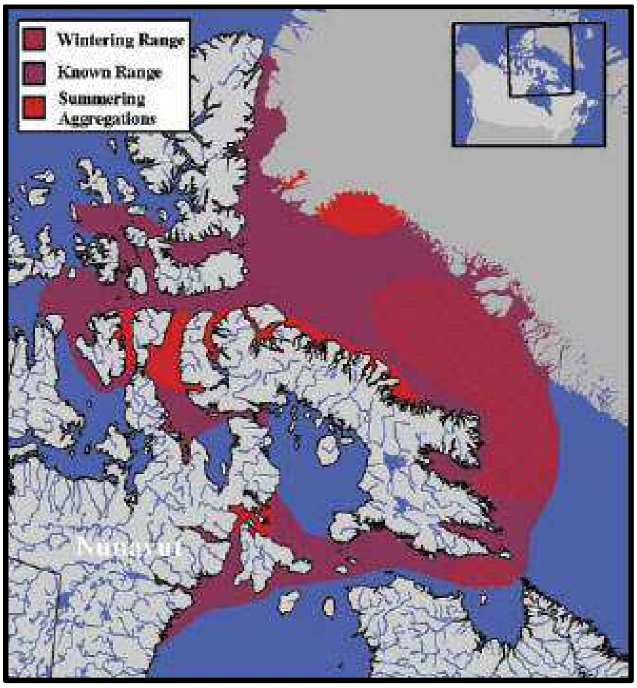

Figure 3.1: Narwhal distribution in Baffin Bay (www.dfo-mpo.gc.ca).

Population

The aggregate circumpolar population of narwhals (all ages) is probably in excess of 80,000 animals. The narwhals that summer in the Canadian High Arctic probably number at least 70,000 animals, accounting for 80 to 90 percent of the world's population (Innes *et al*. 2002; NAMMCO/JCNB 2005). In addition, several thousands of individuals probably summer in the bays and fjords along the East Baffin Island coastline (NAMMCO/JCNB 2005). Aerial surveys conducted over three major narwhal hunting grounds derived abundance estimates of 7,819 on the wintering ground off West Greenland in 2006, and 8,368 and 6,024 in 2007 for summer aggregations of Inglefield Bredning and Melville Bay respectively (Heide-Jørgensen *et al*. 2010a). Winter occurrence of narwhals off West Greenland has been used to index population trends in the stock hunted at several sites along the coast; this time series has exhibited a declining trend in abundance since 1981 (Heide-Jørgensen & Acquarone 2002, Heide-Jørgensen & Reeves 1996, Heide-Jørgensen *et al*. 1993) and continued surveys are required to monitor these trends. It is believed that there are 11 subpopulations of narwhal (Laidre *et al*. 2015), however very limited information exists on population abundance and trends within these subpopulations.

Conservation status

The narwhal was most recently assessed by the IUCN as Near Threatened in 2008, having been previously assessed as Data Deficient in 1996. The West Greenland subpopulation is listed as Critically Endangered on the Greenland Red List (Boertmann 2007). At the global level the species does not qualify for a threatened status under any IUCN criteria, although there is substantial uncertainty about numbers and trends in large parts of the range and clear evidence of decline for specific subpopulations (NAMMCO/JCNB 2005, Laidre *et al.* 2015). Given that uncertainty, the narwhal is unquestionably a conservation-dependent species.

Across the global range of the narwhal, subpopulations are exposed to varying levels of threat and thus require individual assessment. Therefore, a caveat for the global IUCN listing as Near Threatened is that it assumes national and international management authorities will monitor and manage harvest levels. Several small and/or depleted subpopulations (e.g. West Greenland and Hudson Bay) warrant individual assessment as an immediate priority.

Narwhal are listed in Appendix II of CITES and CMS Appendix II.

Behaviour

Narwhals prefer deep or offshore waters throughout their known range (Hay & Mansfield 1989). Narwhals from Canada and West Greenland exhibit high site fidelity to the winter pack ice of Davis Strait and Baffin Bay in regions along the continental slope with high gradients in bottom temperatures, predictable open water and relatively high densities of Greenland halibut (*Reinhardtius hippoglossoides*) (Laidre *et al*. 2004). The wintering grounds may be the most important habitat for narwhals; intense benthic feeding behaviour has been documented between November and March in Baffin Bay and Davis Strait (Laidre *et al*. 2003, Laidre & Heide-Jørgensen 2005), in contrast to low feeding activity during the summer period. This suggests a major portion of the annual energy intake is obtained in winter (Laidre *et al*. 2004, Laidre & Heide-Jørgensen 2005). An examination of dive behaviour data has shown clear differences between the two over-wintering areas (Laidre *et al*. 2003). In the northern over-wintering area, narwhals spent most of their time diving to depths between 200 and 400 m while narwhals in the southern over-wintering area spent less time at shallow depths and most of their time diving to 800 m or deeper, spending over three hours at these depths per day and traveling 13 minutes per round trip to reach these depths (Laidre *et al*. 2003).

The narwhal's diet is composed of fish, squid, and shrimp (Hay & Mansfield 1989; Heide-Jørgensen 2009), especially Arctic fish species, including the Greenland halibut and Arctic cod (*Arctogadus glacialis*) (Laidre and Heide-Jørgensen 2005a). Narwhals feed mostly in deep water and possibly at or near the bottom. Dives of up to 1,500 m and 25 minutes are documented (Laidre *et al*. 2003) with seasonal differences in the depth and intensity of diving (Laidre *et al*. 2002, Laidre *et al*. 2003). Predators include killer whales, polar bears, and possibly occasionally Greenland sharks and walruses (Hay & Mansfield 1989).

Most narwhal pods consist of 2-10 individuals but they may aggregate to form larger herds of hundreds or even thousands of individuals (Jefferson *et al*. 1993). The estimated generation length (average age of parents of the current cohort) is 24 years (Taylor *et al*. 2007).

3.2.2 Beluga (*Delphinapterus leucas*)

The beluga whale is a medium sized, distinctive light coloured or white toothed whale. Adult belugas may reach a length of 5 m (average size is about 4 m). Males may weigh up to 1,500 kg and females 1,360 kg. Beluga whales lack a dorsal fin and do not typically produce a visible "blow" when breathing at the surface.

Distribution

Beluga whales are distributed in high latitudes of the Northern Hemisphere from the west coast of Greenland westwards to Svalbard (O'Corry-Crowe 2002). Satellite telemetry, genetic studies, and organochlorine analyses show belugas have strong matrilineally driven seasonal site fidelity to fjords and estuaries for summering and they migrate to separate wintering grounds (O'Corry-Crowe *et al*. 1997, de March *et al*. 2002, Innes *et al*. 2002, O'Corry-Crowe *et al*. 2002). Nearly 30 years of dedicated survey effort off West Greenland has revealed a shift in distribution of beluga whales in response to changes in sea-ice coverage; belugas appear to have expanded their distribution westward as new areas on the banks of West Greenland open up earlier in spring with reduced sea-ice coverage or early annual ice recession. This is in contrast to the relatively confined distribution of belugas near the coast in limited open areas in the early 1980s, when sea-ice cover was greater (Heide-Jørgensen *et al*. 2009).

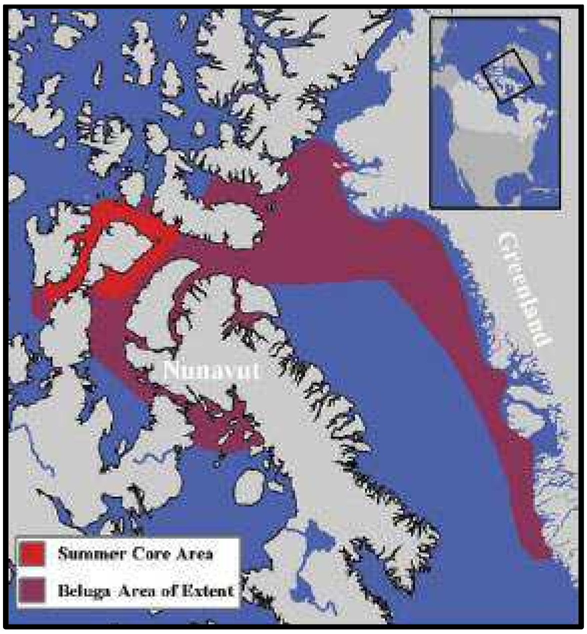

Figure 3.2: Beluga habitat in Baffin Bay and the high east Arctic (www.dfo-mpo.gc.ca).

Breeding

Female belugas typically give birth to a calf every three years. Most mating occurs between April and July, but mating may occur at other times of year (Heide-Jørgensen & Teilmann 1994, Kelley *et al*. 2014). Gestation is likely to last 13-16 months (Heide-Jørgensen & Teilmann 1994). Calves are born over an extended period that varies with location. Births usually take place in shallow bays or estuaries where the water is warm (10-15 °C). In the Canadian Arctic calves are born between March and September, while in Hudson Bay the peak of calving is in late June and in Cumberland Sound, most calves are born from late July to early August (Cosens & Dueck 1990). Calves nurse for up to two years.

Population

The global beluga population consists of numerous subpopulations or stocks with varying degrees of differentiation. The International Whaling Commission's Scientific Committee (IWC 2000) organised information on belugas on the basis of 29 provisional management stocks. Some of the stock boundaries overlap spatially and seasonally, complicating assessment (Laidre *et al.* (2015) suggests 19 beluga subpopulations). While good abundance estimates are available for some beluga stocks, the sizes of others are virtually unknown; Laidre *et al.* (2015) note that of 19 sub populations suggested, there is population trend data on abundance estimates for just five of them. Three are declining, one is increasing and one is stable. 74% of sub populations are subject to harvests. Total numbers worldwide are well above 150,000 animals, with many portions of the range not surveyed. In the Eastern Canadian High Arctic, a survey in 1996 estimated 21,213 belugas in the waters surrounding Somerset Island (Barrow Strait, Peel Sound and Prince Regent Inlet; Innes *et al*. 2002). For West Greenland, data from aerial surveys flown in late winter between 1981 and 1994 suggested beluga numbers had decreased by 62% over that period, probably because of over-harvesting (Heide-Jørgensen & Reeves 1996). Catch statistics assessed in 2000 estimated numbers at only 22% of 1954 levels and the decline was similarly attributed to overharvesting (Alvarez-Flores & Heide-Jørgensen 2004). Aerial surveys in 1999 confirmed this decline with an estimate of 7,941 individuals (Heide-Jørgensen & Acquarone 2002). More recent aerial surveys in 2006 and 2008 derived an abundance estimate of 10,595 belugas (95% confidence interval 4,904–24,650) in West Greenland (Heide-Jørgensen *et al*. 2009) which is not statistically different from the 1999 estimate but may suggest a slight recovery from the population decline observed over the previous 25 years. Heide-Jørgensen *et al*. (2003) estimate that approximately 30% of the Eastern Canadian High Arctic/Baffin Bay beluga stock migrates to West Greenland for overwintering.

The Baffin Bay stocks of beluga were commercially hunted in the late 1800s (Reeves & Mitchell 1987) and have had average reported subsistence landings around 700 belugas per year from 1954 to 1999 (Heide-Jørgensen 1994, Heide-Jørgensen & Rosing-Asvid 2002). The catch of belugas in West Greenland increased in 1968 and has since remained well above sustainable rates. The stocks of the Baffin Bay belugas wintering off West Greenland declined in number by 62% between 1981 and 1994 (Heide-Jørgensen *et al*. 1993, Heide-Jørgensen & Reeves 1996). The estimated stock sizes of belugas wintering off West Greenland in 1999 was approximately 4,100, suggesting this harvest has reduced the West Greenland stock to about 11% of stock size estimated in 1861 (Innes & Stewart 2002). The recent increase in the abundance of belugas in West Greenland to 10,595 (Heide-Jørgensen *et al*. 2009) coincides with a decline in catches since the mid-1990s. Catches have been below 500 per year since 1999, and a new quota installed in 2004 limited the catches to 160 whales per year, considerably less than the average catch level off 688 belugas per year in the 1990s (Heide-Jørgensen *et al*. 2009). Furthermore, no ice entrapments of belugas have been observed since 1990, suggesting a reduction in large-scale natural mortality events.

Conservation status

The beluga was most recently assessed by the IUCN as Near Threatened in 2008, having been previously assessed as Vulnerable in 1996. At the global level the species does not qualify for a threatened status under any of the IUCN criteria although there is substantial uncertainty about numbers and trends for at least some large parts of the range. Given that uncertainty, the beluga whale is unquestionably a conservation-dependent species.

Across the global range of belugas, subpopulations are subject to differing levels of threat and warrant individual assessment. Some subpopulations clearly qualify for threatened status and only one of these – the Cook Inlet subpopulation – has been assessed thus far (as Critically Endangered; Lowry *et al*. 2006). Other potentially threatened subpopulations that are well-defined and well-studied, such as those in West Greenland, should be assessed separately as soon as feasible.

Behaviour

Belugas are relatively well-studied as a result of carcass sampling from hunts, along with considerable effort from studies employing satellite-linked radio-tracking techniques (Richard *et al*. 1998; Heide-Jørgensen *et al.* 2003; Hobbs *et al*. 2005). Belugas occur seasonally (mainly in summer) in coastal waters as shallow as 1–3 m deep but also in deep offshore waters (800 m). They occupy estuaries, continental shelf and slope waters, and deep ocean basins in conditions of open water, loose ice, and heavy pack ice. Belugas generally prefer to spend winter months in shallow or coastal areas, usually with light or highly moveable ice cover (Barber *et al*. 2001, Suydam *et al*. 2001, Heide-Jørgensen *et al*. 2003).

Some belugas undertake large-scale annual migrations between summering and wintering sites (Hobbs *et al*. 2005). Large numbers of migratory belugas occur along the north-western and northern Alaskan coast, in the Canadian high Arctic and in western Hudson Bay. At certain times of the year, those whales migrate thousands of kilometres, in some cases as far as 80°N into dense pack ice (Suydam *et al*. 2001) or thousands of kilometres into the North Water polynya or to the pack ice off West Greenland (Richard *et al*. 1998; Heide-Jørgensen *et al*. 2003).

Dives may last up to 25 minutes and animals may reach depths of 800 m. Belugas have a diverse diet, which varies greatly from area to area. Although a range of species of fish are considered to be the primary prey items (including salmon, herring and Arctic Cod), belugas also feed on a wide variety of molluscs (such as squid and octopus) and benthic crustaceans (shrimps and crabs). Polar bears and killer whales are known predators of belugas throughout their Arctic range (Frost *et al*. 1992).

3.2.3 Bowhead whale (*Balaena mysticetus*)

These large, rotund whales are among the largest animals on earth, with individuals weighing up to 100 tonnes (Reeves & Leatherwood 1985). Males grow to 14–17 m in length and females 16–18 m, perhaps as long as 20 m. The head constitutes over a third of the bulk of the body, and the baleen plates may reach lengths of 4 m (no other whale has baleen longer than 2.8 m) with 230–360 plates on each side of the mouth, making the capacious mouth quite possibly the largest of any animal. The blubber of bowhead whales is up to 28 cm thick, covered by an epidermis up to 2.5 cm thick. This combination of blubber and skin is the thickest of any whale species, providing insulation from the icy waters.

Distribution

Bowhead whales are found only in Arctic and subarctic regions. They spend much of their lives in and near the pack ice, migrating to the high Arctic in summer, and retreating southward in winter with the advancing ice edge (Moore & Reeves 1993). The International Whaling Commission recognises five stocks, one of which is the Baffin Bay-Davis Strait stock (Rugh *et al*. 2003). However, animals satellite-tagged in Cumberland Sound off southeast Baffin Island moved into Prince Regent Inlet, the Gulf of Boothia, Foxe Basin and the Hudson Strait (Dueck *et al*. 2006); animals tagged in

West Greenland also moved to Prince Regent Inlet and Hudson Strait. There is thus no clear geographical division between the Hudson Bay-Foxe Basin and the Baffin Bay-Davis Strait stocks and the IWC Scientific Committee currently regards the stock identity question as open (Heide-Jørgensen *et al*. 2006, IWC 2007). Laidre *et al* 2015 refer to four stocks.

The distribution of the Baffin Bay-Davis Strait stock is centred in summer in the eastern Canadian High Arctic archipelago and along eastern Baffin Island (Figure 3.3). The whales move out of summering areas as ice forms in autumn to wintering areas in polynyas (Holst & Stirling 1999), unconsolidated pack ice, and open water near the ice edge off West Greenland (Reeves and Heide-Jørgensen 1996) and eastern Baffin Island. The summering grounds include Cumberland Sound, the well-studied late summer and autumn feeding ground in Isabella Bay (Finley 1990), Lancaster Sound, Admiralty Inlet, and Eclipse Sound.

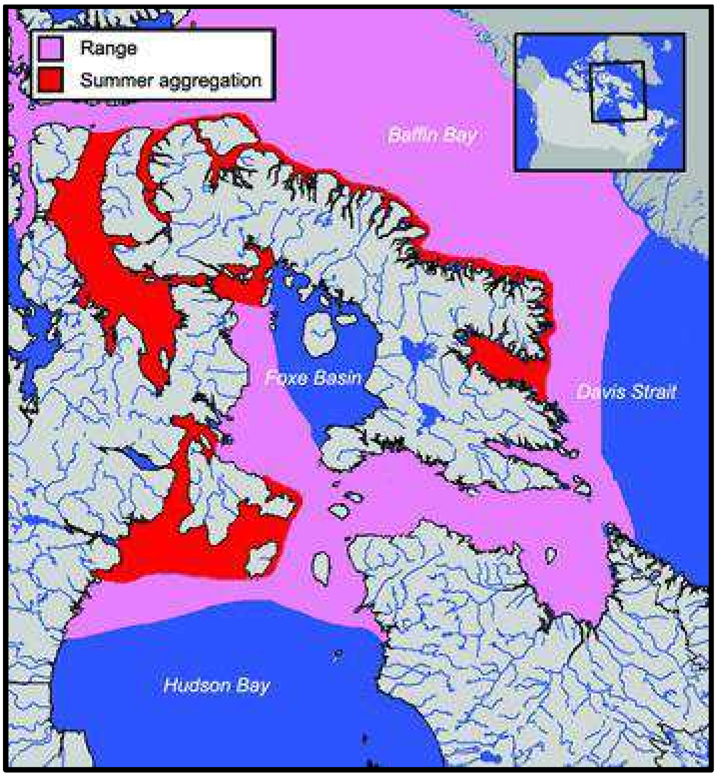

Figure 3.3: Bowhead whale distribution, Eastern Canada / Western Greenland population (www.dfo-mpo.gc.ca).

Breeding

Sexual activity occurs between pairs and in boisterous groups of several males and one or two females. Breeding has been observed from March through August, conception is thought to occur primarily in March. Females give birth to a calf every 3-4 years after a 13-14 month gestation. Age and sex segregation of bowheads occurs in the Eastern Canadian Arctic and West Greenland waters on a large scale (Heide-Jørgensen *et al*. 2010c). For the most part, the waters of north-western Hudson Bay, Foxe Basin, Gulf of Boothia and Prince Regent Inlet appear to be occupied by cows, calves and sub-adults. The waters of the east coast of Baffin Island, Baffin Bay and Davis Strait seem mainly to be occupied by adult males and, probably, resting females. It is likely that pregnant cows leave the wintering areas and either calve *en route* to summering locations or calve once they arrive.

The small number of calves taken in West Greenland waters by the commercial whalers suggests that pregnant females may also migrate across Baffin Bay from Greenland, arriving at the Pond's Bay area either with near-term foetuses or newborn calves (Heide-Jørgensen *et al*. 2008).

Although there are indications that Disko Bay is an important feeding ground for bowhead whales there is also evidence from acoustics that this bay could be a mating ground (Heide-Jørgensen *et al*. 2010c). Intensive singing activity of bowhead whales, with the population demonstrating up to three unique songs, has been recorded in April 2007 (Stafford *et al*. 2008; Tervo *et al.* 2009). Singing is an activity that is usually attributed to male display in baleen whales and the fact that most singing activity was recorded during the spring mating period makes it plausible that mating between the relatively few males and the large proportion of females occur in Disko Bay (Heide-Jørgensen *et al*. 2010c).

Population

All bowhead subpopulations were severely depleted by commercial whaling, which had begun in the northeastern Atlantic by 1611 (Ross 1993). Minimum pre-whaling subpopulation sizes are estimated to have been 12,000 for the Hudson Bay-Foxe Basin and Baffin Bay-Davis Strait subpopulations (Woodby & Botkin 1993) although the status of the Hudson Bay-Foxe Basin and Baffin Bay-Davis Strait animals relative to pre-whaling levels remains unclear. Despite protection for more than 100 years, no signs of recovery have been documented for bowhead whales in Baffin Bay. Bowhead whales in this area are widely dispersed throughout the year and no surveys have so far covered the full range of the population (Reeves & Heide-Jørgensen 1996). Despite this, the range-wide abundance probably numbers over 10,000 individuals, with provisional estimates of 7,300 (3,100–16,900) for parts of the range of the Baffin Bay-Davis Strait stocks (Cosens *et al*. 2006). Assuming that bowhead whales in eastern Canada and West Greenland belong to one stock, this estimate of over 7,000 whales is still considered provisional by the IUCN (Reilly *et al*. 2012). Small-scale abundance estimates have been made for certain areas including 1105 whales in Isabella Bay on the east coast of Baffin Island in 2009 (95% CI: 532−2294; Hansen *et al*. 2012) and 744 whales in Disko Bay (95% CI: 357–1,461; Rekdal *et al*. 2015).

No quantitative estimates of population trends are available, but Inuit hunters and elders report that they are observing more bowheads in the eastern Canadian Arctic and West Greenland than they did in the 1960s–1970s and that the geographic distribution of the whales has expanded in recent years (Koski *et al*. 2006). After almost a century of virtual absence from Greenlandic waters, bowhead whales started to reappear in Disko Bay around 2000 and appeared in increasing numbers for several years (Reeves & Heide-Jørgensen 1996, Heide-Jørgensen *et al.* 2007a). In 2006, the abundance of bowhead whales in Disko Bay was estimated at 1,229 individuals (CV = 0.47, 95% CI: 495–2,939) based on sightings during an aerial survey (Heide-Jørgensen *et al*. 2007a). A genetic capture-recapture estimate of 1,410 individuals (CV = 0.23, 95% CI: 783–2,038) was obtained by Wiig *et al*. (2011), based on samples collected locally in Disko Bay during the period 2000–2010. The estimates provided by this genetic method apply to some unknown portion of the Eastern Canada-West Greenland stock from which the bowhead whales in Disko Bay originate. A dual approach has subsequently been used to assess if the population increase in Disko Bay is a continuing trend (Rekdal *et al*. 2015). An aerial survey in 2012 yielded an abundance estimate of 744 whales (CV = 0.34, 95% CI: 357–1,461) whilst a genetic method relying on determining sex, mitochondrial haplotypes and genotypes of nine microsatellite markers resulted in an estimate of 1,538 whales (CV = 0.24, 95% CI: 827–2,249). While the aerial survey is considered a snapshot of the local spring aggregation in Disko Bay, the genetic approach estimates the abundance of the source of this aggregation. The studies indicate that an increase in abundance observed between 1998 and 2006 has levelled off.

Conservation status

Heavy commercial hunting depleted all populations of bowhead whales. The International Whaling Commission protected bowheads from commercial whaling at its inception in 1946 and today the global population appears to be increasing, due primarily to the increase in the large Bering-Chukchi-Beaufort subpopulation, even though the trends in the remaining populations are unclear. The Baffin Bay-Davis Strait stock has also recovered significantly since the end of commercial whaling; an estimate of over 7,000 animals for part of the range of the Hudson Bay-Foxe Basin and Baffin Bay-Davis Strait stocks combined is still provisional, but it is unlikely that the final numbers would be so low that these subpopulations would qualify for a threatened category. Bowhead whale numbers in eastern Canada and West Greenland are probably still below their pre-whaling levels, but as the main reductions occurred before a three-generation time window, the species is listed as Least Concern on the IUCN’s Red List. However, the Baffin Bay/Davis Strait population of bowhead whale is listed as Near Threatened on the Greenland Red List (Boertmann 2007).

In 2007, Greenland was given a quota of two bowhead whales per year in the quota period 2008-2012 by the IWC, with the possibility of carrying over up to two whales from one year to the next. Greenland started the bowhead whale hunt in spring of 2009 and the first two landings were given to the Greenlandic people in connection with the introduction of Self-Government. Bowhead whale hunting is under a national testing period (Kapel & Petersen 1982, Caulfield 1997, IWC 2007).

This species has been included in CITES Appendix I since 1975; Canada had a reservation against this listing until 1978. The species is listed in CMS Appendix I.

Behaviour

The seasonal distribution of bowhead whales is strongly influenced by pack ice (Moore & Reeves 1993). During the winter, bowheads occur in areas near the ice edge, in polynyas, and in areas of unconsolidated pack ice. During the spring, these whales use leads and cracks in the ice to penetrate areas that were inaccessible during the winter due to heavy ice coverage. In the summer and autumn they concentrate in areas where zooplankton production is high or where large-scale biophysical processes create local concentrations of calanoid copepods (Finley 1990, Finley *et al*. 1998). Bowhead whales are the Arctic’s largest and most-dependent marine mammal predator of zooplankton (Laidre *et al*. 2007), so the food chain leading up to this species is short and is strongly impacted by physical variables such as sea-ice cover and temperature. Small to medium-sized crustaceans form the bulk of the bowhead's diet (Lowry *et al*. 2004) although the diet includes at least 60 species including mysids and gammarid amphipods. Bowheads feed in the water column and skim feed at the surface.

A high longevity (over 100 years and with indications of as much as 200 years or so) is suggested by biochemical methods and the finding of historical stone harpoon heads in hunter-killed animals

(George *et al*. 1999, 2012). If this high longevity is confirmed, it would be among the longest known for a mammal. Taylor *et al*. (2007) estimate the generation time for bowhead whales to be around 52 years.

3.2.4 Other cetaceans which regularly frequent Baffin Bay

Mysticetes

3.2.4.1 Fin whale (Balaenoptera physalus)

The fin whale is a slender balaenopterid with its maximum girth being 40% to 50% of total length. In the Northern Hemisphere, female fin whales typically reach 22.5 m with males reaching up to 21 m. Body mass typically ranges from 40 to 50 metric tonnes (Aguilar 2002). The pigmentation of a fin whale's head and baleen is strikingly asymmetrical with the right ventral side of the head being white and the front third of the right baleen being notably paler in colour.

Distribution

Although their occurrence in West Greenland likely spans most of the year, West Greenland must still be considered a summer feeding ground for fin whales that generally spend the winter at more southern latitudes in the North Atlantic (Heide-Jørgensen *et al*. 2010b). The stock delineation of fin whales in the North Atlantic is unresolved but it is currently considered that fin whales in West Greenland comprise an isolated stock with limited exchange with the East Greenland-Iceland stock or the Newfoundland-Labrador stock even though genetic studies indicate a large exchange of individuals between areas (Bérubé *et al*. 2006; IWC 1992). Fin whales have been found in dense aggregations in offshore areas, particularly southwest of Disko Bay (Heide-Jørgensen & Laidre 2007, Laidre *et al*. 2010). A negative correlation between the advancing sea ice front and fin whale frequencies in the Davis Strait indicates that future changes in sea ice conditions from global warming might change the distribution and migratory patterns of fin whales near the poles (Simon *et al*. 2010).

Breeding

The acoustic activity of fin whales in Davis Strait has been monitored using bottom-moored acoustic recorders (Simon *et al*. 2010). Fin whale call frequencies peaked in November–December, showing that fin whales are present in Davis Strait much later in the year than previously expected. The closely timed peaks in song activity and conception time imply that not all fin whales migrate south to mate, but rather start mating at high latitudes rather than or before migrating.

Population

The population of fin whales off West Greenland has been estimated as 3,230 (CV: 0.44) in 2005 (Heide-Jørgensen *et al*. 2008) and 4,468 (CV: 0.45) in 2007 (Heide-Jørgensen *et al*. 2010b). These results are underestimations because they were not corrected for the proportion of animals that were diving and therefore unavailable to be counted by the observers. The only earlier estimate of fin whale abundance off West Greenland accepted by the IWC Scientific Committee dates from 1987-88 and is 1,100 (95% CI 520-2,100; IWC 1992). Together, the three estimates show an increasing trend in West Greenland fin whales, with an estimated natural increase of 6.5% (95% CI:

1.6-10%) per year (Witting 2012). This rate of increase is similar to the rates of increase observed for fin whales in East Greenland, Iceland and the Faroe Islands (4.2%; Witting 2012).

Conservation status

Fin whales are globally listed as Endangered by the IUCN Red List (Reilly *et al*. 2013). During the 1960s and 1970s, up to 13 fin whales per year were taken by hunters off Greenland. Catches have been regulated by IWC aboriginal subsistence quotas since 1977 and the average catch has been 12 fin whales per year. The quotas have ranged from 6 to 23 whales per year, and since 1995 have remained stable at 19. Surveys carried out in 2004 in order to update abundance estimates of large whales were unsuccessful and, due to the uncertain status of the stock, the Greenland Home Rule voluntarily reduced the quotas for 2006 and 2007 to 10 fin whales per year. The following year, Greenland was given a quota of 19 fin whales per year for the quota block 2008-2012 (Kapel & Petersen 1982, Caulfield 1997, Simon *et al*. 2007). During the IWC Annual Meeting in 2010, the Greenland Government agreed to a reduction of the fin whale quota from 19 to 16 (IWC 2010). The Greenland Government on a voluntarily basis further reduced the catch limit for the West Greenland stock of fin whales from 16 to 10 for each of the years 2010 to 2012 in connection with the obtained quota of nine humpback whales (IWC 2015).

Behaviour

Fin whales are one of the most abundant cetaceans in the Davis Strait off Western Greenland, where they likely play an important role in an ecosystem that experiences large temporal and spatial fluctuations in primary and secondary production over the year (Laidre *et al*. 2010). Singing activity in the Davis Strait is strongly linked to daylight hours, suggesting fin whales might feed during the few daylight hours of the late fall and early Arctic winter (Simon *et al*. 2010).

3.2.4.2 Humpback whale (Megaptera novaeangliae)

Readily distinguished from other large whales by their long flippers, adults may reach up to 17 m in length although 14-15 m is more typical, with females generally larger than males (Clapham & Mead 1999). Adults typically weigh 25-40 tonnes.

Distribution

Humpback whales arrive predictably in Baffin Bay from southern breeding grounds in May and remain in the area at least throughout autumn. Humpback whales occur seasonally in areas such as Disko Bay and Paamiut (Heide-Jørgensen & Laidre 2007) yet may also occur year round at other coastal sites such as Nuuk Fjord (Boye *et al*. 2010). Humpback whales may be encountered in both inshore and offshore waters of Baffin Bay (Heide-Jørgensen & Laidre 2007).

Breeding

Resightings of individual whales indicate that the West Indies is the main breeding ground for whales that feed in West Greenland (e.g. Stevick *et al*. 2003).

Population

An estimated 3,272 (CV = 0.50) humpbacks occupy the coast of West Greenland (Heide-Jørgensen *et al*. 2012). Following other similar surveys, including an abundance estimate of 1,306 (95% CI=570-

2,989) for offshore and coastal areas of West Greenland (Heide-Jørgensen & Laidre 2007), it has been suggested that the numbers of humpback whales off West Greenland appear to have been increasing annually at 9.4% per year (S.E. = 0.01) since 1984 (Heide-Jørgensen *et al*. 2012). This is considerably higher than the reported increase of 3.1% per year observed in the West Indies breeding grounds (Stevick *et al*. 2003).

Conservation status

Globally, the available population estimates for humpback whales total more than 60,000 animals. The IUCN currently list this species as of Least Concern. The IWC prohibited the catching of humpback whales off Greenland in 1986, due to uncertainties about the size of the stock. In 2010, Greenland was given a quota of nine humpback whales per year, with the possibility of carrying over up to two whales from one year to the next (IWC 2015).

Behaviour

The departure of bowhead whales from West Greenland coincides with the arrival of several subarctic cetacean species, including the humpback whale (*Megaptera novaeangliae*). Humpback whales feed on various species of schooling fish, especially capelin (*Mallotus villosus*), which aggregate at productive sites on the banks and in shallow areas, where they feed on recently ascended zooplankton. Humpback whales in Greenland also feed on sandeels (*Ammodytidae* spp.) and krill (*Meganyctiphanes norvegica* and *Thysanoessa* sp.; Laidre *et al*. 2010).

Little is known about the movements of humpback whales around Greenland or how whales move between foraging sites. Identifying focal areas where humpback whales frequently occur and forage in summer is important for both understanding how whales use the coast of West Greenland and for future work to identify critical prey species concentrations. Furthermore, large changes in physical oceanography have been identified along the banks of West Greenland. Sea surface temperatures (0-40m depth) have dramatically increased over the past 50 years, with maximum recorded value of 3.8°C in 2005 (Ribergaard *et al*. 2006). Thus, it is important to identify feeding grounds for humpback whales in order to monitor changes in the local hydrology and how those changes might manifest themselves on prey species.

Satellite telemetry suggests that humpback whales use much of the West Greenland waters by remaining relatively stationary at suitable feeding grounds for a period of days and then moving up to hundreds of kilometres to a different location, where they remain stationary again (Heide-Jørgensen & Laidre 2007). This pattern is consistent with an ongoing photo-identification study in a fjord in central West Greenland, where individual humpback whales seem to return year after year, remain in the fjord for several days, and then leave (Boye *et al*. 2010).

3.2.4.3 Minke whale (Balaenoptera acutorostrata)

Minke whales in the Northern Hemisphere reach maximum lengths of 10.7 m (males are slightly shorter reaching 9.8 m). Maximum weights of 9,200 kg have been recorded.

Distribution

Minke whales have been found in in offshore areas of Baffin Bay, particularly southwest of Disko Bay (Heide-Jørgensen & Laidre 2007, Laidre *et al*. 2010). Evidence that the stock of minke whales of West

Greenland extends beyond the areas where the whales are caught is given by the fact that the majority of the animals harvested are females, even though the minke whales give birth to approximately the same number of male and female calves (Simon *et al*. 2007). The sex bias of the catch can only be explained if a significant part of the population, including a majority of males is out of reach for the Greenlandic hunters.

Breeding

The distribution and population structure of Baffin Bay minke whales on their wintering areas are unknown. There may be at least four different wintering or breeding areas for minke whales in the North Atlantic (Andersen *et al*. 2003).

Population

Aerial surveys in 2007 provided a fully corrected estimate of 17,300 (CV: 0.42) minke whales off West Greenland (IWC, 2010; Heide-Jørgensen *et al*. 2010d). Earlier abundance estimates include a 2005 estimate of 10,800 (CV: 0.59; Heide-Jørgensen *et al*. 2008) whales, a 1993 estimate of 8,370 (CV: 0.43; Larsen 1995), and a 1987/88 estimate of 3,266 (CV: 0.31; IWC 1990). These estimates, however, are not directly comparable because they are based on different methods. A time series of relative and comparable abundance estimates from 1984 to 2007 show a rather varying index with no apparent trend (Heide-Jørgensen & Laidre 2008). These numbers relate to the abundance and density of minke whales in the areas surveyed. The actual size of the West Greenland stock is probably larger, and the time series of relative abundance indicate that there may not be a consistent fraction of minke whales from the North Atlantic that use the West Greenland banks as a summer feeding ground.

Conservation status

Minke whales are listed globally by the IUCN red list as a species of Least Concern (Reilly *et al*. 2008c). Since 1975, catches of minke whales by Greenlanders have been regulated by IWC aboriginal subsistence quotas. Until 1985, the quotas were higher than the average catches. Since 1986, the quotas for West Greenland have ranged from 60 to 200 minke whales per year, and remained stable at 175 whales per year since 1998 (with the exception of 2008-2009 having a quota of 200), with the possibility of carrying over up to 15 whales from one year to the next.

Behaviour

Minke whales have been recently divided into two species; the Antarctic minke whale (*Balaenoptera bonaerensis*) which is confined to the southern hemisphere, and the common minke whale (*B. acutorostrata*) which is cosmopolitan (Rice 1998). These species undertake synchronized seasonal migrations to feeding areas at their respective poles during spring, and to the tropics in the autumn where they overwinter. Differences in the timing of seasons between hemispheres prevent these species from mixing. Recent analysis of mitochondrial and microsatellite DNA profiles in the Arctic Northeast Atlantic, however, has described at least one *B. bonaerensis* in 1996 and a hybrid with maternal contribution from *B. bonaerensis* in 2007. Paternal contribution was not conclusively resolved (Glover *et al*. 2010). This is the first documentation of *B. bonaerensis* north of the tropics, and, the first documentation of hybridization between minke whale species.

3.2.4.4 Sei whale (Balaenoptera borealis)

The sei whale is a cosmopolitan baleen whale, with a mainly offshore distribution, occurring throughout the North Atlantic (Rice 1998). Measuring 14-20 m in length and weighing up to 36 metric tons, the sei whale is the third largest baleen whale (Horwood 1987). The body is dark grey with variable white undersides. The sei whale may be the fastest of the large whales, able to cruise at 14 knots with a maximum speed of 35 knots recorded (Horwood 1987, Olsen *et al*. 2009).

Distribution

The distribution of sei whales is not well known, but they are found in all oceans and appear to prefer mid-latitude temperate waters (Jefferson *et al*. 2008). Sei whales migrate between tropical and subtropical latitudes in winter and temperate and sub-polar latitudes in summer, staying mainly in water temperatures of 8-18°C and tend not to penetrate to such high latitudes as other rorquals (Reilly *et al*. 2008a). Their winter distribution seems to be widely dispersed and is not fully mapped (Horwood 1987, 2002). Sei whales observed off West Greenland are part of a mid-Atlantic oceanic population with little site fidelity that uses ice-free waters from June to October (Boertmann & Mosbech 2011). Sei whales have been found in small groups in offshore areas, particularly southwest of Disko Bay (Heide-Jørgensen & Laidre 2007, Laidre *et al*. 2010).

Population

Sei whale populations were depleted by whaling, and their current status is generally uncertain (Horwood 1987). The global population is thought to be ~80,000 (Horwood 2002), and there are an estimated 12,000–13,000 in the North Atlantic (Cattanach *et al*. 1993). Ship-based surveys conducted in 2005 estimated the abundance of sei whales off West Greenland at 1,599 (95% CI=690-3,705; Heide-Jørgensen *et al*. 2007b). This estimate is low, as the entire potential habitat was not covered and corrections for whales missed by observers or diving whales were not applied.

Breeding

The distribution and population structure of Baffin Bay sei whales on their wintering areas are unknown.

Conservation status

The sei whale is listed globally as Endangered (Reilly *et al*. 2008a) on the IUCN red list and on the Greenland Red List as Data Deficient (Boertmann & Mosbech 2011).

Behaviour

Sei whales feed almost exclusively on krill and have been infrequent visitors on the West Greenland banks for the past several decades (Kapel 1979). Although historical data are lacking, high krill biomass in recent years may have led to an increase in sei whale presence in Baffin Bay (e.g. Laidre *et al*. 2010).

3.2.4.5 Blue whale (Balaenoptera musculus)

The blue whale is the largest animal in the world, with an average length of 25–26 m and average weight of 100–120 tonnes, females being larger than males. Blue whales are globally distributed from the equator to polar waters, moving to high latitudes for feeding during summer and to low latitudes for feeding during winter. Their main prey is krill (*Euphausia* spp.).

Distribution

Due to lack of survey effort, their presence in Baffin Bay is not clearly defined, but they have at least been reported form the southern part (e.g. Heide-Jørgensen & Laidre 2007). However, as in the Eastern Atlantic and Antarctica, they may be present in offshore waters up to the ice edge. One of three blue whales photo-identified off West Greenland in July-August 1988 had been photographed in the Gulf of St. Lawrence in August 1984 and August 1985 (Reeves *et al*. 1998). This suggests that blue whales in Davis Strait and the Gulf of St. Lawrence belong to the same population.

Breeding

Winter calving grounds for the blue whales occurring off West Greenland are unknown. Observations of blue whales off West Greenland are rare, but unpublished data indicates that blue whales use the Davis Strait area (Reeves *et al*. 1998).

Population

Global population size remains at a very low level. There may be approximately 1,500 blue whales in the North Atlantic (Pike *et al*. 2004).

Conservation status

The IUCN Red List classifies blue whales as Endangered globally and Vulnerable in the North Atlantic (Reilly *et al*. 2008b).

Behaviour

No information is available on the behaviour of blue whales in the high Arctic.

***Odontocetes*:**

3.2.4.6 Sperm whale (Physeter macrocephalus)

Sperm whales are the largest of the odontocetes and the most sexually dimorphic; adult females reach 11 m in length and 15 tonnes, whilst a physically mature male may reach 16 m and 45,000 kg (Rice 1988). The most distinctive feature of the sperm whale is its massive head, reaching up to a third of total body length (Whitehead 2009).

Distribution

The sperm whale has a large geographic range (Rice 1988) and is found in nearly all marine regions, from the equator to high latitudes, but is generally found in continental slope or deeper water. Information for the Arctic is limited. Berzin (1971) reviewed captures of sperm whales in the Davis Strait as far back as 1812, including a mention from 1870 about sperm whales being relatively scant in the region, and a report of 181 males caught by a fleet of seven boats in 1937. Sperm whales are still regularly reported in ice-free areas in the Davis Strait (e.g. Heide-Jørgensen & Laidre 2007, Boertmann & Mosbech, 2011). The presence of sperm whales would be expected during ice-free periods in suitable habitats, such as deep-sea waters close to continental slopes and underwater canyons with abundance of cephalopod or fish prey.

Population

There have been no dedicated surveys for sperm whales in Baffin Bay. The International Whaling Commission considers that all sperm whales in the North Atlantic belong to a single stock (Donovan 1991), an assumption supported by genetic analyses (Lyrholm & Gyllensten 1998). The North Atlantic stock is likely to consist of over 10,000 individuals (Whitehead 2002).

Breeding

The breeding behaviour of the sperm whales of Baffin Bay is unknown.

Conservation status

The IUCN Red List currently classifies sperm whales as Vulnerable (Taylor *et al*. 2008).

Behaviour

Although there are no detailed studies, the behaviour of sperm whales in the Arctic is likely to be similar to other high latitude populations. With increasing age, male sperm whales are normally found in the higher latitudes of both hemispheres, usually by themselves or in small groups (Best 1979, Caldwell *et al*. 1966, Rice 1988, Teloni *et al*. 2008).

3.2.4.7 Killer whale (Orcinus orca)

Killer whales are top predators that occur in all oceans, but tend to concentrate in colder regions with high productivity. They feed on prey that varies in size from herring to adult blue whales.

Distribution

Killer whales occur widely in Arctic waters, yet their abundance, movements, site fidelity, and specific distribution are poorly known (Forney & Wade 2006). Generally, killer whales are sighted during ice-free months and often near areas with high densities of other marine mammals, such as summering grounds for belugas and narwhals. Historically, it is believed that certain “choke points” existed where sea ice inhibits killer whale movement, thereby restricting their Arctic distribution. However with changing sea ice levels, advancement in the distributon of these ice-avoidaing predators has been seen (Higdon & Fergenson, 2009). In the eastern Canadian High Arctic, killer whale habitat includes eastern Lancaster Sound and associated inlets or fjords around Baffin Island e.g., Eclipse Sound, Admiralty Inlet, and Prince Regent Inlet (Reeves & Mitchell 1988). The killer whale frequents the Davis Strait and Baffin Bay region in summer months (Dunbar & Moore 1980, COSEWIC 2008). Heide-Jørgensen (1988) reviewed published and unpublished information available on killer whales in Greenland and carried out a questionnaire-based investigation of sightings of killer whales. Observations occurred in all areas of West Greenland, and sightings were most frequent in Qaanaaq, Disko, Nuuk and Qaqortoq. Information regarding use of offshore habitat by killer whales is lacking.

Population

Inuit are reporting increases in killer whale presence within coastal Nunavut waters (Ferguson *et al*. 2012); killer whales are not actively hunted by the peoples of Nunavut.

Breeding

The breeding behaviour of the killer whales of Baffin Bay is unknown.

Conservation status

Killer whales are hunted in Greenland, partly for human subsistence and partly to feed dogs, but also because they are considered as a pest (i.e. as competitors to seal and whale hunters; Boertmann & Mosbech 2011). Killer whales are listed as Data Deficient on the global IUCN Red List (Taylor *et al*. 2013).

Behaviour

Little is known about what proportion of different types of killer whales occurs in Arctic waters (i.e. mammal-eating vs. fish-eating). Stomach contents of 30 killer whales harvested in Disko Bay, West Greenland in February 2003 contained only Lumpsucker fish, despite the fact these killer whales were taken in an area with a large abundance of bowhead whales, ringed seals, narwhals, belugas, and other potential marine mammal prey items (Laidre *et al*. 2006a).

Killer whales tend to be seen inshore during the spring and summer, likely searching for prey such as seals (Leatherwood *et al*. 1976) and juvenile bowhead whales (Finley 2001). Few observations have been collected of killer whales during winter in Arctic ice conditions. It is generally assumed that killer whales avoid the Arctic pack ice (Heide-Jørgensen 1988) despite the fact many killer whales occur and thrive in the dense pack-ice of the Antarctic. It is possible that changes in sea ice (lighter sea ice cover and earlier break-up) will alter (or have already altered) the occurrence of killer whales in Arctic waters. These changes may facilitate increased or longer visits by killer whales to ice-free Arctic areas. The predicted reduction of annual sea ice, together with a longer open water season, could lead to an increase in killer whale predation on other marine mammals (Laidre *et al*. 2006a).

3.2.4.8 Long-finned pilot whale (Globicephala melas)

Adult long-finned pilot whales reach lengths of 6 m, with males larger than females (Olson 2009). Most individuals are black or dark grey with a robust body, thick tailstock and bulbous melon.

Distribution

The long-finned pilot whale occurs in temperate and sub-polar zones and, according to most literature, ranges from Disko Bay and Ungava Bay in the North West, from 68° N in eastern Greenland across Iceland and the Faroe Islands to mid-Norway, and south to North Carolina, the Azores, Madeira and Mauritania (e.g. Jefferson *et al*. 2008). Greenlandic catch statistics show, however, that pilot whales occasionally occur as far north as Uummannaq and Upernavik in late summer or early autumn (Boertmann & Mosbech 2011). Their occurrence is probably correlated with the influx of relatively warm Atlantic water (Heide-Jørgensen & Bunch 1991).

Population

Pilot whales occurring in Greenland probably represent vagrants from a single large North Atlantic population. Abundance of pilot whales on the banks of West Greenland was estimated in 2007 to be 8,133 (CV = 0.41, 95 % CI 3,765–17,565; Hansen & Heide-Jørgensen 2013). The surveys only covered part of the range of pilot whales in West Greenland and it can be considered a minimum estimate.

Breeding

The breeding behaviour of the pilot whales of Baffin Bay is unknown.

Conservation status

Pilot whales are caught opportunistically in West Greenland (Boertmann & Mosbech 2011). Annual catches in West Greenland vary between 0 and 300, where most animals are caught south of Disko Bay. Long-finned pilot whale is listed as Data Deficient on the global IUCN Red List (Taylor *et al*. 2008).

Behaviour

Density surface modelling has indicated that the preferred habitats for pilot whales in summer are deep offshore areas off mid-west Greenland (Hansen & Heide-Jørgensen 2013) with a preference for depths between 300 and 2,000 m, at least 30 km from land. Pilot whale sightings and catches are reported along the coast of Greenland from Qaqortoq in the south to Upernavik in the north between May and October, which suggests a summer–winter movement following the spring bloom of primary production and subsequent pulses in fish and squid abundance (Hansen & Heide-Jørgensen 2013).

3.2.4.9 Northern Bottlenose whale (Hyperoodon ampullatus)

The Northern Bottlenose whale is a beaked whale found only in the northern North Atlantic. A medium sized whale at 7 to 9 m, dolphin like in appearance, with a beak and falcate dorsal fin, but much larger than most dolphins (COSEWIC, 2011). The species is among the deepest and longest divers of all mammals and is known for its tendency to approach vessels (COSEWIC, 2011).

Distribution

Northern bottlenose whales are found in deep (>500 m) continental shelf waters of the North Atlantic, from New England, USA to Baffin Island and southern Greenland in the west and from the Strait of Gibraltar to Svalbard in the east (c. 38ºN to 72ºN; Gowans 2002). The pelagic distribution extends from the ice edges south to approximately 30°N. There are five recognized areas of concentration, two of which are in the western Atlantic, the Scotian Shelf and off Labrador, which includes southern Baffin Bay (COSEWIC, 2011). These two populations are genetically distinct.

These cold temperate to subarctic whales are found in deep waters, mostly seaward of the continental shelf (and generally over 500-1,500 m deep) and near submarine canyons. They sometimes travel several kilometres into broken ice fields, but are more common in open water.

Population

Global abundance has not been estimated; the Baffin Bay-Davis Strait–Labrador Sea stock's abundance has not been estimated either. Most subpopulations of the species are probably still depleted, due to large kills in the past; over 65,000 animals were killed in a multinational hunt that operated in the North Atlantic from c. 1850 to the early 1970's (Mitchell 1977; Reeves *et al*. 1993).

Little is known about populations in central and western North Atlantic (Reyes *et al*. 1993). For statistical consideration, Christensen (1975) assumed that all the bottlenose whales caught east of Greenland belonged to a single subpopulation, while Mitchell (1977) defined Cape Farewell (Greenland) to divide west and east North Atlantic catches (Culik 2004). The whales in the Baffin Bay-Davis Strait – Labrador Sea region have been genetically linked to the population off Iceland (COSEWIC, 2011).

Breeding

Northern Bottlenose whales become sexually mature at 7 to 9 years old and 8 to 13 years old for males and females respectively, with the females giving birth approximately every 2 years. They are thought to live for at least 37 years, with the generation time being around 15.5 years. It is unknown whether or not the Baffin Bay-Davis Strait-Labrador Sea populations migrate for breeding.

Conservation status

IUCN has listed the Northern Bottlenose whales as Data Deficient (Taylor *et al*. 2008), and COSEWIC as Special Concern (COSEWIC, 2011). Similar beaked whale species suffer from threats that could cause widespread declines include high levels of anthropogenic sound, especially military sonar and seismic surveys and it is assumed Northern Bottlenose whales are similarly sensitive. The population is thought to remain depleted from whaling, although abundance estimates for many of the stocks have not been conducted. As the decline from whaling took place more than three generations ago; the combination of possible declines driven by vulnerability to high-level anthropogenic sound sources is believed sufficient that a 30% global reduction over three generations (53 years; Taylor *et al*. 2007) cannot be ruled out (Taylor *et al*. 2008). Additionally, entanglement in fisheries gear and pollution from contaminants are thought to threaten northern bottlenose whale recovery (COSEWIC, 2011).

The species was included in the International Whaling Commission schedule in 1977, with recommendations that northern bottlenose whales be granted Protected Stock status with zero catch limit (Klinowska 1991). Populations or stocks are not defined; this, together with estimates of present abundance), should be the focus of future studies (Culik 2004; Dalebout *et al*. 2006).

Behaviour

The species occupies a very narrow niche; the primary food source is squid of the genus *Gonatus* (Hooker *et al*. 2001; Whitehead *et al*. 2003). The whales may also occasionally eat fish (such as herring and redfish), sea cucumbers, starfish, and prawns. They do much of their feeding on or near the bottom in very deep water (> 800 m, and as deep as 1,400 m; Hooker and Baird 1999).

4. Importance of hearing to narwhals and other cetaceans

Summary

- Sound is essential to cetaceans, as they use sound for social interactions, to forage, to orientate and to respond to predators.
- The exact hearing range and sensitivities of most cetacean species, including the narwhal and bowhead whales, are unknown.
- More research has been conducted on the vocalisations of narwhal, beluga and bowhead whales.
- Anthropogenic noise is categorised as a pollutant, and is either impulsive (such as pile driving or seismic) or continuous (such as shipping). These two types of noise can have different impacts on marine mammals.
- The most extreme physical impact of noise on cetaceans is hearing loss and injury; however, this is likely relatively uncommon. The most regularly reported and potentially harmful impacts from noise on cetaceans are behavioural, and include displacement and avoidance of potentially important habitat and migration routes, and masking of vocalisations.
- Due to ever increasing levels of shipping activity, coupled with intensifying effects of climate change resulting in reductions of sea ice in the Arctic, noise from anthropogenic sources in the Artic has been increasing rapidly. As Arctic species have not previously been subjected to these types of noise, impacts on certain Arctic species have the potential to be more severe than in areas which have suffered from gradual increases in noise pollution over previous decades.

4.1 Auditory system in marine mammals

All cetaceans produce sounds in various important contexts. They use sound in social interactions as well as to forage, to orientate and to respond to predators. As a sensitive auditory system is essential for receiving these signals, hearing is arguably the most important sense used by cetaceans and this is reflected in the high degree of neural auditory centre development. Dolphins and whales devote three times more neurons to hearing than any other animal (Ketten 2002). The temporal lobes, which control higher auditory processing, dominate their brain, and they appear to have faster auditory and signal processing capabilities than any other mammal.

All marine mammals have a fundamentally mammalian ear which has adapted to the marine environment to provide broader hearing ranges than are common to land mammals. Audiograms are available for approximately 10 species of small odontocetes that have been tested as captive animals. However, there are 90 species of cetacean and the majority are large, highly mobile animals that are not approachable or testable by normal audiometric methods. Therefore, direct behavioural or physiological hearing data are not available for nearly 80% of the genera and species of concern for coastal and open ocean sound impacts. For those species for which no direct measure or audiograms are available, hearing ranges are estimated with mathematical models based on ear anatomy obtained from stranded animals or inferred from emitted sounds and playback experiments in the wild. The combined data from audiograms and models show that there is considerable variation among cetaceans in both absolute hearing range and sensitivity. Their composite range is from infrasonic (below 20 Hz, the 'normal' lower limit of human hearing) to ultrasonic (above 20 kHz, the upper limit of human hearing).

4.1.2 Toothed whales

The dolphins and porpoises (odontocete cetaceans) produce sounds across some of the widest frequency bands that have been observed in animals (see Richardson *et al*. 1995 for review). Their social sounds are generally in the range audible to humans; from a few hundreds of Hz to several tens of kHz, but specialized clicks used in biosonar (echolocation) for prey detection and navigation extend well above 100 kHz. Odontocetes are excellent echolocators, capable of producing, perceiving, and analysing ultrasonic frequencies well above human hearing. Odontocetes commonly have good functional hearing between 200 Hz and 100 kHz, although some species may have functional ultrasonic hearing to nearly 200 kHz. The majority of odontocetes have peak sensitivities (best hearing) in the ultrasonic ranges although most have moderate sensitivity to sounds from 1 to 20 kHz. No odontocete has been shown to have exceptionally responsive hearing below 500 Hz.

4.1.2.1 Narwhal

Narwhals are known to rely on sound to communicate (Ford & Fisher 1978), to navigate, and to forage (Miller *et al*. 1995). In general, narwhal acoustic communication is poorly understood, because the species is restricted to the high Arctic and has not been studied in captivity (Hay & Mansfield 1989). Narwhals emit broadband echolocation clicks of very short duration to navigate and forage (Au 1993, Stafford *et al*. 2012). The maximal peak-to-peak source level measured for narwhal clicks is 218 dB re 1µPa (Møhl *et al*. 1990). Although produced with a rate similar to beluga whales (10–500/s; Watkins *et al*. 1971, Miller *et al*. 1995, Stafford *et al*. 2012), narwhal clicks are generally produced at lower frequencies (2–100 kHz for narwhal vs. 30-120 kHz for beluga; Sjare & Smith 1986, Roy 2010, Stafford *et al*. 2012).

Narwhals also use a variety of different sounds for communication including clicks; they also use vocalisations with significantly lower frequencies including whistles (tonal sounds) and pulsed sounds (Ford & Fisher 1978). Whistles are narrowband, frequency modulated sounds between 300 Hz and 10 kHz (Ford & Fisher 1978). Pulsed sounds involve a short burst or long series of pulses (clicks) with a mean dominant frequency of 12–20 kHz (Ford & Fisher 1978, Watkins *et al*. 1971), but can probably far exceed 100 kHz (this upper extent is limited by the recording system; Møhl *et al*. 1990). Source levels of narwhal whistles and pulsed calls are not known (Shapiro 2006). Some pulsed sounds with a high click repetition rate possess a tonal character with harmonically related sidebands (Ford & Fisher 1978). More recently, Shapiro (2006) has found differences in the characteristics of calls emitted by two narwhals fitted with recorders. However, it is not clear if these results are associated with individual or group-specific differences (Shapiro 2006). In addition, there is no published data on context-related variation in narwhal vocal behaviour except a recent study from Nunavut in Canada suggesting similarities among whistles but not pulsed calls produced in similar behavioural contexts (Marcoux *et al*. 2012). Thus, it is possible that some narwhal whistles are behaviour-specific. Narwhal communication calls range from 400 Hz to 14.5 kHz (Marcoux *et al*. 2012). Narwhals appear to produce more, lower frequency pulsed calls than belugas although this interpretation is based on low sample sizes and should be treated with caution.

Narwhals and belugas are closely related phylogenetically (Messenger & McGuire 1998) and have partially overlapping geographic range distributions (Innes *et al*. 2002). The two species largely overlap in their vocal repertoire and although hearing in the narwhal has not yet been investigated, it is assumed to be comparable to that of the beluga whale (see below). Beluga whale hearing becomes increasingly directional with higher frequencies and a similar response is expected for narwhals, as it has been demonstrated in other echolocation toothed whales (e.g. Kastelein *et al.* 2005).

4.1.2.2 Beluga whale

Like narwhals, beluga whales use broadband echolocation clicks of very short duration to navigate and forage. Belugas produce click sounds ranging from 30 to 120 kHz at rates of 35–450 clicks/s (Sjare & Smith 1986, Roy *et al*. 2010); most click energy is centred around 100-115 kHz and has peak-to-peak source levels up to 225 dB re 1µPa (Au 1993). Hearing studies of belugas held in laboratory settings have generally shown sensitive and broadband hearing abilities, similar to other odontocetes (Awbrey *et al*. 1988, Finneran *et al*. 2005, Klishin *et al*. 2000, Mooney *et al*. 2008, Ridgway *et al*. 2001, White *et al*. 1978). Measurements taken from wild individuals in Alaska were broadly similar to those measured in captivity (Castellote *et al*. 2014). An audiogram shows the hearing sensitivity of an animal and in general, audiograms are U-shaped with the areas of best sensitivity at the lowest values; audiograms measured for beluga whales suggest sensitive hearing between 22 to 110 kHz with the absolute lowest (i.e. best) hearing thresholds between 45 and 80 kHz (Figure 4.1). Beluga whale hearing becomes increasingly directional with higher frequencies. This increase in hearing directionality improves their echolocation capabilities by making them less susceptible to background noise and clutter echoes (i.e. returning echoes from other objects than the intended target; Mooney 2008).

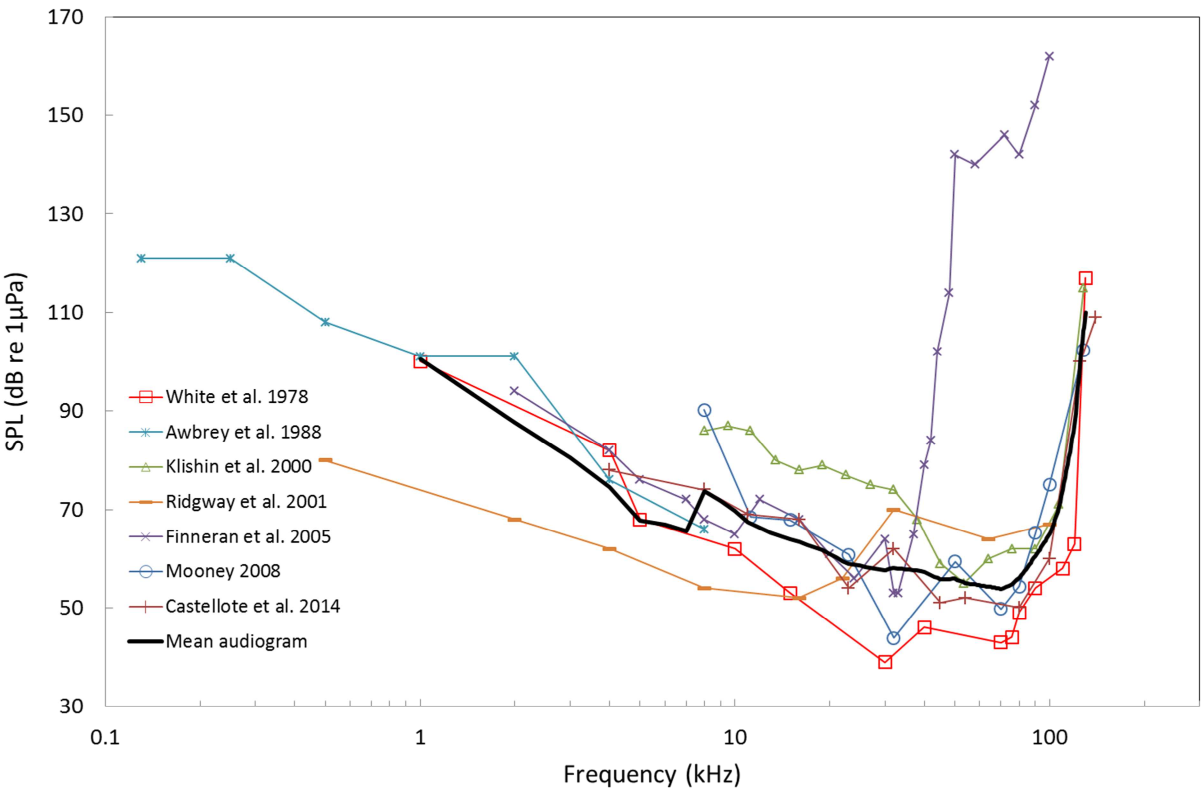

Figure 4.1: Summary of audiograms measured from beluga whales; all are from captive animals except the audiogram presented by Castellote *et al*. 2014. A mean audiogram for all measurements is shown as a black line; this mean audiogram does not include those values presented by Finneran *et al*. (2005) as this individual was thought to be suffering from hearing loss due to an aminoglycoside antibiotic treatment.

Beluga whales use a variety of different sounds for communication and their diverse vocal repertoire has often led them to be referred to as the 'canaries of the sea' (Sjare & Smith 1986, Karlsen *et al*. 2002, Belikov & Bel'kovich 2008, Delarue *et al*. 2011). They use clicks for communication as well as vocalisations with significantly lower frequencies including whistles and pulsed calls. Beluga whale communication sounds range from 260 Hz to 20 kHz, but with dominant frequencies from 1 to 8.3 kHz (Richardson *et al*. 2005, Sjare & Smith 1986). As background noise typically overlaps beluga audiograms in the range 4–40 kHz, potential increases in background noise due to anthropogenic activities, even if moderate, could cause considerable masked hearing.

4.1.3 Baleen whales

The large whales (mysticetes) generally produce low-frequency sounds in the tens of Hz to several kHz band, with a few signals extending above 10 kHz. These sounds appear to serve predominantly social functions, including in reproduction and maintaining contact, but they may also play some role in spatial orientation. No mysticete species has been directly tested for any hearing ability, but functional models indicate their functional hearing commonly extends to 20 Hz, with several species including blue, fin and bowhead whales predicted to hear infrasonic frequencies as low as 10-15 Hz. The upper functional range for most mysticetes has been predicted to extend to 20-30 kHz.

4.1.3.1 Bowhead whale

The functions of bowhead whale sounds remain poorly understood despite recording efforts spanning over more than 20 years. Most descriptions of bowhead whale sounds are primarily from recordings of the Bering Sea population near Alaska, with a few studies recording sound from the Davis Strait–Hudson Bay population (Tervo *et al*. 2009). The majority of the sounds recorded from migrating bowhead whales off Point Barrow, Alaska have been low frequency, frequency modulated (FM) calls (Ljungblad *et al*. 1982, Clark & Johnson 1984, Cummings & Holliday 1987) with reported frequency ranges of 25–600 (Ljungblad *et al*. 1982), 50–300 (Clark & Johnson 1984) and 25–900 Hz (Cummings & Holliday 1987). The calls were descending, ascending, constant, or inflecting in frequency (Clark & Johnson 1984). The duration of all of these calls ranged from short 0.5 s signals to long and melodic 4–5 s tones (Clark and Johnson 1984).

Singing behaviour is considered to be an advanced form of vocalization in baleen whales and bowhead whales produce songs as well as calls, with a total frequency range for both types of sound being between 25 Hz and 2.6 kHz (Stafford *et al*. 2008, Tervo *et al*. 2009). A song is composed of units, phrases, and themes produced in sequence. At least three distinctive songs have been recorded from bowhead whales during their spring migration in Disko Bay, Western Greenland, between February and May (Tervo 2006, Stafford *et al*. 2008). Songs have been documented to change within and between seasons (Tervo *et al*. 2007), with recordings from the end of February to middle of March being characterised by higher call rates and a greater diversity of call types than recordings made later in the season (Tervo *et al*. 2009). It appears that song produced during the winter months contains more song notes than song from the spring making the winter song more variable (Tervo *et al*. 2009). The apparent mean source level of bowhead song has been measured as 185±2 dB rms re 1 µPa with a mean centroid frequency of 444±48 Hz (Tervo *et al*. 2012). The estimated active space of these song notes is between 40 and 130 km, an order of magnitude smaller than the estimated active space of low frequency blue and fin whale songs produced at similar source levels and for similar noise conditions (Tervo *et al*. 2012). This has been interpreted as a coevolution of higher frequency, more complex songs with relatively small scale breeding aggregations as compared to fin and blue whales.

Hearing in bowhead whales requires further elaboration. However, anatomical studies of the inner ear in the northern right whale (*Eubalaena glacialis*), a close relative of the bowhead whale, suggest that this species has a hearing range from 10 Hz to 22 kHz (Parks *et al*. 2007). This study is the only study to directly infer the complete hearing range of any baleen whale.

4.2 Types of anthropogenic noise

Pollution can be defined as the release of a potentially harmful chemical, physical, or biological agent to the environment as a result of human activity (e.g. Johnston *et al*. 1996). Underwater noise is now recognised as a pollutant. For example, the 1982 United Nations Convention on the Law of the Sea includes the word ‘‘energy’’ to define ‘‘pollution of the marine environment’’ (article 1.1.4) and energy in this context includes acoustic or noise pollution (Dotinga & Oude Elferink 2000). The EU’s Marine Strategy Framework Directive (MSFD, 2008/56/EC) requires member states to determine Good Environmental Status (GES) for their marine waters, and each member state must put in place a marine strategy which requires an initial assessment of the environmental status of that member state’s waters using a series of 11 descriptors. Underwater noise is captured in descriptor 11 and specifies that the ‘introduction of energy, including underwater noise, is at levels that do not adversely affect the marine environment’ (European Commission 2010). In 2014, the Convention on Biological Diversity hosted a workshop with the aimto improve and share knowledge on underwater noise and its impacts on marine and coastal biodiversity. The workshop developed practical guidance and toolkits to minimize and mitigate the significant adverse impacts of anthropogenic underwater noise in order to assist Parties and other Governments in applying management measures, as appropriate (UNEP, 2014).

Extraneous noise is ever-present in the marine environment, either as naturally occurring signals (including intermittent geological activity, biological signals, rainfall and breaking waves) or increasingly, from anthropogenic sources. Anthropogenic noise is an important component of virtually every human endeavour in the oceans, whether it be shipping, transport, exploration, extraction, research, military activities, construction, or recreation. In many parts of the ocean, low-frequency bands below a few hundred Hz that were once dominated by ambient noise from wind and waves, are now dominated by background noise from shipping traffic and seismic exploration activities among others (Andrew *et al*. 2011, Chapman & Price 2011, Hildebrand 2009, McDonald *et al*. 2006, Richardson *et al*. 1995). Two main issues of concerns are the physiological and the behavioural impacts on individuals and populations from repetitive short-term, small-scale, high intensity impulsive noise exposures (i.e. sonar, seismic surveys) and from long-term, large-scale, lower intensity continuous noise exposures (i.e. shipping). International regulatory bodies typically treat these types of sound differently; for example as part of the EU’s MSFD, the descriptor for noise includes two indicators (Dekeling *et al*. 2014):

1. *Distribution in time and place of loud, low and mid frequency impulsive sounds*:

   Proportion of days and their distribution within a calendar year over areas of a determined surface, as well as their spatial distribution, in which anthropogenic sound sources exceed levels that are likely to entail significant impact on marine animals measured as Sound Exposure Level (in dB re 1µPa^2-s) or as peak sound pressure level (in dB re 1µPa peak) at one metre, measured over the frequency band 10 Hz to 10 kHz.

2. *Continuous low frequency sound*:

   Trends in the ambient noise level within the 1/3 octave bands 63 and 125 Hz (centre frequency) (re 1µPa rms; average noise level in these octave bands over a year) measured by observation stations and/or with the use of models if appropriate.

4.3 Effects of noise:

Marine mammals use sound in social interactions as well as to forage and navigate; extraneous noise may therefore interfere with these functions, either by affecting the auditory pathway or by modifying behaviour. Interference with communicative functions is considered to be particularly adverse. Noise has the potential to interfere with vital rates including critical biological parameters such as growth, survival, and reproduction (NRC 2005). Over the last few decades, there has been considerable interest in the science and management of the effects of anthropogenic sounds on marine life (Southall *et al*. 2007).

Anthropogenic sounds include sounds that are produced intentionally (such as sonar or seismic airgun impulses) or as a by-product of some activity (such as from ship engines or pile driving activities). Much attention has focused on the acute effects of military sonar on marine mammals in response to stranding events that have occur during or after military sonar-training operations (e.g. D'Amico *et al*. 2009). The potential effects on marine mammals of other acute sound-producing activities (e.g. oil and gas exploration, offshore construction and the deployment of offshore energy facilities such as wind farms) have also been assessed. In addition, there has been increasing recognition of the extent to which some of the more ubiquitous noise sources, such as large ships, can either individually or cumulatively mask communication signals of marine mammals (Clark *et al*. 2009). There has been a related realisation that overall increases in oceanic background noise from chronic activities can alter acoustic habitats over large regions in ways that may be detrimental to marine mammals that rely on sound for basic life functions (Andrew *et al*. 2002; McDonald *et al*. 2008). Indeed, anthropogenic ocean noise can be described as a chronic, habitat-level stressor (Ellison *et al*. 2012) and there is special concern for Arctic ecosystems (Moore *et al*. 2012, Southall *et al*. 2007). It is very difficult to document and measure levels of stress in free ranging whales, but a long term study on hormone levels in right whales provided evidence that ship noise increases stress in right whales (Rolland *et al* 2012). Right whales are closely related to bowhead whales, and it might be assumed that the physiological response would be similar. Experimental studies of captive beluga have similarly shown elevated stress hormone levels in response to seismic airgun noise (Romano *et al* 2004). The increase in human activities now allowed by the reduction in sea ice is increasing ocean noise in the Arctic, including areas that have previously been acoustically pristine (Moore *et al*. 2012). Although the biological consequences of elevated ambient noise are not well understood, there is sufficient evidence to suggest that at some threshold, noise could negatively affect sound-dependent marine mammals (National Academy of Sciences 2005, Richardson *et al*. 1995, Tyack & Clark 2000). Additionally, the introduction of anthropogenic noise into the Arctic marine environment is an additional stressor to wildlife which are already being impacted by pressures from climate change, ocean acidification, increased fisheries and hunting. The effects of noise pollution cannot therefore be considered in isolation as these changes may cause cumulative or even synergistic impacts.

Animals exposed to either natural or anthropogenic sound may experience physical and psychological effects, ranging in magnitude from slight to severe. Potential impacts depend on spatial relationships between the sound source and the animal receiver, the sensitivity of the receiver, the received exposure level, the signal duration and duty cycle, and numerous other factors (see Richardson *et al*. 1995). The same acoustic source may have radically different effects depending on operational and environmental variables, and on the physiological, sensory, and psychological characteristics of exposed animals. It is important to note that these animal variables may differ (greatly in some cases) between individuals of a species and even within individuals depending on various factors (e.g. age, season and behavioural state). Responses elicited can depend both on the context (feeding, mating, migrating, etc.) in which an individual is ensonified and on a host of experiential variables (see Wartzok *et al*. 2004). Consequently, certain effects may be poorly described with simple measures such as sound pressure level alone, and may only be predictable when additional variables are considered.

4.3.1 Auditory masking

Noise may partially or entirely reduce the audibility of signals, a process known as auditory masking. For example, based on worst-case theoretical models, the ramming noise from ice breakers was predicted to mask beluga calls at a range of 40 km, and to cause disturbance at 46 km (Erbe & Farmer 2000). The extent of interference depends on the spectral, temporal, and spatial relationships between signals and masking noise, in addition to other factors. Similarities in morphology and mammalian cochlear functional dynamics suggest that auditory data from terrestrial mammals may be reliably used in some situations where marine mammal data are lacking.

4.3.2 Auditory threshold shift

Animals exposed to sufficiently intense sound exhibit an increased hearing threshold (i.e. poorer sensitivity) for some period of time following exposure; this is called a noise-induced threshold shift (TS). Factors that influence the amount of TS include the amplitude, duration, frequency content, temporal pattern, and energy distribution of noise exposure. The magnitude of TS normally decreases over time following cessation of the noise exposure (Southall *et al*. 2007). If TS eventually returns to zero (i.e. the threshold returns to the pre-exposure value), it is called a temporary threshold shift (TTS). Recovery of nominal hearing function may occur quickly, and the amount of TTS measured depends on the time elapsed since the cessation of noise exposure. If TS does not return to zero after a relatively long interval (in the order of weeks), the residual TS is called a noise-induced permanent threshold shift (PTS). The distinction between PTS and TTS depends on whether there is a complete recovery of TS following noise exposure. PTS is considered to be auditory injury and may involve the destruction of sensory cells in the inner ear or metabolic exhaustion of sensory cells, support cells or even auditory nerve cells. Some of the apparent causes of PTS in mammals are severe extensions of effects underlying TTS (e.g. irreparable damage to the sensory hair cells). Others involve different mechanisms, such as exceeding the elastic limits of certain tissues and membranes in the middle and inner ears and resultant changes in the chemical composition of inner ear fluids (Ward 1997, Yost 2000).

The relationship between TTS and PTS depends on a highly complex suite of variables concerning the study subject and the exposure. This relationship remains poorly understood, even for humans and small terrestrial mammals in which this topic has been investigated intensively (Kryter 1994, Yost 2000). For marine mammals, recent data are available regarding sounds that cause modest TTS (generally < 20 dB decrease in sensitivity) in a few species of odontocetes and pinnipeds. No data exist on exposures that would cause PTS in these taxa. Consequently, the only current option for estimating exposure conditions that would cause PTS-onset in marine mammals is to use the available marine mammal TTS data combined with data from terrestrial mammals on TTS growth rates with increasing acoustic exposure (Southall *et al*. 2007). Using this approach, peak sound pressure levels of 230 dB re 1µPa and SEL levels of 198 dB re: 1 µPa^2-s have been proposed as limits for both single and multiple pulses to avoid PTS onset (Southall *et al*. 2007).

4.3.3 Behavioural reactions to sound

Changes in behaviour are inherently difficult to evaluate. Behavioural responses to sound are highly variable and context-specific and the animals' reaction may vary greatly depending on season, behavioural state, age, sex, as well as the intensity, frequency and time structure of the sound causing behavioural changes (Wartzok *et al*. 2004). They range from very strong reactions, such as panic or flight, to more moderate reactions where the animal may orient itself towards the sound or move slowly away. Some sounds that are audible to animals may elicit no overt behavioural response. This is most common when the sound does not greatly exceed the minimum detectable level and is not increasing or fluctuating (Richardson *et al*. 1995). Inability to detect an overt response does not necessarily mean that there is no subtle behavioural (or other) effect, however. When observable reactions do occur, they may include orientation or attraction to a sound source, increased alertness, modification of their own sounds, cessation of feeding or social interaction, alteration of movement/diving behaviour/breathing rate, temporary or permanent habitat abandonment and, in severe cases, panic, flight or stranding, sometimes resulting in injury or death (e.g. Richardson *et al*. 1995; Evans & England 2001; Gordon *et al*. 2004; Scheifele *et al*. 2005; Cox *et al*. 2006; Nowacek *et al*. 2007). Minor or temporary behavioural effects are often simply evidence that an animal has heard a sound and may not indicate lasting consequence for exposed individuals.

Except for naïve individuals, behavioural responses depend critically on the principles of habituation and sensitisation. An animal's exposure history with a particular sound affects whether it is subsequently less likely (habituation) or more likely (sensitisation) to respond to a stimulus such as sound exposure. The processes of habituation and sensitisation do not necessarily require an association with a particular adverse or benign outcome. Rather, individuals may be innately predisposed to respond to certain stimuli in certain ways. These responses may interact with the processes of habituation and sensitization for subsequent exposure (Southall *et al*. 2007).

4.3.4 Non-auditory effects

The auditory system appears to include the organs most susceptible to noise exposure, at least in humans (e.g. Ward 1997). The limited data on captive marine mammals exposed to various kinds of noise support a similar conclusion, suggesting that TTS-onset occurs at levels which may be below those required for direct non-auditory physiological trauma. Noise exposure does have the potential to induce a range of direct or indirect physiological effects on non-auditory structures. These may interact with or cause certain behavioural or auditory effects or they may occur entirely in the absence of those effects. Noise exposure may affect the vestibular and neurosensory systems. For instance, in humans, dizziness and vertigo can result from exposure to high levels of noise, a condition known as nystagmus (Oosterveld *et al*. 1982; Ward 1997; Halmagyi *et al*. 2005). Little is known about vestibular functions in marine mammals. There are significant differences in vestibular structures in some marine mammal species compared to most land mammals (Wartzok & Ketten 1998; Ketten 2000). The non-auditory effect now being most actively discussed in marine mammalogy is nitrogen gas bubble growth, resulting in effects similar to decompression sickness in humans. Jepson *et al*. (2003) and Fernández *et al*. (2004, 2005) hypothesised that lesions (gas and fat emboli) observed in individual beaked whales found stranded after military sonar exercises were somehow caused by in vivo nitrogen bubble formation. Osteonecrosis in sperm whales has further been suggested as a chronic result of nitrogen bubble formation (Moore & Early 2004). Other toothed whales, including Risso's and common dolphins, harbour porpoise, Blainville's beaked whale (Jepson *et al*. 2003) and various other species of live-stranded dolphin (Dennison *et al*. 2015) are also known to suffer the effects of nitrogen bubble formation in certain tissues.The acoustic causative mechanism for formation of these emboli, if any, is unknown.

4.3.5 Behavioural context

Focusing exclusively on the amplitude of the received sound ignores a diverse suite of environmental, biological, and operational factors (i.e. context) that may affect both the perception of received sounds and complex behavioural responses that they may invoke (Ellison *et al*. 2012). There is compelling evidence that a variety of factors can determine the form, probability, and extent of an animal's response to sound. Accounting for these factors will require a fundamental shift in the current approach used to manage anthropogenic sounds in the ocean. Southall *et al*. (2007) reviewed the existing data on hearing and the effects of anthropogenic sounds on marine mammals. Data on the effects of sound on terrestrial species was used to derive noise-exposure criteria, acknowledging gaps in data on the hearing capacity of many species, including all mysticete cetaceans. It was concluded that there are sufficient data to establish initial quantitative exposure criteria for direct physical effects (injury). However, it was also concluded that a comparable approach to assessing behavioural effects based solely on received sound level was not warranted. In an effort to evaluate behavioural responses to sound more systematically, Southall *et al*. (2007) derived a qualitative, 10-step index for the severity of behavioural response on the basis of the observed physical magnitude of the response (e.g. minor change in orientation, change in respiration rate, fleeing the area) and its potential biological significance (e.g. cessation of vocalisations, abandonment of feeding, separation of mother and offspring). When this severity index was applied to reports of behavioural observations relative to the received sound level, Southall *et al*. (2007) found that the exposure sound level (e.g. the zones-of-influence or dose–response approach) fails to reliably predict the probability of identifiable behavioural responses. They also noted that behavioural responses are strongly affected by the context of the exposure and by the animal's experience, motivation and conditioning. These factors may have an equal or greater importance than sound level for predicting the probability of the type or severity of a response.

4.4 Noise in the Arctic

The dramatic loss of sea ice over the past decade is resulting in unprecedented human access to the Arctic. Projections of an ice-free summer by 2040 (Serreze 2011) have prompted investment for a wide variety of offshore activities, including shipping, oil and gas development, tourism, commercial fishing and scientific research. Navigation of the Northeast and Northwest Passages by commercial shipping is now occurring to transport goods (Farré *et al*. 2014). Increased opportunities for the exploration for oil and gas reserves have led to an increase in the number and geographic extent of seismic surveys between July and December in the Arctic. The seasonal opening of Arctic waters also has prompted countries to increase military training activities at high latitudes and to define or extend their continental shelf boundaries (Berkman & Young 2009). The expansion of commercial fisheries and tourism is expected to follow the seasonal sea-ice retreat. The National Snow and Ice Data Center recently announced the 2014 to 2015 winter sea ice reached its maximum extent early and was the lowest in the satellite record.

All of these offshore activities generate noise, ranging from the low-frequency cavitation of ship propellers to the powerful impulses from icebreaking, seismic survey airguns and sonars (Hildebrand 2009). Overall, the increase in human activities precipitated by sea-ice loss is generating an increasing level of underwater noise in the Arctic marine environment, including in areas that have previously not experienced anything approaching these levels of activity (Moore *et al*. 2012).Anthropogenic noise has gradually been increasing in the acoustically pristine Arctic since the advent of industrialisation, albeit on a smaller scale than the increases currently occurring. In the 19th century, for example, after the implementation of auxiliary steam engines in the commercial whaling fleet, whalers found that bowhead whales were more readily approached under sail than with the engine running (Lubbock 1937). When commercial whaling vessels switched from steam-power to noisier diesel engines, whales were found to be more 'frightened' (Tønnessen & Johnsen 1982), an example of rapid sensitisation to disturbance in an area historically devoid of anthropogenic noise. In the Arctic region today, acoustic habitats vary by region and season primarily in response to the type and extent of sea-ice cover and the concomitant human activities. Increasing levels of commercial shipping and cruise-based tourism will contribute greater amounts of low-frequency noise into the acoustic habitat. Noise from oil and gas activities (e.g. seismic surveys, pile driving, drilling, and production operations) will also contribute to background levels, particularly in the low-frequency band. Coastal development will add vessel noise, as well as impulsive sounds from pile driving. If commercial fisheries expand, there will be a cumulative increase in low-frequency vessel noise, and fish-finding sonars will contribute high-frequency sound energy. Given these and a range of possible noise sources associated with military operations, involving vessels, sonars, and aircraft, acoustic habitats in the Arctic are certain to change dramatically in the foreseeable future.

With regard to noise, an important consideration in the Arctic, is the presence of a set of oceanographic conditions associated with the cold that can 'trap' sound near the surface, allowing sounds to be transmitted over very long distances. Low frequencies travel particularly well in this 'surface duct' as it reduces the normally disruptive interactions of the sound with the sea floor. It should also be noted that the natural background noise levels will also be different in the presence of ice, being somewhat louder around the ice edge due to wave-ice interactions.

The other major consideration in the management of Arctic impacts from noise is the lack of information about the animals living there due to the geographical remoteness and inaccessibility. This prevents managers from making informed, environmentally appropriate decisions, such as determining optimal (least harmful) locations and timing for particular activities around habitats of importance to marine mammals. Similarly, many of the animals in these locations have not previously been regularly exposed to noise from human activities, so it is not possible to determine with any certainty how they will react. The end result of all these elements is that assessing, managing and mitigating the impact of noise in the Arctic is even more difficult than it already is elsewhere. Basic biological and ecological knowledge is lacking and the additional complications presented by the Arctic environment mean that the information needs for effective management here are greater than in most other areas. Additional complications arise when cumulative impacts of Arctic industry are considered, as noise impacts cannot be considered in isolation. These issues should be given due consideration before the industrial development of the Arctic proceeds further.

5. The narwhal; a particularly sensitive Arctic species

Summary

- There a number of specific characteristics of narwhals and aspects of their ecology and life histories that are of particular note and should be taken into consideration when assessing the potential for adverse impacts to the species. A key consideration for narwhals is the combination of pressures from various environmental and anthropogenic activities which, in addition to noise pollution from increased oil and gas development, are in combination, posing an increasing threat to the continued survival of this species/population.
- Narwhals are considered to be the most specialised of the ice whales, inhabiting the Arctic year round, with the close association with sea ice being fundamental to their ecology and survival in terms of both feeding and shelter/protection from predators and other threats (natural and human).
- Narwhals exhibit a narrow geographic distribution, extremely high site fidelity to summering and winter feeding habitat, as well as regular and predictable migrations between these areas. Between 80-90% of the global population of narwhals summers in Baffin Bay and the Canadian High Arctic.
- Narwhals appear to carry particularly high persistent organic pollutant and heavy metal contaminant burdens (with potential immune, neurological and reproductive significance).
- Narwhal are subject to harvesting and indications are that hunting pressure is increasing (e.g. as a result of changes in the sea ice conditions, providing increased access to narwhals). For example, there has been a doubling of narwhal catches by hunters in Siorapaluk, North Greenland since 2002. In contrast to beluga and bowhead whales, which in some locations may now be slowly increasing in numbers, indications are that narwhal populations are in decline.
- There is a general lack of data on narwhal population abundance and population trends for all 11 subpopulations.
- In addition to the described aspects of the species biology, unprecedented changes in the Arctic environment are underway which are having significant impacts on the narwhal's ecology and habits, including wide spread changes in the sea ice cover, extent and thickness, resulting in changes to the ice environment as well as huge increases in human activity and disturbance, for example from ship traffic (noise, ship strike risk, shipping accidents and introduction of alien species), oil and gas exploration and production, tourism, commercial fishing and pollution.

5.1 The sensitivities of the narwhal

Narwhal are spatially, and ecologically unique cetaceans facing a range of threats to their survival. This section aims to describe the compounding pressures on the species and how the additional impacts from loud noise sources described in this briefing may be compounded by their sensitivity to their changing environment and other threats presently facing them.

Narwhal have been described by experts as the most specialised of the ice whales (Laidre *et al.* 2008). They have a narrow geographic distribution, highly specialised feeding habits and habitat choice. Some 80-90% of the global population of narwhals summers in Baffin Bay and the Canadian

High Arctic. Data on narwhal abundance and population trends are severely deficient – there are no data available on trends for any of the 11 sub populations of narwhals. In comparison, data are available on trends for 5 of 19 beluga subpopulations and 2 of 4 bowhead whale sub populations (Laidre *et al.* 2015).

Narwhals (as with other Arctic marine mammals) are highly mobile and undertake large seasonal movements, ranging across regional and international boundaries, requiring international cooperation in terms of management. They demonstrate complex social systems, are extremely long lived and exhibit very high site fidelity and predictable, regular migrations; individuals return to the same wintering grounds year after year.

Narwhal are known to be highly vocal, with complex social systems and are highly evolutionarily adapted to use their acoustic ability to navigate to and find breathing holes in the ice (being one of the only Arctic species that over-winters in dense pack ice, indeed no other species of cetacean occupies such dense winter sea ice cover for such a long period of time). They are thought to be extremely long lived – individuals are estimated to live at least 100 years. The oldest recorded whale from one study was a 115 year old female (Garde *et al.* 2007), but maximum age in a population with less disrupted (by hunting) age structure may be considerably higher. The life spans of these Arctic species (such as narwhal and bowhead whale) are considerably longer than relatives from lower latitudes. Palsbøll *et al*. (1997) found very low genetic diversity between narwhals from Canada, West Greenland and East Greenland, a scenario resembling that seen in severely depleted whale stocks. This may be as a result of historic population bottlenecks, likely caused by previous dramatic habitat changes.

Recent investigations of the narwhal tooth/tusk have revealed extraordinary sensory capability, with each tusk containing up to 10 million nerve endings – this may allow the ability to constantly sense environmental stimuli and assist with seeking mates or prey (Nweeia *et al.* 2014). Males may use tusk length to determine social rank, but have not been observed using tusk for fighting or other aggressive behaviour. Due to the sensitive nature of narwhal tusk, it is perfectly plausible that narwhal might detect sound vibrations through their tusk, although no research on this has yet been undertaken.

5.2 Narwhals and climate change

Beluga and bowhead whales a have a circumpolar distribution, while the narwhal occurs primarily in the North Atlantic Arctic (Heide-Jørgensen 2009, O'Corry-Crowe 2002). The dependency of beluga and narwhal on sea ice is likely due to their prey being ice-associated either directly via living in association with sea ice or indirectly via the nutrients falling through the water column from sea ice. However, both species can travel far from sea ice and some populations routinely spend many months in ice-free habitats (e.g. Cook Inlet beluga, West Greenland narwhal). Protection from killer whales might also play a role in their use of ice-covered waters. Additionally, the shelter offered from wave activity in ice covered waters, particular during storms, may serve as an attractant (Kovacs *et al.* 2011).

Although the primary period of feeding is thought (from analysis of stomach content of hunted individuals) to take place in winter, feeding has never been observed as they feed offshore amongst sea ice in the dark; all information on feeding in narwhal is from stomach contents of hunted animals. They winter for up to 5 months under the sea ice in Baffin Bay-Davis Strait area – finding cracks in the ice to breathe following extraordinary dives to depths of 1500m (Laidre *et al.* 2003). The focus on intensively feeding in the winter is the opposite of sub-arctic whale species–and may provide an insight into their specialisation required by this species to occupy Arctic seas.

They exhibit very predictable migration patterns, and undertake extensive annual migrations (>1,000 km) that last approximately two months (Koski & Davis 1994, Dietz *et al.* 2001, Heide-Jørgensen *et al.* 2002 & 2003, Innes *et al.* 2002). These very regular migrations are now showing signs of disruption and owing to their restricted habitat preference, high site fidelity, low genetic diversity, and dependence on open water during their 6-month stay on the winter feeding grounds, narwhals have limited options for alternative strategies relative to changes in their habitat in Baffin Bay (Heide-Jørgensen *et al.* 2003).

Narwhals from Canada and West Greenland have high site fidelity to the winter pack ice of Davis Strait and Baffin Bay in regions along the continental slope with high gradients in bottom temperatures, predictable open water (<5%), and a very restricted and specialist diet composed of relatively high densities of Greenland halibut (Laidre *et al.* 2004). Narwhals are highly adapted to pack ice habitat surviving winter periods in up to 90% pack ice (Laidre & Heide-Jørgensen 2011) where there is limited open water (Laidre *et al*. 2004, Laidre & Heide-Jørgensen 2005). Thus the wintering grounds may be the most critically important habitat for narwhals. Intense benthic feeding behaviour has been documented between November and March for narwhals from northern Canada and West Greenland (Laidre *et al*. 2003, Laidre & Heide-Jørgensen 2005) and, in contrast to low feeding activity during the summer period, suggests a major portion of the annual energy intake is obtained in Baffin Bay in winter (Laidre *et al*. 2004, Laidre & Heide-Jørgensen 2005).

Calving occurs in spring, and little feeding has been observed in summering areas – the reasons for visiting specific coastal summer habitat is unclear (Laidre & Heide-Jørgensen 2005). However, in recent summers, narwhals, sometimes in relatively large groups, have been observed in areas of the High Arctic where this species had rarely or never been reported previously. For example, in 2011 and 2012 groups were seen in Canada's Dolphin and Union Strait, well west of the previously known normal range (Reeves *et al.* 2013).

Major changes in the sea ice are occurring, and between 1979 and 2013, statistically significant trend have been shown in terms of earlier spring sea ice retreat, later autumn sea ice advance and therefore longer summers (Laidre *et al.* 2015). Effects of climate change on ice habitats used by narwhal are uncertain as is the species capacity to adapt. Changes in the Arctic sea ice conditions in narwhal habitat are resulting in increased access by hunters, as well as shipping, oil and gas producers (OGP) and natural predators such as killer whales. Loss of pack ice in wintertime benthic feeding habitat is also of particular concern. A marked increase in narwhal catches since 2002 at Siorapaluk, the northern most community in Greenland, has been interpreted as reflective of major changes in sea ice conditions that give hunters easier access to the animals by boat in June and July (Neilsen 2009). It is unclear how to interpret recent observations of live narwhals or dead stranded ones along the ice-free west coast of Spitsbergen (Norwegian Polar Institute, Marine Mammal Sightings Database 2012).

In the case of narwhals, loss of pack ice in their wintertime benthic feeding habitat may be of particular concern (Kovacs *et al* 2011). Reduced ice cover will also mean that the ice-associated cetaceans will not have this refuge from turbulent water during storm activity; this could indirectly increase energetic costs and possibly directly increase calf mortality. Thus, Arctic cetaceans face multiple challenges without even considering further human impacts, in that they will have to adapt to altered food webs while potentially dealing with increased competition for prey with seasonally migrant species that remain in Arctic waters longer, and in some areas cope with increased levels of predation (Watt *et al* 2013).

5.3 Narwhals and pollutants

Arctic odontocetes such as beluga and narwhal have been shown to carry very significant persistent contaminant burdens from heavy metals and organochlorines (Heide-Jørgensen 2009). Cadmium concentrations seem to be significantly higher in narwhals than in other cetaceans (Born 1994 and references therein). Highest cadmium concentrations were reported from narwhals living along the Canadian coast, whereas lead concentrations were higher in west Greenland animals. Furthermore, Muir *et al.* (1992) noted high concentrations of HCHs in northern waters and remarkably high levels of cadmium in the kidneys and livers of narwhal from Eastern Canadian Arctic and West Greenland waters. Some narwhals had sufficient cadmium in the kidney near the critical limit (100-300 µg g-1 wet weight, MARC Report 1980) for kidney dysfunction in mammals (Muir *et al*. 1992). A comparison of lipophilic POP (persistent organic pollutants) levels in a variety of traditional Greenlandic marine meat products found narwhal mattak (skin and blubber) had higher levels than samples of salmon, halibut, seal and whale meat (Carlsson *et al*. 2013). Narwhal skin as a whole (mattak) is considered to be a delicacy by native Canadian and Greenland people. The concentrations and patterns of polychlorinated biphenyls (PCBs), chlorinated pesticides, and polybrominated diphenyl ethers (PBDEs) were studied in blubber from Svalbard, Norway. In both belugas and narwhals, a broad range of pollutants was found in relatively high concentrations (including PCBs and pesticides). Compared with other marine mammals from the same area, contaminant levels are among the highest levels ever measured. These high levels are likely in part because of a decreased capacity to metabolize contaminants. Metabolic indices indicated that most compounds accumulate to the same degree in belugas and narwhals, but for some toxaphenes and chlordanes, narwhals might have a decreased metabolism and consequently a higher accumulation. A three-times-higher contaminant levels in blubber of narwhals has been explained by substantially higher contaminant levels in their more benthic diet in comparison to belugas (Wolkers *et al.* 2006). The high levels and broad pattern of accumulating pollutants make narwhals and belugas excellent indicators for a wide range of contaminants in the Arctic.

While PCB and DDT concentrations in West Greenland narwhals were half those found in East Greenland and Svalbard (Dietz *et al*. 2004), the concentration of total mercury is 0.59 µg/g (wet wt) in narwhal skin as a whole (mattak), exceeding Canadian Government's Guideline (0.5 µg/g wet wt) for fish export and consumption (Wagemann & Kozlowska 2005). To conclude, human consumption of narwhal mattak seems to bear health risks. Many of these contaminants are endocrine disruptors that can cause reproductive, neurological, and immune system dysfunctions in marine mammals.

5.4 Narwhals and hunting

Narwhals have historically been subject to hunting pressure from opportunistic hunting by commercial whalers and explorers to large scale commercial hunting in early 20th century in the eastern Canadian Arctic (Mitchell & Reeves 1981).

For centuries, narwhal have been an important food source for indigenous communities, with hunting occurring for human consumption, dog food and tusk ivory (e.g. Born *et al.* 1994), with a bias toward the removal of males. In recent decades, population declines around Greenland and northern Canada are most likely attributable to increasingly intensive hunting (Heide-Jørgensen 2004; Heide-Jørgensen & Acquarone 2002). Laidre *et al.* (2015) note that in the modern world, it is rare for large wild mammals, especially top predators, to support nutritional and cultural wellbeing of human communities, as Arctic marine mammals do. Of the sub populations and sub species of Arctic marine mammals considered within the scope of their recent review, 78% are legally harvested.

5.5 Conclusion

In the case of narwhals in the Canadian and Greenland High Arctic, we must consider not only the potential impacts of discrete activities and disturbance from seismic activities over a relatively short time period, but the huge implications of the impacts of climate change, and the general 'industrialization' of a remote, relatively untouched, biologically sensitive and important area, which will result in more severe and sustained impacts on marine life (as occurred with gray whales in response to noise in breeding lagoons; Gard 1974). The resulting cumulative impacts (and stress) on a particularly sensitive species such as the narwhal, could quite realistically jeopardise the long term survival of the species. As Nowacek *et al.* (2013) note, in relation to seismic impacts, a more precautionary approach to the interpretation of available data is especially warranted when either endangered or particularly sensitive species are present, operations occur in critical feeding or breeding habitat, surveys occur in pristine areas with naïve animals, or multiple operations are to occur simultaneously or sequentially in the same general area. As narwhal are one of the most sensitive species to anthropogenic noise, this precautionary approach in relation to seismic testing is particularly important.

Of all the Arctic cetacean species, data seems to be most seriously lacking for the narwhal in terms of population abundance, status and trends (Laidre *et al*. 2015). This situation is confounded by the remote geography, cryptic behaviour and wide distribution – posing serious logistical challenges to research efforts for data collection. However, the result is that lack of baseline data will limit the utility of future assessments, and thus ability to monitor impacts on this species.

6. How far could the sound from the seismic testing travel with an intensity that could harm whales and particularly narwhals?

Summary

- This section defines the term "harm" to describe physical damage to auditory organs which includes temporary and permanent changes to hearing.
- Temporary damage (Temporary Threshold Shift or TTS) to hearing in cetaceans has been determined for several species at close ranges to seismic airgun sources (within a few hundred metres).
- Permanent damage to auditory organs (Permanent Threshold Shift or PTS) resulting from seismic airguns has not been documented; however Southall *et al*. (2007) considered that a noise exposure capable of inducing 40 dB of TTS will cause PTS-onset in marine mammals.
- Much controversy surrounds the various attempts to define safety limits for exposure of marine mammals to intense underwater sound; one of the main problems is lack of good and relevant data.
- The range at which an individual could suffer TTS or PTS as a result of exposure to loud noise depends on a number of variables, including the number and size of the airguns being used in the survey and the general environment, as well as how the modelling of the impact is conducted. Therefore it is often better to examine the sound pressure levels which would cause the impact.
- Audiograms do not currently exist for narwhal and bowhead whales, and as such, audiograms from other similar species are used to assume similar impacts.
- Beluga whales, which are the whale proxy used for narwhal, have been found to develop TTS to a sound exposure level (SEL) of 186 dB re 1 µPa^{2}s from a single pulse and at a peak-to-peak sound pressure level of 226 dB re 1 µPa (recovery to within 2 dB of the original hearing sensitivity after 4 minutes). Assuming the upcoming seismic surveys of Baffin Bay use similar sized airguns to the previous 2D and 3D surveys, beluga (and therefore it is assumed narwhal too) would suffer from TTS at 260 metres from a single airgun pulse or when considering multiple pulse impacts, the noise threshold to induce TTS would occur at 14 airgun pulses (an exposure time of less than 162 seconds) at a range of 1 km from the array, and 54 airgun signals (11-12 minutes) at a range of 2 km.
- TTS and PTS are amongst the most extreme and immediate physiological harm which can occur to marine mammals as a result of exposure to seismic survey noise at close proximity to the source (several hundred metres). Other reactions, such as displacement, avoidance and behavioural changes, occur at much greater distances from the noise source and may therefore, be extremely detrimental to the health of entire populations in the long term. Understanding of potentially lethal non-auditory effects (e.g. nitrogen gas bubble growth) in response to seismic surveys is entirely lacking in narwhals, although it has been found in other odontocete whales exposed to intense noise from military sonar
- Studies of the impacts of loud noises on cetaceans have been undertaken on captive animals, and therefore caveats are significant (including related to individual variability, the effect of long term captivity on individual animals hearing and study methodologies)

6.1 Background information on hearing loss

During this section the term 'harm' is used to describe physical damage to auditory organs which includes temporary and permanent threshold shifts in hearing. Hearing loss affects an animal's ability to navigate, communicate, and detect predators and prey (Erbe & Farmer 2000). Exposure to intense sounds may produce an elevated hearing threshold or threshold shift in marine mammals (Finneran *et al.* 2001). The definition of a threshold shift seems to be widely accepted by acousticians as a 6 dB or larger increase in threshold over pre-exposure levels (Finneran *et al.* 2000; Schlundt *et al.* 2000; Southall *et al.* 2007; Lucke *et al.* 2009). If the threshold returns to the pre-exposure levels after a period of time it is known as a temporary threshold shift (TTS), however if the threshold does not return to the pre-exposure levels, it is called a permanent threshold shift (PTS) and the animal's hearing is permanently damaged (Finneran *et al.* 2001). This can be caused by the destruction of sensory cells in the inner ear, or by metabolic exhaustion of sensory cells, support cells or even auditory nerve cells (Ramboll 2013). Hearing loss is usually only temporary (TTS) and the animal will regain its original detection abilities after a recovery period, but in prolonged or repeated exposures, where the ear is exposed to TTS-inducing sound pressure levels before it has had time to recover, TTS may build, and a TTS of 40 dB (Southall *et al*. 2007) or 50 dB (Ketten 2012) will often result in permanent damage. For both PTS and TTS the sound intensity is an important factor for the degree of hearing loss, as is the frequency, the exposure duration, and the length of the recovery time.

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 (Boertmann *et al.* 2010). However, some progress has been made in recent years, as summarised by Southall *et al.* (2007). In the USA, a received sound pressure level of 180 dB re 1 µPa (root mean square or rms) has hitherto been used as a mitigation standard to protect whales from Level A harassment (i.e. PTS) (Miller *et al.* 2005; MMPA 2007); however this level is now being reviewed in response to Southall *et al*. (2007) to provide more appropriate limits. Similarly, the threshold suggested for avoiding Level B behavioural disruption from impulsive noise (160 dB re 1 µPa rms) is also under review. Level B harassment is defined as having the potential to disturb a marine mammal or marine mammal stock in the wild by causing disruption of behavioural patterns, including, but not limited to, migration, breathing, nursing, breeding, feeding, or sheltering but which does not have the potential to injure a marine mammal or marine mammal stock in the wild (MMPA 2007).

TTS can be calculated with regard to the sound level needed to induce TTS from a single pulse. It can however also be elicited by exposure to several airgun pulses with a total cumulative SEL above the TTS threshold (Popov *et al.* 2014; Southall *et al.* 2007). The number of pulses needed to induce TTS increases with range (four times as many pulses per doubling in range to cause TTS when assuming spherical spreading; Wisniewska *et al.* 2014).

6.2 General information for all species

There is relatively little known about the sound levels that induce acoustic trauma in cetaceans. From studies of captive odontocetes (bottlenose dolphins and beluga whales) it has been suggested that short-term temporary threshold shifts are unlikely to have severe biological consequences as thresholds return to baseline values after small levels of threshold shift. Lucke *et al*. (2009)

measured TTS in a harbour porpoise using impulses from a small 20 in^3 airgun. The threshold shift of hearing sensitivity at 4 kHz following exposure to a SEL of 164.5 dB re 1 μPa^2s was only 1.8 dB above predefined TTS criterion. However, subsequent tests at the same frequency measured a 9.1 dB threshold shift following exposure to a SEL of 165.5 dB re 1 μPa^2s, and a 15 dB shift after exposure to a SEL of 165.8 dB re 1 μPa^2s, providing clear evidence of TTS. No statistical change in hearing sensitivity was observed after exposures to similar source levels at 32 kHz or 100 kHz. As these values are much lower than those proposed by Southall *et al*. (2007) to avoid injury from a single pulse in high-frequency odontocetes (198 dB re 1 μPa^2s), this illustrates the problems involved in extrapolating physiological responses from one species to another and even one individual to another.

Understanding TTS response levels is an important damage criterion for management and policy decisions. Furthermore, since there are no empirical data on PTS-onset, the relationship between TTS-onset and rate of TTS growth with increasing exposure levels is a critical step towards understanding upper bounds on 'acceptable' noise level exposure that could result in longer term auditory damage. As there are no experimental data inducing this upper bound, it is necessary to examine data from terrestrial mammals, where the relationship between TTS and PTS is still not thoroughly understood despite extensive experimentation. Southall *et al*. (2007) assumed that a noise exposure capable of inducing 40 dB of TTS will cause PTS-onset in marine mammals. Although this assumption is precautionary, since there are cases of complete recovery from shifts of this magnitude in terrestrial counterparts, the risk is high for irreversible damage, possibly involving different underlying mechanisms of recovery. With particular reference to pulsed sound, Southall *et al*. (2007) assumed a slope of 2.3 dB TTS per dB of noise exposure to estimate SEL exposures responsible for PTS-onset. The resulting expectation was that PTS-onset (40 dB TTS) would occur on exposure to a frequency-weighted SEL 15 dB above that associated with TTS-onset (6 dB TTS). For non-pulsed sound, such as that from a passing vessel, approximately 20 dB above that causing TTS-onset is required to induce PTS-onset based on 1.6 dB TTS per dB of noise. Although non-pulsed sounds are generally outside the scope of this literature review, it is worth a brief mention given that seismic operations contribute both pulsed and non-pulsed noise into the environment from the combination of airgun transmissions and vessel noise.

Rate of hearing recovery could also be an indication of impact severity. Nachtigall *et al*. (2003) and Nachtigall *et al.* (2004) provide an opportunity to compare two similar experiments measuring TTS in a bottlenose dolphin following exposure to octave-band noise. In the 2003 study, TTS was measured approximately 20 minutes after a 30-min net exposure to a maximum SPL (sound pressure level) of 179 dB re 1 µPa resulting in an average 11 dB shift. In the 2004 experiment, TTS was measured 5 minutes after nearly 50-min exposures of the same frequency with a maximum SPL of 160 dB re 1 µPa, resulting in 4 to 8 dB shifts. TTS was only slightly lower despite a large reduction in the exposure energy level. This was attributed to measuring threshold shifts within smaller time windows following exposure to the sound, i.e. allowing less opportunity for hearing recovery (Southall *et al.* 2007).

The study mentioned above by Lucke *et al.* (2009) using a small 20 in^3 airgun to test the hearing sensitivity of a harbour porpoise at 4 kHz found that the rate of recovery slowed during the recovery period, and was better described by a log-fitted curve than a linear correlation. By applying this function, hearing sensitivity would recover back to TTS criterion levels 55 hours after exposure to

202.1 dB re 1 µPa (rms). This would indicate that recovery periods for 'high-frequency' cetaceans are considerably longer than for 'mid-frequency' cetaceans following a comparable amount of threshold shift. Nachtigall *et al*. (2004) found that TTS recovery in captive bottlenose dolphins occurred within minutes or tens of minutes depending on the amount of shift.

6.3 Arctic species

Despite the assumed relatively poor low-frequency hearing thresholds of small- and medium sized odontocetes, they are capable of hearing the pulses from airgun arrays operating many tens of kilometres away (Richardson *et al.* 1995). At a frequency of 100 Hz, a sound needs to be at a received level of about 120 dB in order to be heard by a beluga (Awbrey *et al*. 1988). Captive studies on some dolphin species have shown that they may suffer from TTS when exposed to noise at levels between 193-196 dB re 1 µPa for one second intervals at the frequency range of 20 kHz (Ridgway *et al.* 1997). Beluga whales developed TTS to a sound exposure level (SEL) of 186 dB re 1 µPa^{2}s from a single pulse and at a peak-to-peak sound pressure level of 226 dB re 1 µPa (recovery to within 2 dB of the original hearing sensitivity after 4 min) (Finneran *et al.* 2002). A similar criterion for PTS and TTS may be assumed for narwhals and bowhead whales. A separate investigation of captive belugas found the highest TTS with the longest recovery duration was elicited by lower frequency noise (11.2 to 22.5 kHz; Popov *et al*. 2013); at higher noise frequencies (45 and 90 kHz) the TTS decreased. When conducting these experiments it is assumed that these species are most vulnerable to TTS in the same frequency range used by the species itself for vocalisations (Hildebrand 2004). Following this assumption, it would mean baleen whales, such as the bowhead whale, would be most vulnerable to low frequency noise (<1 kHz), while beluga whales would be most vulnerable to medium frequency noise (1 – 10 kHz; Dalen 2007).

PTS has not been measured in any cetacean species. By dividing cetaceans into functional hearing groups (M-weighting) (Table 6.1), Southall *et al.* (2007) proposed peak sound pressure levels of 230 dB re 1µPa and SEL levels of 198 dB re 1 µPa^{2}s as criteria both for single and multiple pulses respectively. For multi-pulse sources such as airgun arrays, the SEL criteria consider the cumulative effect of multiple exposures. Southall *et al.* (2007) sum multiple exposures assuming no hearing recovery between exposures. Using these levels it is possible to model the noise level which could cause permanent damage to cetaceans. It is important to keep in mind that the criteria for cetaceans are based on data from small mid-frequency odontocetes and thus may not be valid for larger whales (beaked whales, sperm whales and baleen whales) or high-frequency species (such as porpoises and *Kogia* species) for which no information on either TTS or PTS thresholds is available (Lucke *et al*. 2009; Boertmann *et al.* 2010). Erbe (2002) found that orcas could suffer permanent hearing damage if they were exposed to noise above a critical level over a longer time period, based on acoustic modelling.

Table 6.1: Functional hearing groups and associated auditory bandwidths (Miller *et al.* 2005).

Functional hearing group	***Estimated auditory bandwidth (Hz)***
Low-frequency cetaceans – mysticetes (such as bowhead whale, humpback whale etc.)	7 Hz – 22 kHz
Mid-frequency cetaceans – some odontocetes (such as beluga, narwhal & bottlenose dolphin)	150 Hz – 160 kHz
High-frequency cetaceans – odontocetes specialised for using high frequencies (such as harbour porpoise, beaked whales)	200 Hz – 180 kHz

Although narwhals are known to be highly sensitive to noise and disturbance from human activities, no direct studies have been conducted on the effects of seismic airgun noise on narwhals (Heide-Jørgensen *et al.* 2013), and as such the impact of seismic testing on belugas may be used as a proxy. Narwhals are known to show long-distance displacement from approaching vessels even at relatively low received levels; Finley *et al.* (1990) reported that narwhals disappeared from an area up to 80 km away from an advancing icebreaker, a responsiveness which is exceptional in the literature on marine mammals (Heide-Jørgensen *et al.* 2013). Belugas (which are assumed in most impact assessments to have similar hearing to narwhals) were modelled to suffer a TTS of 12–18 dB if the whales stayed within 40 m of an icebreaker's median bubbler system noise and within 120 m of icebreakers ramming noise for over 30 minutes (Erbe & Farmer 2000). Given the high mobility of beluga whales, this was determined to be unlikely. However, for a TTS of 4.8 dB to occur, an animal would only have to be within 1–2 km of median bubbler system noise and 2–4 km of ramming noise for 20 minutes, which was thought to be more likely (Erbe & Farmer 2000). Although narwhals may respond in a physiologically similar way to belugas, they appear to react in a behaviourally different way to disturbance. As individuals tend to exhibit a 'freeze' response rather than a 'flee' response (Laidre *et al*. 2006a), it is entirely likely that narwhals, unlike belugas, may stay close enough to a sound source to allow TTS.

The range at which individuals are from a signal in order to suffer TTS or PTS is not straightforward to estimate in a generic way as it very much depends on the number and size of the airguns being used in the survey and the general environment, as well as how the modelling of the impact is conducted. Therefore it is often better to examine the sound pressure levels which would cause the impact. Assuming the upcoming seismic surveys in Baffin Bay, both in Canadian and Greenlandic waters are similar to those 2D and 3D seismic surveys of recent years (see Section 2), TTS in beluga (and it is assumed narwhal) could occur at 260 metres from a single pulse from a 4240 in^3 airgun array. This would equate to a received SEL of 174 dB re 1 µPa^{2}s at 1000 m based on a peak-to-peak source level of 262.2 dB re 1 µPa (Wisniewska *et al*., 2014). When considering multiple pulses, the noise threshold to induce TTS would occur at 14 airgun pulses (an exposure time of less than 162 seconds) at a range of 1 km from the array, and 54 airgun signals (11-12 minutes) at a range of 2 km (Wisniewska *et al*., 2014). Using the M-weighting model Southall *et al*. (2007) delineated five groups of functional hearing in marine mammals and developed a generalised frequency-weighting (called "M-weighing") function for each), the noise levels that will result in permanent injury (PTS) would be reached at a distance of 18 metres from the airguns (≥198 dB SEL M_{MF}) for beluga, and 32 metres from the airguns (≥198 dB SEL M_{LF}) for bowhead whales, when using 4240 in^3 airgun array, with a received peak-to-peak source level of 262.6 dB re 1 μPa (LGL & Grontmij 2012). Although some avoidance reactions from animals is assumed to occur in order to protect them from injury, when examining the four surveys which occurred in the Greenlandic waters of Baffin Bay in 2012 simultaneously, Wisniewska *et al*. (2014) noted that for animals which are less likely to avoid vessels (such as bowhead whales and pinnipeds) and therefore still nearby during the shooting, the risk of injury is very real, as “they would have to cover long ranges in a short time to avoid summing of levels to a value that causes TTS”.

7. How far could the sound travel with an intensity that could scare whales and particularly narwhals?

Summary

- This section defines the term "scare" to mean avoidance, displacement and startle-type behavioural reactions.
- Avoidance reactions by whales and dolphins in relation to anthropogenic noise sources are the most commonly observed response and avoidance is often observed over great distances (many tens of kilometres) from the source of the disturbance.
- Although there have been no direct studies of the reactions of narwhal to seismic noise, it is well known from Traditional Knowledge, and from studies of narwhals' reactions to the presence of icebreakers, that this species is extremely sensitive to noise and disturbance. Narwhals have displayed obvious avoidance behaviour at distances of over 80 km to noise emitted by icebreakers, which although continuous rather than impulsive noise, indicates how acutely sensitive this species is to disturbance. As beluga hearing is assumed to be comparable to that of the narwhal, the responses by beluga whales detailed below may be assumed for narwhals in the absence of any specific observations.
- Narwhals were reported in unusual ice-entrapment events, correlated with seismic testing activities between 2008 and 2010; it has been suggested that the ice entrapments occurred because the whales' regular migrations were disrupted as they were trying to avoid (or were disturbed by) the noise. This is covered in more detail in section 11.
- Beluga whales have demonstrated avoidance reactions to seismic noise at a distance of 20 km from the seismic airgun arrays, where the received level was approximately 130 dB re 1 µPa (rms). Beluga whales have also shown avoidance to icebreaker noise at ranges of up to 80 km.
- Belugas' stress hormone levels increase with exposure to seismic sounds; this can affect the immune system or otherwise compromise the health of animals. In response to other noise sources, belugas have been shown to change their dive patterns and vocalisations and call rate at distances of 40–60 km from icebreakers.
- The reactions of bowhead whales to seismic surveys have been well documented, although appear to be somewhat context-dependent, with migrating bowhead whales being distinctly more sensitive than those involved in feeding activities. Migrating animals have been documented to display avoidance behaviour at distances of 30-50 km from a seismic array.
- Although it is often considered that avoidance behaviour protects cetacean species from more serious damage and impact from anthropogenic noise sources such as seismic airguns, the knock-on effects of the avoidance can have significant population level impacts. Moving away from critical habitats and food sources or altering migration patterns can cause secondary lethal and chronic impacts, i.e. if impacts cause individual whales to get insufficient food or expend extra energy, their individual reproductive success may be diminished and this could have repercussions at a population level, especially in such long-lived, k-strategist (with long gestation and slow maturation) mammals.

7.1 Introduction

For this section, the notion of whales being "scared" will be considered in relation to avoidance, displacement and startle behavioural reactions. Of all the documented impacts of seismic airguns on cetaceans, avoidance is the most commonly documented behavioural response. The impacts of stress are also covered in this section.

7.2 All species

In reviews of data from mammal observers during seismic operations, mysticete (baleen) whales have generally been reported to be encountered further from airguns during times of firing, and heading away from the airgun noise sources (Stone & Tasker 2006). Mysticete species demonstrate large variance in their response to airgun sounds, and this appears to depend on their gender and behavioural state at the time of impact. In humpback whales, avoidance reactions, or lack of, were specific to the sex classes in the groups (McCauley *et al*. 2000) with male humpback whales actively approaching the airguns at speed, and groups with females creating a standoff range of around 1.3 km to a single airgun (McCauley *et al*. 2000). Scaling up the airgun noise levels to those of an average 3D array, the potential range for avoidance by humpback whale groups with females was found to be 7-12 km in key habitats (McCauley *et al.* 2000). In other studies, humpback whales have been noted to show no clear evidence of large scale avoidance to seismic airgun noise (Malme *et al.* 1985, Weir 2008a), although more subtle startle responses have been noted when airguns were first fired (Malme *et al.* 1985) and localised avoidance within 2-3 km of the source has been recorded (Weir 2008a).

Fin whales were documented to show a very strong avoidance reaction to seismic airguns from long term acoustic recordings by Castellote *et al.* (2012); singing fin whales were shown to have strong reactions to seismic airgun noise, moving out of a large study area within the first 24 hours of airguns firing 285 km away, and not returning until 14 days after the 10 day survey (Castellote *et al*. 2012). The authors also compared responses in areas characterised by different levels of shipping noise, and noted persistent displacement of whales by seismic activity, suggesting that fin whales have a lower tolerance for airgun sounds than noise from shipping. However, other observations document no avoidance reactions in fin whales to seismic survey noise (Stone & Tasker 2006) which may be due to the behavioural state the fin whales were in at the time.

Critically endangered western grey whales off Sakhalin Island, Russia, were displaced by seismic surveys from their primary feeding area, returning only days after seismic activity stopped (IWC 2005). Grey whales demonstrated 90% avoidance to seismic airgun noise at received levels of 180 dB re 1µPa (Malme *et al*. 1983, 1984), showing avoidance at distances of up to 24 km (Würsig *et al*. 1999), but no large scale avoidance over their whole feeding grounds (Yazvenko *et al*. 2007).

Avoidance behaviour by odontocetes (toothed whales) in response to seismic surveys is less well documented and shows a variety of responses. In general, small odontocetes show significant declines in sighting rates during seismic shooting activity compared to non-shooting periods, demonstrating strong lateral spatial avoidance extending at least as far as the limit of visual observation in response to active airguns (Stone & Tasker 2006). Killer whales (Stone & Tasker 2006), common dolphins (Goold & Fish 1998), bottlenose dolphins (Ridgeway *et al.* 1996), pilot whales (Stone & Tasker, 2006; Weir, 2008b), sperm whales (Mate *et al.* 1994; Madsen *et al.* 2002), spotted dolphins (Weir, 2008a, Gray & van Waerebeek 2011) and harbour porpoise (Bain & Williams 2006) have all been documented demonstrating avoidance responses to seismic airgun noise.

Data are limited for larger toothed whales. However, as deep-diving species may be unavailable for surface observation for the majority of their lives, it is important not to assume a lack of avoidance based on a paucity of data.

7.3 Arctic species

7.3.1 Narwhals

There are no studies of reactions of narwhals to seismic noise. However, there are studies and observations of the responses of narwhals to other noise sources, which are indicative of how these animals may react to seismic noise. Traditional knowledge from Inuit hunters has observed that narwhals are sensitive to, and avoid noise from machines and explosions (Remnant & Thomas 1992, Stewart *et al*. 1995). Lee and Wenzel (2004), noted that Inuit hunters found narwhal were so sensitive to sound, that noise associated with snow mobiles, and even people walking on the ice, would impact how closely narwhal would come to the ice edge. Mittimatalingmiut elders believe that contemporary snowmobile noise had drastically changed narwhal migration behaviour along the floe-edge (Lee & Wenzel 2004). Narwhals demonstrate two different reactions in response to noise from icebreakers: they most often displayed an antipredator response (see section 8) interpreting the noise as a threat; however, they have also been observed fleeing rapidly from an area up to 80 km from an advancing icebreaker (Finley *et al.* 1990). Narwhals were recorded to react to icebreaker noise at received levels as low as 94-105 dB re 1 µPa rms in the 20-1000 Hz frequency band (Finley *et al.* 1990). Similar reactions may be expected in response to the presence of seismic vessels. Circumstantial evidence of this exists in the lack of any MMSO (Marine Mammal and Seabird Observer) sightings or observations of narwhal during four simultaneous 3D seismic surveys in Baffin Bay in 2012 (Vanman & Durinck 2012, Lacey *et al*. 2013) from the seismic vessels in areas where narwhals would normally be present at this time of the year (Dietz & Heide-Jørgensen 1995). Heide-Jørgensen *et al*. (2013) conducted three visual surveys of narwhals during the 2012 seismic season and found that narwhals during the second and third studies (conducted during the seismic surveys) were distributed significantly closer to shore and in a smaller area in relation to a survey conducted there in 2007, and were found in significantly more closely spaced groups (Heide-Jørgensen *et al.* 2013). Additionally, Reeves *et al*. (2013) noted that in recent summers relatively large groups of narwhals have been observed in areas of the High Arctic where this species has rarely or never been reported previously. This change in distribution is most definitely in part due to the major changes in sea ice conditions; however these years have also experienced an increase in seismic survey activity. Such changes in distribution or activity have the potential for lethal knock-on impacts in such a harsh, marginal environment. Heide-Jørgensen *et al*. (2013) hypothesised that three large ice entrapments in 2008 to 2010 were linked to seismic survey activities in the local area, with narwhal remaining in their coastal summering zones, delaying their autumn migration, due to the avoidance of seismic noise (for more information please see Chapter 11).

7.3.2 Beluga whales

Belugas are also highly sensitive to disturbance from noise (Lawson 2005), showing avoidance reactions to seismic operations (Miller *et al*. 2005) at distances of up to 20 km from a seismic airgun array (Abgrall *et al*. 2008, Miller *et al*. 2005) where the received level was approximately 130 dB re 1 µPa rms (Miller *et al*. 2005). Beluga whales have also been reported to demonstrate extreme avoidance reactions to quieter noise sources; Finley *et al*. (1990) showed that belugas react strongly to icebreaker noise (Cosens & Dueck 1993), being displaced at ranges of up to 80 km from the icebreaker, reacting by fleeing rapidly away from the direction of the icebreaker (Erbe & Farmer 2000).

In Baffin Bay, belugas migrate near ice covered waters, therefore variations in behaviour or travelling routes due to disturbance can be fatal, as belugas can also become trapped in the ice (Wisniewska 2014).

Romano *et al.* (2004) measured stress hormones in a number of species in response to seismic sound. The loud, impulsive noise produced from a seismic gun caused significantly increased mean norepinephrine, epinephrine, and dopamine levels immediately after a high level of exposure in a captive beluga whale (Romano *et al*. 2004). All three of these stress hormones increased significantly with increasing noise levels. These hormone levels remained high even 1 hour after noise exposure, which is surprising given their short half-life. Stress effects or physiological changes, if chronic, can inhibit the immune system or otherwise compromise the health of animals (Weilgart *et al*. 2013).

7.3.3 Bowhead whales

The reactions of bowhead whales to seismic surveys have been well documented, and appear, as with many species of mysticete, to be context-dependent (Robertson *et al*. 2013). Migrating bowhead whales appear to be distinctly more sensitive than those involved in feeding activities (Koski & Johnson, 1987, Richardson *et al.* 1999, Lyons *et al*. 2009, Christie *et al*. 2010, Blackwell *et al.* 2013) having been documented to display avoidance behaviour at distances of 30-50 km from a seismic array (Koski & Johnson 1987, Richardson *et al*. 1999) and large vessels (McDonald *et al*. 2012, Blackwell *et al*. 2013). Bowhead whales engaged in feeding activities however, do not demonstrate avoidance unless the received levels exceed 160 dB re 1 µPa (Richardson *et al.* 1986, 1999, Southall *et al.* 2007) at approximately 6 km from the seismic source, although other behavioural changes, such as fewer blows (breaths) per surfacing, occur before this threshold.

Further anecdotal evidence from Gordon *et al.* (2003) recorded overt avoidance behaviour at ranges of 6-8 km, swimming away from the vessels and airgun source. Richardson *et al*. (1987) also noted, from a four year study in the Beaufort Sea, that progressively increasing industrial activities affected bowhead distribution, with considerably fewer bowhead whales seen in an area as drilling and industrial activities increased in the 1980s. Some bowhead whales have been documented avoiding approaching diesel-powered vessels at distances of greater than 4 km (Richardson *et al*. 1985, Koski & Johnson 1987); individuals can be displaced by as much as several kilometres. Fleeing behaviour has been elicited at low noise levels; the received level of a small diesel-powered vessel near fleeing bowheads was only ~84 dB re 1 µPa in the dominant ⅓-octave band at a distance of 4 km (Koski & Johnson 1987). Some bowhead whales have exhibited stronger avoidance reactions in response to low but increasing noise levels from an approaching vessel than louder broadband noise levels (Wartzok *et al*. 1989). Individuals actively engaged in social interactions or mating may be less responsive to the movements of boats.

8. How far could the sound travel with an intensity that could affect whales' behaviour and particularly narwhals?

Summary

- This section covers the behavioural reactions to seismic testing, such as swim speed / diving pattern changes, changes in vocalisation and masking.
- Changes in behaviour are inherently difficult to evaluate and even more difficult to mitigate. They range from very strong reactions, such as panic or flight, to more moderate reactions where the animal may orient itself towards the sound or move slowly away.
- There are generally fewer data available for odontocetes (toothed whales) than mysticetes (baleen whales) although this likely relates to difficulties in studying these species (e.g. less predictable habitat use and lower observer-availability at the surface in relation to baleen whales) rather than a lack of behavioural effects.
- No research has been conducted specifically on the behavioural impacts of seismic noise on narwhals. Narwhals most often react to disturbance /loud noise such as icebreakers, with an anti-predator response, huddling together, ceasing vocalisations and slowly sinking at distances of ~50 km from the noise source.
- Bowhead whales' behavioural reactions to seismic are well documented; they initiate avoidance reactions, reduce their vocal activity, reduce their time on the surface and demonstrate subtle changes in locomotion and respiration in response to seismic airgun sounds. However the scale of the reactions is context-dependent.

8.1 General species information

Several Arctic species have demonstrated sensitivity to noise and more specifically, to seismic activities. Due to the close proximity to the source required to cause physical injury from sound (see Section 6), the possible significant impacts at a population level to animals from seismic noise may more often result from behavioural reactions (Boertmann *et al*. 2010). Unfortunately, changes in behaviour are inherently difficult to evaluate and linking cause and effect is challenging. Altered behaviour ranges from very strong reactions such as panic or flight, to more moderate reactions where the animal may orientate itself towards the sound or move slowly away, change diving or breathing behaviour or cease vocalising.

Behavioural responses in response to seismic surveys, although varied and often subtle, are of concern due to the possible resulting effect of higher energetic demands, reduced group cohesion, higher predation and decreased reproduction (Weilgart 2007). These effects could arguably seriously impact the whole population and as such, noise is considered to contribute to the decline or lack of recovery in some species (IWC 2007, Weilgart 2007).

As baleen whale species exhibit stereotypical migratory behaviour and high site fidelity, more information is available on the effects of seismic surveys on these species. Several species of baleen whale have demonstrated tendencies to change respiration rates (blue whales, Bowles *et al*. 1994, grey whales, Malme *et al*. 1988, Würsig *et al.* 1999) and alter orientation away from the airguns (blue whales, Bowles *et al*. 1994) while seismic surveys were occurring. Many studies have shown grey whales exhibit behavioural reactions and avoidance to seismic airgun sounds (e.g. Malme *et al*. 1988), with a study by Ljungblad *et al*. (1988) recording normal feeding behaviour and a nursing mother and calf 42 km from the seismic vessel. Grey whales exposed to seismic noise levels of about 153 dB re 1 µPa zero-to-peak and 159 dB peak-to-peak on their feeding grounds also swam faster and straighter over a larger area with faster respiration rates during seismic operations (IWC 2007).

A behavioural response that is often documented in mysticetes is a change in vocal activity. Fin whales have been found to cease calling (Clark & Gagnon 2006) when in the presence of multiple seismic surveys operating concurrently; however songs would resume within a few hours after seismic activity stopped. This finding was supported by Castellote *et al*. (2012) which provided evidence that male fin whales from two different subpopulations modify song characteristics when subjected to increased background noise conditions. In fact, in areas where several seismic surveys were recorded simultaneously, fin whale sounds were masked entirely by the high-level of airgun noise (Nieukirk *et al*. 2012). Around 250 male fin whales appeared to stop singing for several weeks during a seismic survey, resuming singing within hours or days after the survey ended (IWC 2007b).

Other mysticete species have also exhibited changes in vocal behaviour in response to seismic surveys. Acoustic recorders deployed for nine months off Angola documented a significant reduction in the number of singing humpback whales with increasing received level of seismic survey pulses (Cerchio *et al*. 2010). Off the east coast of the US, humpback whale song was reduced, concurrent with transmissions of low-frequency pulses approximately 200 km away (Risch *et al*. 2012). McDonald *et al*. (1995) noted that a blue whale stopped calling in the presence of a seismic survey 10 km away. Blue whales in the St. Lawrence Estuary modified vocalisations in response to a seismic survey using a low-to-medium power sparker (Di Iorio & Clark 2010).

Behavioural changes by odontocetes (toothed whales) in response to seismic surveys are less well documented. Pilot whales have been observed altering orientation away from airguns (Stone & Tasker 2006) while seismic surveys were occurring. Tyack (2009) noted distinct changes and cessation in foraging activity in sperm whales, reduced buzz rates and significantly reduced swimming speeds, with foraging activity reduced by 20-60% during airgun activity (Jochens *et al.* 2008). Tagged sperm whales in the Gulf of Mexico did not appear to avoid a seismic airgun survey, though they significantly reduced their swimming effort during noise exposure along with a tendency toward reduced foraging (Miller *et al*. 2009). Whales significantly reduced their fluke stroke effort by 6% during exposure to seismic noise compared with after. Moreover, there were indications that prey capture attempts were 19% lower during airgun noise exposure; even small reductions in foraging rate could result in lower reproductive rates and have negative consequences for the population. This study highlights how reactions to airguns can be quite subtle and hard to detect, particularly for deep-diving species that may be unavailable to surface observation for the majority of their lives.

8.2 Arctic species

Arctic species are known to be particularly sensitive to noise (Lawson 2005, Wisniewska *et al*. 2014), displaying avoidance behaviour to man-made noise sources including seismic and icebreakers (see Section 7 for more details). Other behavioural reactions by Arctic species to noise sources noted include changes in swimming speed, variation or cessation of vocalisations and cessation in feeding, all of which are covered in more detail below.

8.2.1 Narwhals

As noted previously, narwhals have been documented to show extreme reactions to the noise from icebreakers. They have been documented displaying an anti-predator response to the noise from ice-breakers; huddling together, staying motionless at the surface while remaining in physical contact with each other, ceasing vocalisations and changing their diving behaviour to sink slowly below the surface (Finley *et al*. 1990, Cosens & Dueck 1988, 1993). These responses have been recorded at received levels as low as 94-105 dB re 1 µPa rms in the 20-1000 Hz frequency band (Finley *et al*. 1990) and at distances of 55-40 km from the noise source (Finley *et al*. 1990; Miller & Davis 1984; Cosens & Dueck 1988, 1993). This anti-predator response, which has been noted in the presence of killer whales (Laidre *et al*. 2006b), may be observed more often than a fleeing response in narwhals as this species is not considered fast swimming (Heide-Jørgensen *et al*. 2013). Observations of narwhals tagged with satellite-linked time-depth recorders showed that horizontal speeds averaged 1.4 m s^{-1} (range = 0.81–2.36 m s^{-1}) and vertical speeds were within approximately 10% of this range (Dietz & Heide-Jørgensen 1995), values which are among the slowest reported for any marine mammal (Williams 2009). This responsiveness at such great distances is exceptional in the literature on marine mammal disturbance (see Richardson *et al*. 1995). The responsiveness of narwhals is confirmed by the paucity of sightings obtained from vessels passing through areas known to have high densities of narwhals from hunting returns and aerial surveys (Heide-Jørgensen *et al*. 2010a; Heide-Jørgensen *et al*. 2013). Observers on active seismic survey vessels rarely, if ever, encounter narwhals, even when surveying areas where narwhals are known to occur (Lang & Mactavish 2011). It is unknown whether this observation is due to the animals disappearing before the survey vessels are within the observers' range of visual detection (Heide-Jørgensen *et al*. 2013) or if the the animals are submerged below the surface as a result of their 'anti-predator' response.

These responses to low level continuous noise sources demonstrate how sensitive narwhals presumably are also to impulsive seismic noise, as noise from 2D and 3D seismic surveys has been documented at much higher noise levels than those that have been reported to cause impact above. The notable lack of a flight response may lead to narwhals receiving a much larger 'noise dose' than other species that may actively move away from the noise source.

8.2.2 Belugas

Although avoidance responses to seismic noise sources have been well documented in beluga whales (see Chapter 7) other behavioural reactions have received little research effort. Exposure to sound pressure levels between 130 and 150 dB re 1µPa from airgun array pulses have been documented inducing behavioural reactions in wild beluga whales (Miller *et al*. 2005, Southall *et al*. 2007). However, not all individuals showed a reaction with no apparent changes in behaviour from some animals, at received levels of well above 150 dB re 1µPa (Miller *et al*. 2005).

More research has been conducted on the behavioural changes of beluga in response to other noise sources, most notably to ship traffic, especially icebreakers. Finley *et al*. (1990) showed that belugas react strongly to icebreaker noise (measured by Erbe & Farmer 2000 to have median amplitude of 197 dB re 1 µPa between 100 Hz and 22 kHz) by changing dive patterns, grouping into large pods and performing long dives close to or beneath the ice edges. Cosens and Dueck (1988) observed changes in beluga swimming behaviour at distances of 40–60 km from an icebreaker in Lancaster Sound in the Canadian High Arctic, concluding that these animals avoid an icebreaker as soon as they detect them. Beluga vocal behaviour has also been recorded changing notably in reaction to icebreaker presence, with belugas making a large proportion of falling tonal and noisy pulsive calls, apparent alarm calls, at ranges of 80 km to the icebreakers or large vessels (Finley *et al*. 1990). Furthermore Lesage *et al.* (1999) observed beluga whales reducing their calling rates when vessels were approaching and shifting the frequency band of their calls while Scheifele *et al*. (2005) noted increased call source levels when vessels are in close proximity. The upward shift in frequencies, repetition of calls, and emission of strong and acoustically simple calls appear to be strategies to increase signal detectability (Lesage *et al.* 1999). Beluga reactions begin when broadband (20-1000 Hz) received levels of ship noise are ~94-105 dB re 1µPa, near the levels at which belugas might barely hear the higher frequency components of ship noise (Richardson & Würsig 1997). High traffic levels in the Saguenay – St. Lawrence Marine Park are likely to mask beluga whale calls; assuming no behavioural or auditory compensation, half of the time, beluga potential communication range was reduced to less than 30% of its expected value under natural noise conditions, and to less than 15% for one quarter of the time, with little dependence on call frequency (Gervaise *et al*. 2012). The echolocation band for this population of belugas was also affected by shipping noise. These changes, and the reduction in calling rate to near silence, are likely to reduce communication efficiency also.

8.2.3 Bowhead whales

Bowhead whales' behavioural reactions to seismic noise are well documented; they initiate avoidance reactions (Richardson *et al*. 1986, 1995, 1999; Koski *et al.* 1987; Miller *et al*. 2005 – see Chapter 7), reduce their vocal activity (Blackwell *et al*. 2013), reduce their time at the surface (Robertson *et al*. 2013) and demonstrate subtle changes in locomotion and respiration (Richardson *et al*. 1986) in response to seismic airgun sounds. However a recent study by Robertson *et al.* (2013) concluded that although dive durations were affected by the presence of seismic operations, the scale of the reactions are context-dependent i.e. the level of the effects depended on other variables such as season and whale activity. Migrating bowhead whales appear to be distinctly more sensitive than those involved in feeding activities (Koski *et al.* 1987, Richardson *et al*. 1999, Lyons *et al*. 2009, Christie *et al*. 2010, Blackwell *et al*. 2013). Migrating animals are more prone to disturbance, with an onset of significant responses around received levels of 120 dB re 1 µPa (rms over pulse duration), whereas avoidance is not generally observed in feeding bowheads unless the received levels exceed 160 dB re 1 µPa (Richardson *et al*. 1986, 1999, Southall *et al*. 2007).

Feeding bowhead whales did not cease feeding and exhibit avoidance beyond 6 km from the airgun source (Richardson *et al*. 1986) and only demonstrated avoidance when received levels exceeded 160 dB re 1 µPa (Richardson *et al*. 1986, Miller *et al*. 2005). Richardson *et al.* (1986) did however observe subtle behavioural responses in feeding bowhead whales at ranges of six to 99 km from the airgun source, such as shorter surfacing times and fewer blows per surfacing. Subtle changes in surfacing and diving behaviour were also detected over distances as great as 70 km by Richardson and Malme (1993).

Bowhead whale calls are frequently detected in the presence of seismic pulses, although the number of calls detected may sometimes be reduced (Richardson *et al*. 1986). Blackwell *et al*. (2013) found a significant drop in call localisation rates (CLR, localised bowhead calls) when exposed to median received seismic noise levels of at least 116 dB re 1 µPa (total airgun source of 3,147 in^3). The migrating whales observed by Blackwell *et al.* (2013) demonstrated CLRs which dropped from an average of 10.2 calls/h before the onset of seismic operations to 1.5 calls/h during and after airgun use. This effect was evident for whales that were closest to the seismic source (median distance 41–

45 km), whereas for whales further away (median distance of 104–130 km) experiencing median received levels of less than ca. 108 dB re 1 µPa, there did not appear to be any link between call localisation rates and airgun use.

Additional behavioural responses to seismic sources have been noted by Reeves *et al.* (1983) who observed huddling, whereas Fraker *et al.* (1982) observed the opposite, with the inter-individual distance increasing during seismic activity. These conflicting studies highlight the need for more research on this species to accurately understand the impact of seismic noise, or whether in fact, after an initial startle response, animals may habituate to these sounds (as suggested by Fraker *et al*, 1982).

Wisniewska *et al*. (2014) note that the bowhead whale population in Baffin Bay is particularly vulnerable to the effects of hydrocarbon exploration due to its near-threatened status, the fact that Baffin Bay is a habitat critical to their fitness and that they are sensitive to airgun noise. With that in mind, due to the recent finding that the impact of seismic noise on bowhead whales is context dependent, estimates of abundance and distribution of bowhead whales near seismic surveys used in impact assessments should be context-sensitive and incorporate correction factors that account for sound exposure, season, reproductive status and whale activity (Robertson *et al*. 2013).

8.3 Masking of vocalisations

Clark *et al*. (2009) define masking of communication as a measured loss of communication space as a result of other sound(s), either natural or anthropogenic, relative to that space under quiet ambient conditions. In spite of the short duration of impulses produced by airguns (which was previously thought not to mask biologically significant sounds), the high intensity, broadband frequency range and rate of repetition of airgun pulses have now been shown to cause masking of whale calls. Masking of communication of signals and other sounds could be a highly detrimental impact of seismic noise for some species. Noise can mask communication signals that play a critical role in social cohesion, group activities, mating, warning, or individual identification as well as interfering with environmental sounds and cues (Erbe & Farmer 2000). Masking will be 'biologically significant' if the animals' biological fitness is reduced by a decreased rate of reproduction (Erbe & Farmer 2000). The extent to which masking can affect biological fitness is not yet understood, and is very difficult to address experimentally or quantify (Wisniewska *et al*. 2014). When considering masking by seismic sources, the focus is at lower frequencies below 5 kHz, as this is where the main energy of the pulses is concentrated; however this is also the part of the spectrum that propagates the furthest. Bowhead whales, narwhals and belugas all communicate and vocalise in this frequency range. One way to look at masking is to calculate the range reduction factor, i.e. the reduction in hearing range caused by an increase in background noise level (Møhl 1981).

Nieukirk *et al.* (2004) found seismic noise to be a major contributor to the low-frequency sound field in the North Atlantic when listening for blue (18 Hz), fin (22 Hz), minke (30 Hz), and general baleen whale vocalisations. Recordings from the deep sound channel of the Mid-Atlantic ridge (Nieukirk *et al*. 2012) included low-frequency seismic activity as well as the 20 Hz pulse sounds from fin whales. These basin-wide recordings picked up the sound of airguns from thousands of kilometres away. Although airgun noise fluctuated over time, it was present for more than 80% of days per month for more than 12 consecutive months in some locations, and during 2003 and 2005, the sound of airguns routinely featured in recordings for over 95% of days per month at some sites. The potential for acoustic masking was further recognised when multiple sources of airguns were recorded simultaneously, resulting in high levels of noise that usually obscured any biological sounds in the acoustic data.

Clark and Gagnon (2006) showed that fin whales stopped singing when an average of three, but up to five, seismic survey vessels operated simultaneously. Castellote *et al*. (2012) noted that although during the first 72 h of a seismic survey fin whales continued to sing, a steady decrease in song received levels and bearings to singers indicated that whales moved away from the airgun array source and out of our detection area, and this displacement persisted for a time period well beyond the 10-day duration of seismic airgun activity. The energetic costs of continuing to sing in high noise areas may be significant. Modifying calls to maintain the signal-to-noise ratio could come at a cost to the singer, and it is not known if the communication range is maintained accordingly, so there could still be population-level effects.

In captivity, masking has been demonstrated with increasing severity for icebreaker noise, propeller cavitation and bubbler system noise (Erbe & Farmer 1998). As these sound sources were normalised to provide equal sound exposure levels, it seems likely the bubbler system noise masked beluga vocalisations most effectively as it was most uniformly continuous in terms of frequency and time.

There are several ways for animals to compensate for masking noise. Northern right whales have been found to increase the amplitude of their calls in higher noise conditions (Parks *et al*. 2010), known as the Lombard effect, and show an increase in call frequency as a response to increases in low frequency noise levels (Parks *et al*. 2007). In a study of the echolocation ability of belugas in environments with differing background noise levels, Au *et al*. (1985) observed that the whales shifted their click series toward frequencies with less ambient noise when in the noisiest environment. Changes in vocal parameters could potentially result in increased energy expenditure (Parks *et al*. 2010) which could cause health impacts if experienced for prolonged periods, but the extent of this is unknown.

In a study examining the cumulative effects of four seismic surveys occurring simultaneously in Greenlandic waters of Baffin Bay in 2012, received levels showed a roughly 15 dB increase in M-weighted SEL compared to pre-seismic months. Thus, narwhals residing in the vicinity of the recordings would have, on average, experienced an 86% reduction in hearing range at lower frequencies (Wisniewska *et al*. 2014). During the entire time of their recordings throughout the possible summer seismic season, there were only two breaks of more than ten hours with no airgun activity. Furthermore, the data showed that multiple reflected airgun signals arrived at a given receiver with short time delays, causing long (typically on the order of 4 seconds) effective pulse lengths, and that one pulse would not fade to background noise levels before the arrival of the next seismic signal. Both these findings meant that marine mammals would have had very little time to receive and emit communication signals during seismic season in 2012 (Wisniewska *et al*. 2014). Additionally, Wisniewska *et al*. (2014) noted that pulses originating from several seismic vessels frequently arrived at comparable received levels and overlapped in time. With multiple simultaneous seismic surveys, the time available for 'normal' communication was, thus, reduced even further. Seismic surveying such as this leaves little time for species to vocalise be it for communication, to find food or locate in their surroundings. It is essential, therefore, that future considerations and licensing of seismic survey activity take into account the cumulative impact of seismic surveys within the region.

8.4 Conclusion

If animals experience a temporary habitat loss through displacement during seismic surveys, or important behaviours (such as foraging, mating or nursing of calves) are interrupted at critical times, these effects will impact affected individuals as well as potentially propagating through generations, and contribute to a less favourable conservation status via a loss of population fitness (Wisniewska *et al*. 2014). With such a variety of behavioural responses logged during a huge range of noise levels, it is difficult to assess a general distance from a seismic source, at which the onset of behavioural responses will be noted. One EIA calculated the onset of behavioural impacts in beluga, bowhead and narwhal would occur at 140 dB re 1µPa or 6 km from the seismic source (it should be noted this survey was using the smallest 140 in^3 airguns) (Rambol 2013). Several authors have hypothesised that animals may become habituated to the sounds of seismic surveys after some time and therefore show less extreme reactions (Andersen *et al.* 2012, Finley *et al*. 1990, Richardson *et al*. 1987); however recent examples of significant behavioural impacts in cetaceans as a result of disturbance from icebreakers, ship noise and seismic airguns are still being reported.

9. How far could the sound travel with an intensity that could affect/harm whale calves/young whales?

Summary

- Information detailing the impact of seismic noise specifically on young whales is extremely sparse; there is limited information for humpback, grey and sperm whales.
- Studies off Australia of humpback whale groups with cows present (it is unknown if the cows were pregnant) were found to be more sensitive to seismic noise, although in key breeding and nursing habitat, humpback whales have also shown no specific avoidance while airguns are firing.
- There was no difference in sighting rates observed for grey and sperm whales calves and juveniles when airguns were firing although at least for one of these studies, the observations were being collected at great distances 42 km away from the seismic source.
- Considering how limited the information is on the impacts of seismic on young whales, it is almost impossible to establish if and what impacts noise might have on them. This is an area which urgently needs more research attention, as young whales of all species are being influenced by seismic noise sources around the world on a daily basis.

9.1 Recorded impact of seismic activity on whale calves

There are numerous examples, both anecdotal and published, of alloparental care (baby-sitting by related animals) of cetacean young. In odontocetes (toothed whales), extended periods of maternal care are usual, as the young whales learn from their parents and social group the skills needed to survive and integrate into society. Relatively long periods of immaturity and calf vulnerability explains the benefit of stable patterns of group living, compared to mysticete whales. Familial bonds are known to be strong and cetacean calves are often fed by their mothers for extended periods (up to 2 years – possibly longer); there are even examples noted of orphan calves being fed and nurtured by relatives (as with other higher order mammals, such as elephants). It is well documented in a range of cetacean species that mothers utilise safe, undisturbed habitat areas as nursery grounds to give birth and nurture their young in the first months following their birth. This may be the case with narwhals in terms of the areas they traditionally utilise as summer habitat – these areas may provide specific requirements necessary as nursery areas (it has been noted elsewhere that narwhal winter habitat in deep water with dense pack ice is primarily driven by feeding requirements).

There is extremely limited information on the impact of seismic noise on young cetaceans, in the Artic and more generally. Acoustic-induced stress could have serious consequences on the fitness of exposed individuals, and although presently unquantified in free ranging wild marine cetaceans, some studies on terrestrial animals suggest that exposure to stress in pregnant females can permanently affect the health of offspring (Clark *et al*. 1994).

Extensive experiments conducted by McCauley *et al*. (2000) in Australia showed that resting humpback groups containing cows were more sensitive to airgun sounds than groups that were migrating. Controlled exposure experiments using a single 20 in^3 operating gun resulted in consistent avoidance by groups of resting humpback whales that contained cows. Resting cow groups consistently showed avoidance to airgun exposures in the 140 to 150 dB re 1 μPa rms range (at a range of 1.3 km), whereas one individual, suspected to be a male, continued approaching the airgun until within ca. 100 m when the received level was 179 dB re 1 µPa rms. General behavioural avoidance for most humpback whales subjected to the single airgun trial occurred at around 168 dB re 1 µPa peak-to-peak, equivalent to the full array at about 3 km. The authors scaled results from single airgun approach trials, to levels equivalent to 2,678 in^3 3D seismic array operations, and extrapolated a potential avoidance range of 7 to 12 km for groups that contain cows. The authors acknowledge that this degree of sensitivity is likely dependent on key habitat type, which will determine the behavioural activity of the animals in question e.g. foraging, socialising, resting, or mating. Conversely, Weir (2008) conducted visual monitoring of humpbacks from 3D seismic survey vessels off northern Angola, an area known to be important for breeding, migration, and nursing young. No significant difference in sighting rates were found in relation to airgun operational status (full-array operational, partial, guns off), and there was no evidence of prolonged or large-scale displacement from the region during the 10-month survey.

No significant difference in sightings of sperm whale calves, juveniles or adult females according to airgun status when firing a total volume of either 5,085 in^3 or 3,147 in^3 was noted by Weir (2008). Although the mean distance of sperm whale sightings from source vessel was greater during full-array operations, this difference was not significant. However, Ljungblad *et al*. (1987) noted that grey whales exhibited "normal" behaviour during exposure to seismic airgun sounds, including a mother-calf pair and bottom feeding by other animals. These data were collected at a range of 42 km from the seismic vessel and at this distance; received levels of seismic sounds would have been significantly less. In relation to other noise sources, Ljungblad *et al*. (1983) noted cow-calf pairs in the northern Chukchi Sea seemed particularly sensitive to a turboprop aircraft at 305 m altitude; calves swam beneath adults and were subsequently hard to see.

Considering how limited the information is on the impacts of seismic noise on young whales, it is almost impossible to establish if and what affects noise might have on them; however it would be reasonable to postulate that given the extreme sensitivity of narwhals to disturbance, the effect on their young is likely to be similarly severe. This is an area which urgently needs more research attention, as seismic noise sources are a major contributor to sound pollution in many areas around the world.

A further effect which requires more attention is the masking of contact calls between mothers and their offspring. If avoidance or displacement occurs due to disturbance from seismic sources (see Section 8) resulting in mothers and their calves becoming separated, with compromised ability to use contact calls, reconnection of these animals will be more challenging. However, research has not been undertaken to investigate these impacts.

10. Could seismic noise harm fish or fish larvae, the narwhal's prey?

Summary

- The primary prey of narwhals is the Greenland halibut.
- Greenland halibut are deep-water, semi-pelagic flatfish that inhabit water at depths of ~400–2,000 m. A significant commercial fishery exists for Greenland halibut in Baffin Bay, so any changes which impact narwhal prey will also be of concern in relation to the effects on this fishery.
- Loud noise may have an impact on the development, physiology and survival of invertebrates, larvae and fish eggs
- Although fish eggs and larval (early life stages) can suffer mortality from seismic airgun noise at close distances (within 5 m), the high level of natural mortality (5-15% per day) versus the small percentage of their population to be impacted (0.45%), make the impact of a seismic survey difficult to differentiate from natural mortality.
- The observed impacts of seismic airgun noise on adult fish have been varied in terms of the effects noted, the species which displayed impacts and the size of airguns and source levels of the noise which created observed effects. Therefore generalisations should be interpreted with caution.
- Although seismic airgun noise has been found to be fatal or cause injury to adult fish very close to seismic arrays, it is not this direct mortality or injury from seismic airguns which cause the most worrying impact on fish.
- The aspect of greatest concern for narwhal prey is the behavioural changes that can result, with seismic airgun noise causing certain species of fish to migrate horizontally or vertically within the water column. Decreases in fish catches of up to 50% have been noted for some species. However, for Greenland halibut gillnet fisheries, increases in catch have been reported, most probably due to the increased number of animals moving within the water column due to disturbance by the seismic airgun noise. Following on from this, it is possible narwhal may enjoy a short term increase in their own catch of Greenland halibut; however, in the long term over years or decades of seismic activity in Baffin Bay, increased commercial catches will result in population level impacts for the Greenland halibut, and in turn, the narwhal.

10.1 Background:

10.1.1 Narwhal diet

Narwhal prey selection and foraging intensity have a strong seasonal component (Finley & Gibb 1982, Laidre 2003). In spring, narwhals take Arctic or polar cod at the sea ice edge. In summer, food consumption is at a minimum, as evidenced by hundreds of empty stomachs in diet studies (Mansfield *et al.* 1975, Finley & Gibb 1982, Heide-Jørgensen *et al.* 1994, Laidre 2003b). Feeding resumes in the autumn months as whales move south (Finley & Gibb 1982) and feeding peaks during the winter (Laidre *et al.* 2004). The narwhal's primary prey are fish species such as the Greenland halibut (*Reinharditius hippoglossoides*), capelin (*Mallotus villosus)*, Arctic cod (*Arctogadus glacialis*) and polar cod (*Boreogadus saida*), as well as boreoatlantic armhook squid (*Gonatus fabricii*) and shrimp (*Pandalus borealis*) (Finley & Gibb 1982, Heide-Jørgensen *et al.* 1994, Laidre & Heide-Jørgensen 2005), with the Greenland halibut being their main prey source (Laidre & Heide-Jørgensen

2005, Boertmann & Mosbech 2011, Watt & Ferguson 2014). There appear to be differences in foraging behaviour between various narwhal population wintering grounds with different bathymetries (Laidre *et al.* 2003). Narwhals from Melville Bay, West Greenland, and Eclipse Sound, Canada, share a wintering ground in southern Baffin Bay (Laidre *et al.* 2004). They make significantly more deep dives and spend significantly more time at depths ~800 m than the sub-population of narwhals from Somerset Island, Canada, which occupy a separate and distinct wintering ground farther north (Heide-Jørgensen *et al.* 2003). These differences in diving behaviour have been proposed to indicate differences in local prey availability or foraging choice related to geographic separation of subpopulations (Laidre *et al.* 2003). Diet in male and female narwhals appear to be similar (Watt & Ferguson 2014).

10.1.2 Greenland halibut:

Greenland halibut is a circumpolar, deep-water, semi-pelagic flatfish that inhabits depths of ~400–2,000 m 2007), spending most of its life on the bottom, but migrating into the water column to feed (Boertmann & Mosbech 2011). It is widely distributed in the northwest Atlantic and is found from Davis Strait northward into Baffin Bay. The reproductive biology of Greenland halibut is poorly understood. Larvae in the Davis Strait are carried north by currents and settle on the slopes of offshore Baffin Bay or in coastal deep water fjords of West Greenland (Riget & Boje 1989, Jørgensen 1997). Greenland halibut in Davis Strait and Baffin Bay most likely constitute a single stock and annual stock assessment surveys conducted in 1999 and 2001 estimate the biomass to be about 300,000 tonnes (Treble *et al.* 2000, 2001, Treble & Jørgensen 2002, Jørgensen 2002). The species is the basis of one of the most important fisheries in Greenland (Figure 10.1), operating year-round in coastal fjords with annual catches around 20,000 tonnes (Riget & Boje 1989, Jørgensen 1997). In the 1990s, an offshore fishery developed in Davis Strait with total catches around 10,000 tonnes annually (equal amounts taken in Canadian and Greenland waters). Within the past decade, exploitable offshore resources of Greenland halibut were discovered to the north in the deeper, central Baffin Bay (Boje & Hareide 1993, Treble *et al.* 2000, Treble & Jørgensen 2002). Exploratory fishery licences were issued at depths between 800 m and 1200 m with total allowable catch (TAC) of approximately 13,000 tons (from 2007-2012; Siegstad 2012).

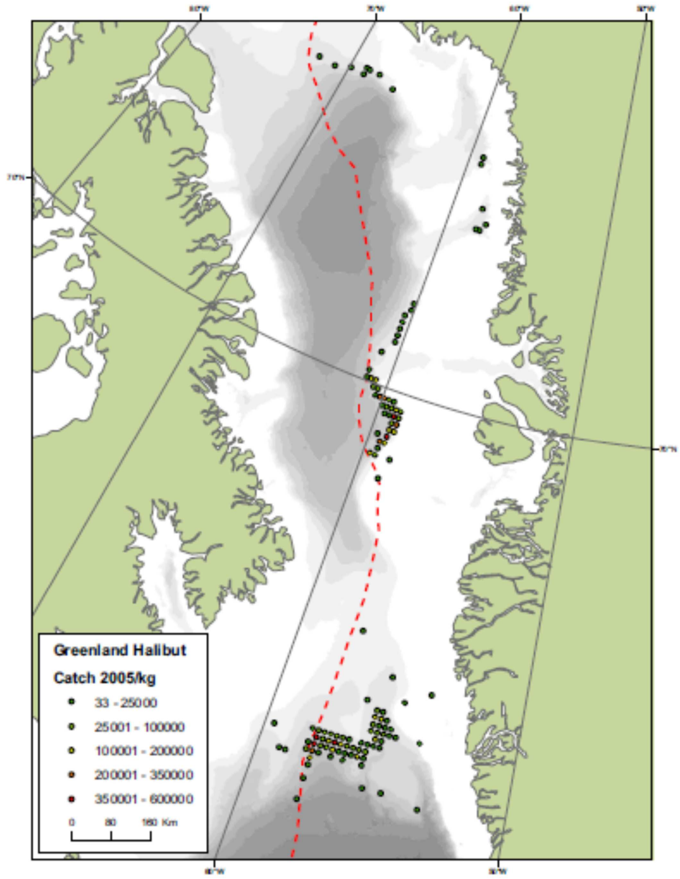

Figure 10.1: The trawling grounds for Greenland halibut, in West Greenland. Hatched red line indicates the border of the Greenland EEZ. Data are from 2005 and provided by the Greenland Institute of Natural Resources. Map from Boertmann *et al.* 2010.

10.1.3 Background on fish hearing

There is a reasonable amount of information on the impacts of seismic and other vibrational noise on fish species. However, as with cetaceans, there is little information available on the hearing abilities of many species. Atlantic cod and Atlantic herring which have received much research effort thus tend to be used as proxy species for all fish species during impact assessments.

Low frequency hearing in fish, below 100 Hz, occurs simply through particle motion (Kalmijn 1989). However at higher frequencies, the presence of air filled sacs, called swim bladders, vibrate from the sound pressure which in turn supply an increase of particle motion to the inner ear. For fish species which have swim bladders, this vibration becomes the dominant stimulus and therefore these fish have increased hearing sensitivities at high frequencies (Fay & Popper 1974). Atlantic cod have swim bladders; however they lack the coupling between the swim bladder and the inner ear (Sand & Hawkins 1983), hearing to top frequencies of around 400 Hz (Berkle 1967). In contrast Atlantic herring swim bladders extend into the inner ear (Blaxter *et al.* 1981) and therefore Atlantic herring can hear into much higher frequencies (4,000 - 13,000 Hz; Enger 1967). The swim bladder makes herring much more sensitive to sound than cod (Olsen 1969). There is no audiogram for Greenland halibut, so we do not know exactly how they hear, however as they do not have swim bladders, it is assumed that they would have less sensitive hearing.

10.2 Noise impacts on fish larvae

The physiological effects of loud noise will mainly impact younger life stages of fish such as eggs, larvae and fry (Kostyuchenko 1973, Dalen & Knutsen, 1987, Booman *et al.* 1992, Kosheleva 1992, Popper *et al.* 2005). At these stages in fish development, the organisms have limited ability to escape in the event of any threat (Dalen 2007). Responses of fish eggs and larvae to seismic airgun sources have varied, from no impact at distances of 1 metre from a seismic source (received levels 222 dB re 1 μPa; Dalen & Knutsen 1986) to lethal and sub lethal damage limited to within 5 metres of the source for a variety of fish species (Kostyuchenko 1973, Booman *et al.* 1996). Overall, Sætre & Ona (1996) determined that seismic noise has a negligible population effect on fish larvae. They estimated the total population mortality of fish larvae at just 0.45% from a typical 3D seismic survey on a typical larval population in the North Sea. As the natural mortality for eggs and larvae is estimates at 5-15% per day, the impact of the seismic survey would be impossible to differentiate from natural mortality (Sætre & Ona 1996).

10.3 Noise impacts on fish

Adult fish would be expected to swim away and avoid a seismic noise source as it approaches, with fish avoidance behaviour 'protecting' the fish from more serious physical damage (Boertmann *et al.* 2010). Behavioural responses have been noted; fish demonstrated an 'alarm' response when 2-5 km from a seismic source by swimming faster, moving to the bottom of the tank and / or tightening school structure or all three; while at the same distance squid also showed significantly altered behaviour (McCauley *et al.* 2000). In experiments where adult finfish were not able to avoid the approaching array, physical damage to their hearing, and even death (Thomson *et al.* 2001) has been observed. The range or size of the source to cause damage has received a fair amount of research but is conflicting; Falk and Lawrence (1973; cited in Davis *et al.* 1998) found the lethal range of airguns (300 in^3, 2000 -2200 psi) was 0.6-1.5 metres at a received level of 226-234 dB re 1 μPa for Arctic cisco, whereas Weinhold and Weaver (1982) found the majority of salmon smolt survived at a distance of 1 metre or 234 dB re 1 μPa from the airguns. However, the long term impacts of such exposure were not reported.

Physical damage (hearing damage or damage to swim-bladders) to fish is thought to occur at close range to the seismic array (Davis *et al.* 1998, Gausland 2000, McCauley *et al.* 2003), perhaps within 15 metres of the source (Gausland 2000, McCauley *et al.* 2003) (from a gun 222.6 dB re to 1 μPa peak-to-peak) or above 180 dB re 1 μPa, with the damage lasting at least two months (McCauley *et al.* 2003). McCauley *et al.* (2003) extrapolated this information and modelled that physical damage would occur at distances less than 500 m from a large seismic array. Furthermore, Enger (1981) and Hastings *et al.* (1996) found that exposure to continuous sounds of 180 dB re 1 μPa (rms) for one to five hours can cause damage to the sensory hair cells that are the fundamental sound receptors in fish. McCauley *et al.* (2000) found some damage to fish hearing organs after 10 exposures to much quieter seismic sounds at received energy levels of 132-182 dB re 1 μPa. Interestingly however, no physiological stress indicators were recorded from finfish species as a result of seismic noise (McCauley *et al.* 2000).

Although physical impacts occur at close range to seismic airguns, avoidance behaviour has been documented at larger distances, and avoidance effects can indirectly lead to fatal conditions via reduced ability to assimilate food, or a change in swimming capacity which makes them more vulnerable in relation to predatory fish (Dalen 2007). Additionally, negative effects on fish stocks may occur if adult fish are displaced from localised spawning grounds during spawning season (Boertmann *et al.* 2010). Studies have shown many fish and marine invertebrates will move away in either or both the horizontal and vertical planes to avoid a seismic source, with these distributional shifts appearing to be relatively short term (e.g. McCauley *et al.* 2000, Hassel *et al.* 2004, Slotte *et al*. 2004).

Changes in catch rates during seismic surveys have often been recorded thought to be due to increased horizontal or vertical movement. Malme *et al.* (1986), Pearson *et al.* (1987) and Skalski *et al.* (1992) examined how the sound energy from a single air gun affected the catches of redfish species by 52%, with the reduced catches explained by fish migrating deeper and staying close to seabed structures during seismic activity. Løkkeborg (1991) and Løkkeborg & Soldal (1993) analysed catch data from logs on line vessels and trawlers that had fished in areas where seismic surveys were carried out. The catch rates from the line vessels increased with increasing distance from the seismic area, with the catch on lines with seismic being 55-80% lower than those set 1-8 nautical miles from this area. In two fishing areas where shrimp trawlers fished during seismic surveys, the by-catch of cod was reduced by 79% and 83% respectively when the shooting started. The observed reductions in catch rates were explained by the fish moving away from the seismic areas. Seismic data acquisition was proven to reduce catch rates of gadoid fishes (haddock and cod) in trawl fisheries in the Barents Sea by about 50% (Engås *et al.* 1996). This occurred not only in the shooting area, but as far as 18 nautical miles away and was more pronounced for large fish compared to smaller fish. Engås *et al.* (1996) noted that the catch rates did not return to normal levels within five days after the seismic survey (when the experiment was terminated). During the Engås *et al.* (1996) study, an increased catch of Greenland halibut in gillnets fisheries was noted, a trend which has been observed elsewhere during seismic activity (Hirst & Rodhouse 2000, Løkkeborg *et al.* 2010 from Boertmann *et al.* 2010), and is most likely the result of more fish moving around in the water column in response to seismic noise (Boertmann *et al.* 2010), a factor which may cause knock-on impacts for increased mortality.

Studies on the impact of seismic survey noise on the catch of Greenland halibut have shown contradicting results. Gillnet catches of Greenland halibut and redfish (*Sebastes* sp.) increased during seismic shooting and remained higher in the period after shooting (Løkkeborg *et al.* 2010). However, in contrast, longline catches of Greenland halibut decreased. However this contradiction may be due to the variation in fishing methods, rather than the reaction of the fish. Another study in Norway using official catch rates during a series of seismic surveys also showed very varied 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, whereas catch rates of redfish and monkfisk (*Lophius piscatorius*) seemed to increase and catch rates of saithe and haddock caught in gillnets decreased. However it should be noted that the majority of the seismic surveys included in the analysis conducted by Vold *et al.* (2009), were 2D (with smaller airgun sizes and therefore lower noise levels) and dispersed in time and space; therefore major influences on the fisheries were not expected. Less notable than horizontal movement in relation to seismic noise, vertical migrations were noted by Slotte *et al*. (2004) in herring, whiting and blue whiting, moving to greater depths in an area where seismic was being shot.

Other behavioural impacts which have been noted when fish receive a strong sound stimulus, are alarm response or an escape reaction (Blaxter *et al.* 1981, Karlsen *et al.* 2004) classified by a typical so-called "C-start" response, as the body of the fish forms a "C" and the body points away from the sound source. Experiments have demonstrated that sound energy transmitted from airguns initiates this type of response on the part of cod (Wardle *et al.* 2001), redfish species (Pearson *et al.* 1987), and sandeel (Hassel *et al.* 2004). A rapid C start reaction was observed from European sea bass and sandeel in relation to air gun shooting at distances of up to 2.5 and 5.0 km respectively (Santulli *et al.* 1999, Hassel *et al.* 2004).

10.4 Conclusion

As the studies noted above indicate, behavioural and physiological reactions to seismic sounds vary between fish species and also according to the seismic equipment used, therefore generalisations should be interpreted with caution (Boertmann *et al.* 2010). Greenland halibut is very different from Atlantic cod and haddock with respect to anatomy, taxonomy and ecology (Boertmann *et al.* 2010). For example, Greenland halibut do not have a swim bladder and therefore their hearing abilities are reduced compared to fish with swim bladders. Moreover, the Greenland halibut fishery in Baffin Bay occurs in much deeper waters than in the Norwegian haddock and Atlantic cod fishery where experiments detailed above have demonstrated such extreme catch reductions (Engås *et al.* 1996). A Norwegian review (Dalen *et al*. 2008) concluded that the results from Engås *et al*. (1996) cannot be applied to other fish species or to fisheries taking place in other water depths. Boertmann *et al.* (2010) believe that seismic activity taking place in the Greenlandic waters of Baffin Bay will produce a risk of reduced catches in areas with intensive seismic activity, affecting only specific fisheries for a period of time. However, as the trawling grounds for Greenland halibut are spatially restricted by bathymetry, alternative fishing grounds may be limited (Boertmann *et al.* 2010) which may compound any impacts observed.

As there is no accepted level of noise which causes injury or behavioural changes in fish, it may be useful to examine the levels used by EIAs to indicate this. One EIA which was conducted in the Greenlandic waters of Baffin Bay (Ramboll 2013), used sound pressure levels (SEL) of 206 dB re dB re 1µPa^{2}s as the noise criteria that would cause PTS (physical damage) from a single pulse (from Halvorsen *et al.* 2011), 187 dB re 1µPa^{2}s SEL to cause TTS (from Halvorsen *et al.* 2011) and multiple pulses at 140 dB re 1µPa peak to cause a behavioural response in fish (from Thomsen *et al.* 2012). Using these criteria, for the 2D seismic survey concerned, fish would show behavioural reactions at distances up to ~60 km from the noise source (using 140 in^3 guns).

11. Could narwhals, or other whales, strand due to seismic testing?

Summary

- Stranding events involving cetaceans have been linked to anthropogenic noise in a range of species.
- Stranding events with causal links to seismic activity are rare, but have been previously suggested in humpback whales, minke whales, beaked whales.
- To date, there have not been strandings of Arctic cetacean species reported as being linked to anthropogenic noise sources, however this may be due to the remote and desolate nature of Arctic coastlines which means that it is possible for stranding events to go unnoticed.
- Indirect mortality caused by anthropogenic noise sources has been noted in humpback whales and harbour porpoises, where, in both species elevated levels of bycatch and entanglement have been reported during man-made noise events.
- Three unusual narwhal ice-entrapments which occurred between 2008 and 2010 were linked to seismic activity occurring during the narwhal autumn migration periods. It was thought that the disturbance from these seismic surveys in the north of Baffin Bay, delayed the autumn departure of narwhal on their migration from the summering grounds, resulting in many animals becoming entrapped in ice. These events occurred in areas where ice-entrapments of narwhal have never been reported before.
- Due to the indirect mortality previously noted in narwhal and other species as a result of disturbance by anthropogenic noise sources, it is imperative that seismic surveys do not occur in Baffin Bay during migration periods for narwhal. Exclusion of narwhal from their critical habitat (i.e. summering / wintering grounds), and disruption to their migrations, even without the increased risk of ice entrapment, could have knock on impacts for this species in Baffin Bay, which already exists there under extreme environmental constraints.

11.1 General background

A number of mass stranding events of cetaceans, mostly involving deep diving species such as beaked whales, have been linked to anthropogenic noise, primarily loud mid-frequency sonar (e.g. Frantzis 1998, Evans & England 2001, Jepson *et al.* 2003, Fernández *et al.* 2005, Cox *et al.* 2006, Brownell *et al.* 2009) but also seismic airgun arrays (Barlow & Gisiner 2006) and underwater explosions (Ketten *et al.* 1993, Ketten 1995). Although beaked whales are the family group most often documented to strand as a result of anthropogenic noise events, strandings of many other odontocete species have been linked to anthropogenic noise. In 2004, there was a near mass stranding of melon-headed whales in Kauai, Hawaii, related to operation of nearby mid-frequency sonar (Brownell *et al.* 2009) and in Madagascar in 2008 over 100 melon-headed whales stranded, most probably due to noise from a multi-beam echo sounder (Southall *et al.* 2013). Other mass stranding events involving spatial and temporal associations with naval activities in recent years have included 145 long-finned pilot whales which stranded and died in a series of three events in the Marion Bay region in the Southeast of Tasmania in 2005 (Department of the Environment & Heritage 2005) and a mixed-species mass stranding event involving 33 short-finned pilot whales, two dwarf sperm whales and one minke whale in North Carolina in 2005 (Hohn *et al.* 2006). A mass stranding of four Cuvier's beaked whales in Almeria, Spain in 2006 (US Navy 2007) and another nine beaked whale mass stranding events in the Mediterranean and Caribbean Seas (Filadelfo *et al.* 2009) were causally associated with naval sonars or other high-intensity acoustic naval activities. Increased numbers of stranded harbour porpoises were associated with naval sonars in Washington State, USA in 2003 (Norman *et al.* 2004) and increased numbers of stranded harbour porpoises (mainly bycaught) were spatio-temporally associated with an international naval exercise in Danish waters in 2005 (Wright *et al.* 2013). Mixed species mass strandings in Taiwan in 2005 were spatially and temporally linked to naval exercises; an increase in strandings was noted for a month long period including dwarf and pygmy sperm whales, striped dolphin, pan-tropical spotted, short finned pilot whale, Longman's beaked whale and Blainville's beaked whale. These were considered 'unusual' strandings compared to previous records; all were deep diving species and those fresh enough to necropsy were in good nutritional condition with recently ingested prey. Although the cause could not be conclusively determined, it is considered possible that multiple acoustic sources combined to produce the unusual pattern of strandings observed (Yang *et al.* 2008). In 2008, the UK's largest documented mass stranding event involved the death of at least 26 common dolphins; the most probable cause was deemed to be concurrent naval exercises including mid-frequency sonars (Jepson *et al.* 2013).

Marine mammals close to underwater detonations of high explosives can also be killed or severely injured, with the auditory organs being especially susceptible to injury (Ketten *et al.* 1993, Ketten 1995). For example, a mass mortality of four long-beaked common dolphins was caused by primary blast injuries (barotrauma) induced by naval activities (munitions disposal) in Southern California in 2011 (Danil & St. Leger 2011). A mass stranding of at least 39 long-finned pilot whales in Scotland in 2011 was correlated in space and time with munitions disposal in northern Scotland; acoustic disturbance from these underwater explosions alongside navigational error were hypothesised to be the most likely factors causing the mass stranding. It should be noted however that appropriate samples could not be taken in the critical time period following death and as the impact of acoustic trauma and hearing derangement could not be reliably assessed, the evidence for this was circumstantial rather than definitive (Brownlow *et al.* 2014).

The association between mass strandings of beaked whales and naval exercises and, in a few cases, a seismic survey (Malakoff 2002, Cox *et al.* 2006, Taylor *et al.* 2004), has raised the possibility that beaked whales exposed to strong "pulsed" sounds may be especially susceptible to injury and/or behavioural reactions that can lead to stranding (e.g. Hildebrand 2005, Southall *et al.* 2007). Hildebrand (2005) reviewed the association of cetacean strandings with high-intensity sound events and found that deep diving odontocetes, primarily beaked whales, were by far the predominant (95%) cetaceans associated with these events, with only 2% being mysticete whales (minke).

Todd *et al.* (1996) reported on humpback whales found fatally entangled in fishing gear at the same time and place as underwater explosions were occurring. Although humpback whales in the area displayed no avoidance or behavioural reactions to the explosions, an unusual pattern of fatal entanglement occurred, suggesting hearing damage or some other compromise to their navigation or sensory systems. Net entanglement rates both at the time and in the nearby area of blasting were dramatically and significantly higher, even though there were fewer fishing nets in the area. Additionally, re-entrapments of the same animals occurred, something that had not happened for the previous 15 years. It is important to note that, based on the whales' behaviour; one would have incorrectly concluded that the explosions did not impact the animals, were it not for the special case of higher and unusual entanglement rates or patterns (Weilgart 2007). Similarly, elevated levels of mortality occurring as a secondary impact to noise were recorded in Denmark for harbour porpoise, another species known to be susceptible to man-made noise. In 2005, approximately 85 harbour porpoises stranded freshly dead along approximately 100 km of Danish coastline, far higher numbers than usual (Wright *et al.* 2012). Due to markings on the carcasses, bycatch was established as the cause of death for most of the individuals. Local fishermen confirmed that they had experienced unusually high porpoise bycatch in nets set for lumpfish. With further analysis, it was determined that several naval vessels were transiting Danish waters ahead of a large multinational naval exercise. Although sonar use was not confirmed, it was thought likely that ships were testing equipment prior to the main exercise, and thus naval activity could not be ruled out as a possible contributing factor (Wright *et al.* 2012).

Additionally, Richardson and Moulton (2012) note that several cases of strandings in the general area where a seismic survey was on-going have led to speculation concerning a possible link between seismic surveys and strandings. However, empirical evidence, such as an examination of hair cells in the inner ear, is often lacking in these examples. For example, suggestions that there was a link between seismic surveys and strandings of humpback whales in Brazil (Engel *et al.* 2004) were not well founded (IAGC 2004, IWC 2007). While in September 2002, there was a stranding of two Cuvier's beaked whales in the Gulf of California, Mexico, when the L-DEO seismic vessel R/V *Maurice Ewing* was operating a 20-airgun, 8490-cu.in. airgun array in the general area. The evidence linking the stranding to the seismic survey was inconclusive and not based on any physical evidence (Malakoff 2002). Despite these caveats, the Gulf of California incident plus the beaked whale strandings near naval exercises involving use of mid-frequency sonar (see above) suggest a need for caution in conducting seismic surveys in areas occupied by beaked whales until more is known about effects of seismic surveys on those species (Hildebrand 2005).

11.2 Mortality in narwhals linked to seismic survey noise

We are not aware of stranding events involving narwhal which have been linked to seismic or other anthropogenic noise activity. However, due to the proximity to sea-ice and the deep water environments that narwhals inhabit, 'strandings', in the usual sense, would be rare occurrences. Heide-Jørgensen *et al.* (2013) did however link changes in narwhal migration patterns and the subsequent ice-entrapment to seismic activity. Narwhals spend much of their year in dense pack ice; however they are still susceptible to ice entrapment, and large numbers of narwhals have been reported over the centuries becoming trapped during winter (February to April; Heide-Jørgensen *et al.* 2013). Although ice entrapments are well reported throughout West Greenland, and Canada, the Disko Bay area of West Greenland is the area with the highest incidence of narwhal ice entrapments (Heide-Jørgensen *et al.* 2013). Three unusual ice-entrapments of narwhal occurred between 2008 and 2010, two of which took place in autumn months in locations where entrapments of narwhals have not been reported before (Heide-Jørgensen *et al.* 2013). The coastal areas in northern Baffin Bay where the narwhals became trapped in 2008 and 2009–10 are usually covered with fast ice in late November, thus it remains a mystery why the whales remained in these areas during freeze-up. During the first entrapment in November 2008, approximately 1000 narwhals were recorded in breathing holes 50 km from open water (Watt & Ferguson 2011). Just before this, in September and October of the same year, 2D seismic activity (up to 37 airguns with maximum volume 4200 in^3) had been occurring in Baffin Bay during the period narwhals would normally be migrating out of Pond

Inlet and Lancaster Sound into central Baffin Bay. In November 2010 and February 2011, two other unusual and lethal incidents occurred with 30-100 and 50-100 narwhal, respectively (Laidre *et al.* 2011); both occurred when seismic activity had been taking place directly before the entrapments (the 2009 seismic survey used four arrays with 12 two-gun clusters and source energy of 3460–4210 in^3). These 2008 and 2009 seismic surveys are the only surveys which have taken place in northern Baffin Bay during late September – October, and therefore the only surveys which have coincided with the narwhals leaving their summer grounds (normally around 25^{th} September; Heide-Jørgensen *et al.* 2002). Both the 2008 and 2009 surveys deployed airgun arrays with sufficient power to produce pulses that would be audible throughout the entire area of Baffin Bay (Heide-Jørgensen *et al.* 2013). There is little doubt that the pulses were audible to narwhals, which would have been within 200 km of the seismic vessels at least during part of the period (Heide-Jørgensen *et al.* 2013).

Although it could be postulated that these rare ice-entrapments are caused by the increasing pressures of climate change, with later freeze-up on the summering grounds possibly delaying the departure of narwhals (Laidre *et al.* 2011), Heide-Jørgensen *et al.* (2013) stipulate that this is inconsistent with the tight schedule of narwhal fall migrations. The whales have for decades left their summering grounds well ahead of the formation of fast ice (Dietz & Heide-Jørgensen 1995, Dietz *et al.* 2008, Heide-Jørgensen *et al.* 2003).

This is the only paper directly addressing the impacts of seismic surveys on narwhal behaviour; however, it highlights the need for certain essential mitigation requirements for seismic surveys in Baffin Bay. As Heide-Jørgensen *et al.* (2013) conclude, a very cautious approach to allowing seismic surveys in narwhal habitats is warranted; indeed, it could be warranted to recommend that, as seismic surveys have previously been reported to alter narwhal migration behaviour, further surveys should not take place during the narwhal migration periods. At this point, it is important to note that the survey site for the upcoming 2D survey scheduled to be conducted in Baffin Bay between July and November 2015, overlaps with the wintering grounds of the narwhal spatially, as well as occurring during the period that narwhals leave their summering grounds on their autumn migration. The project was considered unlikely to affect narwhals (NEB 2014) as the survey is scheduled to take place before November (see Section 2); however if the Heide-Jørgensen *et al.* (2013) theory that seismic surveys may increase the risk of ice-entrapment is correct, this survey could seriously impact the timing and /or route of the narwhal's migration into their wintering grounds.

Heide-Jørgensen *et al.* (2013) additionally acknowledge the urgent need for research specifically on the impacts of seismic airgun noise on narwhals and other artic species, suggesting research on the effects of airgun noise on escape movements, migratory movements, diving activity and vocalisations in addition to monitoring the population trend of narwhals exposed to seismic noise. In 2012, seismic surveys took place in northern Baffin Bay close to one of the two main summering grounds of narwhals in West Greenland (Makhorin *et al*. 2014). No studies were conducted during the critical fall migration period when the population would have passed through areas with seismic activity (Reeves *et al*. 2013).

Although not documented for narwhals to date, hearing damage from anthropogenic activities has been noted to kill other cetacean species indirectly (see above) and may be particularly hard to identify for this species.

11.3 Other Arctic species

Given the well documented reactions of beaked whales to man-made noise sources, Boertmann *et al.* (2010) highlighted that the northern bottlenose whale, the only beaked whale species commonly reported in the Arctic waters around Greenland, should be given particular attention during 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.

12. Conclusions and recommendations

It is widely recognised by regulatory authorities in many countries that there is a risk of injury to whales from loud sound sources and particularly seismic surveys. For example, Australian national policy makes a strong case for the need for seismic surveys to avoid whales. It is stated 'Do not program seismic surveys in areas where and when whales are likely to be breeding, calving, resting or feeding' and 'When planning seismic surveys, avoid, where possible, areas where and when whales are known or are likely to be migrating' (DEWHA 2008). New Zealand adopted a new code of conduct in 2013 which notes the uncertainty in the effectiveness of measures to reduce impacts and that 'The best course of action is simply to avoid conducting seismic surveys in sensitive areas' (DOC 2013).

Since the issue of new licenses for exploration blocks for Baffin Bay in 2010, it is evident that there will be an increasing levels of anthropogenic noise from shipping, seismic surveys and potentially drilling. This is a unique and fragile environment which, until the last few decades has remained relatively untouched and undisturbed; it is inhabited by highly specialised ice associated Arctic species such as the narwhal, beluga and bowhead whale, which are important species to local Inuit communities for subsistence and income. These species are already under pressure from human induced changes to their environment from climate change, increased pollution and harvesting. It is very likely that the addition of a further stressor could have significant population-level impacts.

There are a number of specific characteristics which make many Arctic species, but especially the narwhal, of particular interest and concern; thus aspects of their ecology and life histories should be taken into consideration when assessing the potential for adverse impacts to the species. Narwhals have been described by experts as the most specialised of the ice whales, living exclusively in the Arctic environment, with a close association with sea ice being fundamental to their ecology and survival in terms of both feeding and shelter/protection from predators and other threats (natural and human).

Sound is essential to marine mammals, especially cetaceans, as it is used for social interactions, to forage, to orientate and to respond to predators. The exact hearing range and sensitivities of most cetacean species, including the narwhal and bowhead whale, are unknown. Noise pollution is known to have detrimental impacts on marine mammals. The most extreme impacts from noise on cetaceans are hearing loss, injury and death. The most regularly reported and potentially influential impacts from noise on marine mammals are behavioural, including avoidance of and displacement from potentially important habitat and increased masking of vocalisations.

Temporary hearing loss (TTS) has not been recorded in narwhals. However, beluga whales, a close relative of the narwhal, have been found to develop TTS to a sound exposure level (SEL) of 186 dB re 1 $\mu Pa^2 s$ from a single pulse and at a peak-to-peak sound pressure level of 226 dB re 1 µPa, which equates to distances of around 260 metres from a single airgun pulse or when considering multiple pulse impacts, the noise threshold to induce TTS would occur at 14 airgun pulses (an exposure time of less than 162 seconds) at a range of 1 km from the array, and 54 airgun signals (11-12 minutes) at a range of 2 km. However, although injury through TTS and PTS are amongst the most extreme and immediate physiological harm which can occur to individual marine mammals as a result of exposure to seismic survey noise at close proximity to the source, other reactions, such as avoidance and behavioural changes, occur at much greater distances from the noise source and may therefore, be extremely detrimental to the health of entire populations in the long term. This is even more relevant for Arctic species that may be constrained by local geography and prevailing environmental conditions (e.g. heavy ice cover).

It is evident from the available literature that a variety of impacts from seismic surveys, including disturbance, avoidance, changes in behaviour and vocalisations have been documented in a range of different species of cetaceans. Reactions vary greatly depending on species, individual, behavioural state, age, and impacts are largely documented for those species which are more readily accessible to study (due to their distribution, visibility, habitats, vocalisations, migrations, etc.). Many species for which impacts are not documented in the literature have simply not been subjected to detailed behavioural study; some species remain very challenging to detect, identify and study in the wild. Even in well studied species, responses can be subtle and hard to detect and there are many documented cases of apparent tolerance of seismic noise, which may be misleading.

There have been no direct studies of the reactions of narwhal to seismic noise; however, it is essential to note, that in all cases, a lack of documented response does not imply that there are no impacts. Most studies on the effects of geophysical surveys have been conducted in those areas that have historically been exposed to high levels of seismic activity. Therefore, these studies do not represent a true baseline. Thus, when considering seismic activity in new habitats, such as the Arctic, research specific to the area should be conducted to understand the impacts of noise on the habitat and wildlife. Additionally, several of the cited examples are based on opportunistic data or only consider specific behavioural states in isolation and therefore may provide contradictory findings solely due to their methodology.

It is well known from Traditional Knowledge (TK), and from studies of narwhals' reactions to the presence of icebreakers, that this species is extremely sensitive to noise. Narwhals have displayed obvious avoidance behaviour at distances of over 80 km and anti-predator responses (freezing and stopping vocalising) at 50 km to noise emitted by icebreakers, which although continuous rather than impulsive noise, indicates extreme sensitivity to disturbance. The paper by an eminent narwhal expert linking significant changes in narwhal behaviour to seismic noise determines that seismic noise delayed the narwhals from migrating at the usual time, causing thousands of narwhal to become entrapped in ice and to die, in an area and at a time never previously recorded. If the seismic noise (cause) and the entrapments (effect) are indeed correlated, the fact that the seismic surveys ceased a month before the ice entrapment occurred demonstrates the far reaching impacts seismic surveys can have on the species and habitat both temporarily and spatially. Furthermore, if the seismic surveys did cause the narwhals to delay their migration, the proposed 2D survey being planned for summer-autumn 2015, between July and November, which overlaps with the narwhal wintering area could severely impact their migration to their winter feeding area.

Behavioural reactions to noise and disturbance can lead to a range of longer term impacts including decreased foraging efficiency, increased energetic demands, reduced group cohesion, reduced ability to communicate, higher predation, and decreased reproduction – all of which could cause serious impacts at the population level – resulting in population decline or lack of recovery (in depleted populations). Long-term and population level impacts are very difficult to quantify. Most of the current research is focused on very short term changes, and often has no baseline from before the start of seismic activity with which to compare any future impacts. Additionally, there are many changing variables within the marine environment, both anthropogenic and natural, which can make it very difficult to demonstrate a link between a response and the cause.

For the elusive deep diving toothed whales (e.g. the northern bottlenose whale), on whom the impacts of seismic noise are poorly studied, it is increasingly clear that other sources of intense anthropogenic noise have the potential to cause disturbance, as well as serious injury and death; indeed, there have been several reported cases where it is suspected that these species have been impacted by seismic airgun activity (resulting in strandings). Species, such as the beaked whales, which appear to be found in small, possibly genetically isolated, local populations that are resident year round may therefore be particularly vulnerable to disturbance and population level impacts. Additionally, there is extremely limited information available on the impacts on calves and young whales from seismic activity, and as the seismic testing in Baffin Bay needs to take place in the summer due to ice, which coincides with the breeding and calving season for many types of Arctic wildlife, more research on this topic in this area is urgently needed.

From the papers that demonstrate a clear impact, and those that indicate more subtle changes in behaviour, call rates, migrations, etc., we can infer that harmful effects are likely. Although information on the impact of seismic activities specifically on narwhals is mostly lacking, their extreme reactions to other continuous and quieter noise sources, demonstrates their likely sensitivity to seismic noise also. Additionally, their tendency to react by a ‘freeze and sink’ anti-predator response, rather than a flee response, deems them even more susceptible to injury as they do not typically remove themselves from an area of danger. Demonstrating harm is difficult, but from the growing literature on the subject, it is clear that the research question should no longer be whether there is an impact from seismic airgun noise on cetaceans, as this is clear, but instead, which species/ groups/ critical habitat areas are likely to be at most risk (also taking into account existing data on population abundance and trends), whether the risk of impacts can quantified, as well as minimised, or whether there is an alternative approach to seismic testing, which should be employed.

Limited understanding of the impacts of seismic noise on marine mammals means that the absolute level of risk is difficult to quantify. Nevertheless, the relative risk can be reduced by decreasing the intensity, limiting the bandwidth or reducing the duration of noise to which any individual is exposed, and reducing the number of individuals affected.

When considering the seismic activity which is planned for Baffin Bay in the coming years, it seems justified to urge for extreme caution, given both the lack of data on narwhal status, and on the very limited understanding of the short and long term impact of seismic noise on Arctic species, especially the narwhal. With this in mind, a number of specific issues are highlighted below:

- Seismic testing for oil and gas exploration has been conducted using the same technique for the last 40-50 years. Although it is very accurate and effective in terms of detecting oil and gas deposits, the far reaching environmental, welfare and conservation impacts of the noise produced by this technique need to be considered and addressed. Current regulations and guidelines have been devised by many countries where seismic surveys occur which require operators of seismic airguns to implement mitigation measures involving shut-down of the source in response to whales being detected within a specified zone, in an attempt to reduce the harm to marine mammals from the airgun noise. Similarly soft start may be used, as airguns ramp up to full power gradually. Intuitively such an approach allows marine mammals to move away from the source before being exposed to high noise levels. However, in practice there is limited evidence that this is the case. For example, narwhals exhibiting a ‘freeze and sink’ response may not benefit from soft starts; rather, they may be exposed to more noise over a longer period. Detection by dedicated observers or passive acoustic monitoring systems will only detect a proportion of the whales that enter such a zone, and the likely risk reduction achieved has rarely been quantified. Without an adequate quantified assessment of the risk reduction, mitigation measures may often be applied inappropriately or result in regulators granting approval for activities on the basis of measures that do little to reduce risk.

- In 2013, the Bureau of Ocean Energy Management (BOEM) (a US Government Agency) held a workshop on the Quieting Technologies for Reducing Noise during Seismic Surveying and Pile Driving. It was agreed that airguns produce “waste sound” (mainly the higher frequencies to which some cetacean species are most sensitive), and that with more sensitive receivers, less sound could be used to gather the same quality of data and that technologies are available that introduce minimal sound.
- The most effective way to reduce the effects of seismic surveys is by decreasing the amount of noise released into the ocean. There are two options for this, either fewer surveys or decreasing the intensity or duration of sound during those surveys. The output of the airgun array source level may be reduced (see Wisniewska *et al*. 2014). This can be done either permanently from onset of the seismic survey or it can be adjusted in accordance with the actual on site propagation conditions. By decreasing the source level by 6 dB the ensonified area will be halved and the survey will then only affect 1/4 of the original area and 1/8 of the original water volume, hereby greatly reducing the risk of exposure leading to hearing loss for any animals in these areas. It is therefore of great importance to test and choose the source level beforehand as well as assessing the source level continuously underway as the bottom reflectivity and properties become known.
- This is backed up by simulation modelling undertaken by Leaper *et al*. (*in press*) which indicates that there will be very few instances where mitigation using visual observers can achieve a greater risk reduction than would be achieved by a 3 dB reduction in source level.
- Given that alternative technologies are now within sight, regulatory measures that require source levels for seismic surveys to be reduced should be encouraged. Current mitigation measures are largely ineffective and permits for seismic surveys are rarely refused on environmental grounds but even modest levels of noise reduction could substantially reduce impacts on marine mammals. A combination of regulatory pressures and more research funding will be required to develop these new technologies. Thus, to use the example of windfarm construction noise through pile driving, the German authorities set a 160 dB limit to the noise produced. This resulted in construction companies rapidly developing, testing and adopting measures to reduce the noise levels, including bubble curtains, and various engineering alternatives.
- For any proposed seismic survey in Baffin Bay, the following information should be required for informed decisions to be made about the likely level of risk to narwhals and other marine mammals:

(i) Information on the use of the area to be surveyed and adjacent waters by narwhals and other marine life that may be affected by noise. This should include recent surveys at the time of year the seismic operations are proposed and an understanding of seasonal patterns of habitat use.
(ii) An assessment of relative risk based on the proposed number and intensity of noise sources, sound propagation characteristics, and narwhal / other marine mammal densities – this could be expressed in terms of how many individuals are likely to be exposed to sound greater than certain intensity.
(iii) A quantified assessment of the level of risk reduction that is expected to be achieved by any proposed mitigation measures.
(iv) Greater consideration should be given to the cumulative effects of noise, for example, there is the potential for O&G exploration activities to be taking place in both Canadian and Greenlandic waters of Baffin Bay concurrently, exacerbating the potential for widespread and long term disturbance.

- Decisions about how or whether to conduct seismic surveys should be informed by a quantitative analysis of proposed mitigation measures to judge how effective a given measure is likely to be. In cases where preventing harm to marine mammals is a high priority, the only option may be to prohibit seismic surveys.
- For many Arctic species, perhaps most notably the narwhal, very limited data exist on population trends, migration patterns, and population recovery. Although there is substantial uncertainty about numbers and trends in large parts of the narwhal range, there is clear evidence of decline for specific subpopulations. It is important therefore in these circumstances to protect their critical habitats - breeding/nursery areas, migratory routes and feeding areas - from disturbance while the species is present. As seismic testing has already been implicated in changes in narwhal migrations, it is recommended that future seismic surveys in Baffin Bay are not licensed during narwhal migration periods and indeed there may be a case for delaying seismic operations in particularly fragile ecosystems such as the Arctic until less disturbing technologies are in regular use.

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Appendix 1: An overview of seismic mitigation measures applicable in Baffin Bay and comparison with the Code of Conduct in New Zealand

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This appendix provides a short outline description of mitigation measures/requirements during seismic surveys to reduce disturbance and/or harm to marine mammals in Canadian and Greenlandic waters of Baffin Bay. In addition it includes a comparison with the guidelines adopted in New Zealand, widely regarded to currently represent the most precautionary approach.

The Statement of Canadian Practice with respect to the Mitigation of Seismic Sound in the Marine Environment specifies the mitigation requirements that must be met during the planning and conduct of marine seismic surveys, in order to "minimize impacts on life in the oceans". The Canadian guidelines prioritise the avoidance of "significant adverse effects" on Schedule 1 species on the Species at Risk Act. These include both endangered marine mammals (blue whale, North Atlantic right whale and northern bottlenose whale) and species of special concern (fin whale and Sowerby's beaked whale). The narwhals, belugas and bowhead whales known to use Baffin Bay are currently not listed on Schedule 1. However, certain populations (such as the belugas of the St. Lawrence Estuary and the bowhead whales of Bering-Chukchi-Beaufort) are listed and hence qualify for additional protection outside of the High Arctic.

The Guidelines to Environmental Impact Assessment of Seismic Activities in Greenland Waters presents the minimum requirements for at sea mitigation measures (best practise) to "prevent damage to marine mammals" during seismic surveys and is primarily aimed at preventing animals from being exposed to 'dangerously' high sound pressure levels. Although narwhals, belugas, bowhead whales and walruses are described as "particularly sensitive to seismic surveys", the only additional consideration for these species in Baffin Bay is four protection zones for narwhals (representing summer, winter and autumn migratory habitats) and two for walrus (representing winter habitats).

The New Zealand Code of Conduct for Minimising Acoustic Disturbance to Marine Mammals from Seismic Survey Operations recognises that the potential exists for seismic survey operations at sea to have adverse impacts on marine mammals. The Code aims to "minimise impacts" through a range of required mitigation measures, while still providing for seismic survey operations to be conducted. The code presents higher mitigation standards for 36 Species of Concern, a list which includes all baleen whales and most toothed whales encountered in New Zealand.

When comparing the guidelines in place for Canada and Greenland with those for New Zealand, the latter are broadly more precautionary and are likely to present a lower risk of injury and/or disturbance to marine mammals. However, a lack of detailed research to quantify the reduction in risk leads to some uncertainty in the assessment of the efficacy of mitigation guidelines in general. For example, Greenland's guidelines call for the use of a mitigation gun (the smallest airgun in the array) to be used in certain situations, such as during a line change. Although this may provide marine mammals with a constant low-level indicator of a potentially disturbing sound source and avoid an individual receiving full-exposure without prior warning, there is currently no empirical evidence to suggest this is more beneficial than complete silence. Similarly, it is not possible to assess which scenario is more precautionary: a longer pre-survey scan in deep waters (with the intention of improving the detection probability of deep-diving species in Greenland) or a wider mitigation zone (up to 1500 m in New Zealand instead of 500 m in Canada and Greenland). Without an adequate quantified assessment of the risk reduction, mitigation measures may often be applied inappropriately or result in regulators granting approval for activities on the basis of measures that do little to reduce risk.

A1) An overview of mitigation requirements in place for seismic surveys in Canada

In 2004, Fisheries and Oceans Canada (DFO) invited Canadian and international experts to develop scientific advice on the potential impacts of seismic sound on marine fish, marine invertebrates, marine zooplankton, eggs and larvae of fish and invertebrates, marine turtles and marine mammals. Based on this peer-reviewed advice and an assessment by technical experts of the best available mitigation techniques, a group of federal and provincial experts in marine regulatory policy and practice developed a Statement of Canadian Practice with respect to the Mitigation of Seismic Sound in the Marine Environment (henceforth described as the Statement; DFO 2007). The Statement specifies the mitigation requirements that must be met during the planning and implementation of marine seismic surveys in order to minimise impacts on life in the oceans. These requirements are set out as minimum standards which will apply in all non-ice covered marine waters in Canada and will be given effect through existing regulatory authorities. The Statement is intended to complement existing environmental assessment processes (e.g. settled land claims). For oil and gas seismic activities, Natural Resources Canada and Indian Affairs and Northern Development, the provinces of Nova Scotia, Newfoundland and Labrador, and their related boards, the National Energy Board, the Canada-Newfoundland and Labrador Offshore Petroleum Board and the Canada-Nova Scotia Offshore Petroleum Board, will give effect to the Statement under their respective regulatory instruments. Non-oil and gas related seismic surveys will be regulated by the *Oceans Act*. The Statement sets out mitigation requirements in the following manner:

Application

1. Unless otherwise provided, the mitigation measures set out in this Statement apply to all seismic surveys planned to be conducted in Canadian marine waters and which propose to use an air source array(s).

2. The mitigation measures set out in this Statement do not apply to seismic surveys conducted:
   a. on ice-covered marine waters; or

b. in lakes or the non-estuarine portions of rivers.

Planning Seismic Surveys

3. Each seismic survey must be planned to:
   a. use the minimum amount of energy necessary to achieve operational objectives;
   b. minimise the proportion of the energy that propagates horizontally; and
   c. minimise the amount of energy at frequencies above those necessary for the purpose of the survey.

4. All seismic surveys must be planned to avoid:
   a. a significant adverse effect for an individual marine mammal or sea turtle of a species listed as endangered or threatened on Schedule 1 of the Species at Risk Act; and
   b. a significant adverse population-level effect for any other marine species.

5. Each seismic survey must be planned to avoid:
   a. displacing an individual marine mammal or sea turtle of a species listed as endangered or threatened on Schedule 1 of the Species at Risk Act from breeding, feeding or nursing;
   b. diverting an individual migrating marine mammal or sea turtle of a species listed as endangered or threatened on Schedule 1 of the Species at Risk Act from a known migration route or corridor;
   c. dispersing aggregations of spawning fish from a known spawning area;
   d. displacing a group of breeding, feeding or nursing marine mammals, if it is known there are no alternate areas available to those marine mammals for those activities, or that if by using those alternate areas, those marine mammals would incur significant adverse effects; and
   e. diverting aggregations of fish or groups of marine mammals from known migration routes or corridors if it is known there are no alternate migration routes or corridors, or that if by using those alternate migration routes or corridors, the group of marine mammals or aggregations of fish would incur significant adverse effects.

Safety Zone and Start-up

6. Each seismic survey must:
   a. establish a safety zone which is a circle with a radius of at least 500 metres as measured from the centre of the air source array(s); and
   b. for all times the safety zone is visible,
      i. a qualified Marine Mammal Observer must continuously observe the safety zone for a minimum period of 30 minutes prior to the start-up of the air source array(s), and
      ii. maintain a regular watch of the safety zone at all other times if the proposed seismic survey is of a power that it would meet a threshold requirement for an assessment under the Canadian Environmental Assessment Act, regardless of whether the Act applies. This threshold is stipulated as a pressure of 275.79 kPa at a distance of one metre from the source (i.e. a source level of 229 dB re 1 μPa @ 1m).

7. If the full extent of the safety zone is visible, before starting or restarting an air source array(s) after they have been shut-down for more than 30 minutes, the following conditions and processes apply:
   a. none of the following have been observed by the Marine Mammal Observer within the safety zone for at least 30 minutes:

i. a cetacean or sea turtle,

ii. a marine mammal listed as endangered or threatened on Schedule 1 of the Species at Risk Act, or

iii. based on the considerations set out in sub-section 4(b), any other marine mammal that has been identified in an environmental assessment process as a species for which there could be significant adverse effects; and

b. a gradual ramp-up of the air source array(s) over a minimum of a 20 minute period beginning with the activation of a single source element of the air source array(s), preferably the smallest source element in terms of energy output and a gradual activation of additional source elements of the air source array(s) until the operating level is obtained.

Shut-down of Air Source Array(s)

8. The air source array(s) must be shut down immediately if any of the following is observed by the Marine Mammal Observer in the safety zone:

a. a marine mammal or sea turtle listed as endangered or threatened on Schedule 1 of the Species at Risk Act; or

b. based on the considerations set out in sub-section 4(b), any other marine mammal or sea turtle that has been identified in an environmental assessment process as a species for which there could be significant adverse effects.

Line Changes and Maintenance Shut-downs

9. When seismic surveying (data collection) ceases during line changes, for maintenance or for other operational reasons, the air source array(s) must be:

a. shut down completely; or

b. reduced to a single source element.

10. If the air source array(s) is reduced to a single source element as per subsection 9(b), then:

a. visual monitoring of the safety zone as set out in section 6 and shut-down requirements as set out in section 8 must be maintained; but

b. ramp-up procedures as set out in section 7 will not be required when seismic surveying resumes.

Operations in Low Visibility

11. Under the conditions set out in this section, cetacean detection technology, such as Passive Acoustic Monitoring, must be used prior to ramp-up for the same time period as for visual monitoring set out in section 6. Those conditions are as follows:

a. the full extent of the safety zone is not visible; and

b. the seismic survey is in an area that

i. has been identified as critical habitat for a vocalising cetacean listed as endangered or threatened on Schedule 1 of the Species at Risk Act, or

ii. in keeping with the considerations set out in sub-section 4(b), has been identified through an environmental assessment process as an area where a vocalising cetacean is expected to be encountered if that vocalising cetacean has been identified through the environmental assessment process as a species for which there could be significant adverse effects.

12. If Passive Acoustic Monitoring or similar cetacean detection technology is used in accordance with the provision of section 11, unless the species can be identified by vocal signature or other recognition criteria:

   a. all non-identified cetacean vocalisations must be assumed to be those of whales named in sections 8(a) or (b); and
   b. unless it can be determined that the cetacean(s) is outside the safety zone, the ramp-up must not commence until non-identified cetacean vocalisations have not been detected for a period of at least 30 minutes.

Additional Mitigative Measures and Modifications

13. Persons wishing to conduct seismic surveys in Canadian marine waters may be required to put in place additional or modified environmental mitigation measures, including modifications to the area of the safety zone and/or other measures as identified in the environmental assessment of the project to address:

   a. the potential for chronic or cumulative adverse environmental effects of
      i. multiple air source arrays (e.g. two vessels on one project; multiple projects), or
      ii. seismic surveys being carried out in combination with other activities adverse to marine environmental quality in the area affected by the proposed program or programs;
   b. variations in sound propagation levels within the water column, including factors such as seabed, geomorphologic, and oceanographic characteristics that affect sound propagation;
   c. sound levels from air source array(s) that are significantly lower or higher than average; and
   d. species identified in an environmental assessment process for which there is concern, including those described in sub-section 4b).

14. Variations to some or all of the measures set out in this Statement may be allowed, provided the alternate mitigation or precautionary measures will achieve an equivalent or greater level of environmental protection to address the matters outlined in sections 6 through 13 inclusive. Where alternative methods or technologies are proposed, they should be evaluated as part of the environmental assessment of the project.

15. Where a single source element is used and the ramping up from an individual air source element to multiple elements is not applicable, the sound should still be introduced gradually whenever technically feasible.

A2) An overview of mitigation requirements in place for seismic surveys in Greenland

Prior to opening up new areas for hydrocarbon exploration and exploitation licensing rounds, a Strategic Environmental Impact Assessments (SEIA) for the region is prepared. The SEIA reports and research have been conducted as a co-operation between National Environmental Research Institute, Greenland Institute of Natural Resources and Mineral Licence and Safety Authority. Subsequent applications submitted to the Mineral Licence and Safety Authority to conduct offshore hydrocarbon exploration activities with an expected significant impact on the environment in these areas must be accompanied by an Environmental Impact Assessment (EIA). The EIA is forwarded to the Environment Agency for the Mineral Resources Area (EAMRA) under the Ministry for Nature and Environment. EAMRA draws on the expertise of the scientific institutions Danish National Environmental Research Institute and Greenland Institute for Natural Resources when assessing submitted EIAs. Subsequent offshore hydrocarbon exploration activities in Greenland can only be performed under a prospecting licence, an exclusive licence for exploration and exploitation of hydrocarbons or a licence for scientific surveys. Besides having a licence, the licensee must obtain a specific approval from the Mineral Licence and Safety (MLSA) in order to conduct any offshore exploration activity. To obtain an approval to conduct offshore exploration activities, the licensee shall comply with the provisions of the Mineral Resources Act and related legislation, the provisions of the licence under which the activity is applied for, the provisions of these guidelines and provisions contained in the approval letter.

The EIA guidelines prepared by the Danish Centre for Environment and Energy (DCE) in 2011 are aimed at companies preparing environmental impact assessments of seismic surveys in ice free Greenland waters (Kyhn *et al*. 2011). The guidelines are also valid to other offshore exploration activities to the extent applicable. 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 and narwhal) are designated and maps indicating the most important offshore fishing grounds are provided. To increase the knowledge of seabird and marine mammal distributions and abundance in Greenland the MLSA has made it mandatory for seismic vessels operating in Greenland to collect seabird and marine mammal observation data. The following is a summary of best practise recommended during surveys:

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. 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.

• An injury zone of 200 m shall be applied. If marine mammals are observed within 200 m during full power, the output shall be reduced to the mitigation gun (the smallest airgun in the array in terms of energy output and volume) until the mammal has left the zone.

• 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 than 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 reduced to the mitigation gun, 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.

• Passive Acoustic Monitoring (PAM) of vocalising whales shall be deployed for monitoring purposes during start up at night or during periods when the sea state is above 3. Especially in areas with bowhead whales.

• 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.

• During line changes the array output should be reduced to the mitigation gun, 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 (the mitigation gun).

• Two Marine Mammal and Seabird Observers (MMSO) shall be posted on the source vessel (where the airguns are deployed from) and a minimum of one should be continuously on the lookout particularly for whales and seals during the pre-shooting search and when airguns are operated.

• Observation of marine mammals during shooting and inside the safety zone may not lead to shut-down, but if marine mammals are observed within the 200 m injury zone of the array, output should be reduced to the mitigation gun until the marine mammals are outside the 200 m zone again.

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

• 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 shall be initiated with a ramp-up procedure as above.

This practice is in line with the UK’s Joint Nature Conservation Committee (JNCC) 2010 recommendations, which are the adopted 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.

2 Modelling impact areas of the noise

In order to take account of the area actually ensonified by a seismic survey as well as potential other surveys in the same general area, a model of the expected noise exposure has to be included in the supplied EIA. The model should be based on actual bathymetry, knowledge of sediment properties (to the degree available) and realistic assumptions regarding vertical sound speed profiles and ice cover. Modelling should not be restricted to the surface layer but extend to at least 1000 m depth or the seabed. Horizontally, the model should extend to cover all areas exposed to levels likely to affect marine mammals. If more than one survey is planned for the general area of the model, the model must take account of all surveys to be carried out in the area. Knowledge about other potential surveys must be sought well in advance from the MLSA. A joint model prepared by all the companies planning seismic surveys in the same general area can substitute models prepared individually by each company.

2.1 Estimated noise levels to be presented in the model

The seismic noise propagation model shall result in sound levels at different ranges and depths from the airgun array (depths relevant for the species in the area). Noise levels to be presented in the model are peak-to-peak sound pressure levels referenced to 1µPa (peak-peak), rms sound pressure levels referenced to 1 µPa (rms measured over 90% of pulse duration) and in sound exposure levels referenced to 1 μPa^2s per pulse. For assessment of cumulative effects, the cumulated sound exposure level (across all airgun pulses and all concurrent surveys in the area) per 24 hours should be presented. Modelling should include all biologically relevant parts of the frequency spectrum.

3 Documenting modelled noise propagation loss

Actual sound exposure within the modelled area must be documented at selected and representative locations during the seismic survey. Monitoring can be conducted over the total or a substantial part of the survey period, by means of deployed autonomous data-loggers, or measurements can be obtained from a measuring vessel during a representative part of the survey. Recordings should be made at several depths on each position, preferably down to the maximum depth utilised by species in the area, but at least to a depth below the sound speed minimum, as determined from the vertical sound speed profile. At least three recording ranges must be sampled at least out to a distance of 50 km range from the survey area. Sound speed profiles should be obtained at each recording position, either directly or from measurements of depth, salinity and temperature. The analysed recordings must be delivered in a report to MLSA following the performed survey. The measured received levels must be reported corresponding to the values of the propagation model in peak-peak values, rms and energy flux density.

4 Data intended to be included in the EIA

The survey parameters listed below should be delivered with the EIA:

4.1 Survey data

- Type of survey (2D, high resolution (3D), well testing, other).
- Map of the area with all transect lines shown.
- Start and end dates for the survey.
- Expected duration.
- Duty cycle of operation (in hours/24 hours). Number of hours in the dark per 24 hours.
- Number and types of accompanying vessels.
- Intended use of icebreakers.
- Will survey be carried out in ice?

4.2 Array specifications

- Number and names of vessels towing airgun arrays.
- For each vessel provide geometric layout of complete airgun array with individual volume specified (in PSI per airgun and in^3 per airgun).
- Size of total array (In^3 and PSI for the entire array).
- Firing rate in shots/sec.
- Will sub arrays fire simultaneously or alternate?
- Operation speed of the vessel in km/hours or knots.

4.3 Acoustic properties of the airgun array

- Far field pressure signature (provide figure).
- Frequency spectrum of the far field signature (broadband) (provide figure).
- Source level (source factor) of airgun array on acoustic axis below array, given in all of the following units:
  - dB re 1 µPa zero-peak (broadband).
  - dB re 1 µPa peak-peak (broadband).
  - dB re 1 µPa rms (Over 90%* pulse duration) (provide duration for rms calculation).
  - dB re: 1 $\mu Pa^2 s$ per pulse .
  - Energy, joule/m^2 per airgun pulse.
  - Signal duration. (Define how it is measured).
- Map showing modelled sound pressure levels (rms*), peak-peak and sound exposure level ($\mu Pa^2 s$) for the survey area and surroundings (to levels likely to affect marine mammals or nearest land).
- rms calculated by the 90% energy approach for derivation of the duration.
- Provide description of the noise propagation model, including assumptions of sound speed profiles.

4.4 Specifications of PAM system

- Number of hydrophones.
- Threshold of the recording system.
- Sample rate of the recording system.
- Where will hydrophones be placed?
- Will there be duty cycling of recordings?
- In that case when will the PAM system be used?
- Name of software.
- Species covered.
- Estimated range accuracy, m.

5 Best practice during planning

When planning a seismic survey:

• Use the lowest practicable power levels to achieve the objectives of the survey.

• Seek methods to reduce and/or baffle unnecessary high frequency noise produced by the airguns.

• Seek methods to reduce and/or baffle the emitted airgun noise to increase the directionality of the airguns (this would also be relevant for other acoustic energy sources).

• Determine what marine mammal species are likely to be present in the survey area and assess if there are any seasonal considerations that need to be taken into account, for example periods of migration, breeding, calving or pupping.

• All available species distribution data must be obtained from the Greenland Institute of Natural Resources before planning a survey. The EIA should clearly specify if data deficiency hinders evaluation of possible effects on species in the area, rather than suggesting that no data means no effects.

• Plan surveys so that the timing will reduce the likelihood of encounters with marine mammals. For example when whales are likely to be migrating, mating, calving, resting or feeding.

• If marine mammals are likely to be in the area, only commence seismic activities during the hours of daylight when visual mitigation using Marine Mammal and Seabird Observers (MMSOs) is possible.

• If the operator plans to commence seismic activities during the hours of darkness, or low visibility, or during periods when the sea state is not conducive to visual mitigation (i.e. sea state above 3) Passive Acoustic Monitoring (PAM) must be in place to document presence of species likely to be in the area (as described in the EIA).

• Obtain knowledge from the MLSA about other planned seismic surveys in nearby licensing areas to assess possible cumulative effects from multiple temporally overlapping or consecutive surveys. Further environmental assessment of potential impacts may be necessary if multiple seismic sources (e.g. two vessels on one project or multiple, adjacent projects) are planned to be operated in the same general area. A joint noise propagation model can be supplied by several companies applying to operate in the same general area.

• The proponent should prepare an environmental management plan for the survey that details the management and operational measures that will apply throughout the survey to detect marine mammals and avoid interference or significant impacts. Throughout Greenland's waters, the management plan should assume marine mammals will be encountered.

6 Best practice during surveys

From JNCC's 2010 guidelines unless specifically noted:

6.1 Observations before and during seismic activity

All observations should be undertaken from the source vessel (where the airguns are being deployed from). At least one MMSO must be monitoring the presence of marine mammals and sea birds during daylight hours.

6.2 Pre-shooting search

The pre-shooting search should normally be conducted over a period of 30 minutes before commencement of any use of the airguns. The MMSO should make a visual assessment to determine if any marine mammals are within 500 metres of the centre of the airgun array.

In deep waters (>200 m) the pre-shooting search should extend to 60 minutes as deep diving species (e.g. sperm whale and beaked whale) are known to dive for longer than 30 minutes. A longer search time in such areas is likely to lead to a greater detection and tracking of deep diving marine mammals.

If any marine mammals are detected whilst the airguns are still firing, then no action is required other than for the MMSO to monitor and track any marine mammals. The commencement of the soft-start for any subsequent survey lines should be delayed for at least 20 minutes if marine mammals are detected when the airguns have ceased firing.

If PAM is used in conjunction with visual monitoring the PAM operatives should ensure the system is deployed and being monitored for vocalisations during each designated pre-shooting period.

6.3 Delay if marine mammals are detected within the mitigation zone (500 metres)

If marine mammals are detected within 500 metres of the centre of the airgun array during the pre-shooting search, the soft-start of the seismic sources should be delayed until their passage, or the transit of the vessel, results in the marine mammals being more than 500 metres away from the source. In both cases, there should be a 20 minute delay from the time of the last sighting within 500 metres of the source to the commencement of the soft-start, in order to determine whether the animals have left the area. If PAM is used it is the responsibility of the PAM operatives to assess any acoustic detections and determine if there are likely to be marine mammals within 500 metres of the source. If the PAM operatives consider marine mammals are present within that range then the start of the operation should be delayed as outlined above.

If marine mammals are detected within 500 metres of the centre of the airgun array whilst the airguns are firing, either during the soft-start procedure or whilst at full power, there is no requirement to stop firing the airguns– but see below for marine mammals within 200 m.

6.4 Use of mitigation gun when marine mammals are within 200 m

If marine mammals are detected within 200 metres of the centre of the airgun array whilst the airguns are firing at full power, firing should be reduced to only the smallest airgun in the array, a so-called mitigation gun, which should prevent further approach of animals to the array. Full power may be regained as soon as the animals have left the 200 m protection zone. This is an additional requirement to the JNCC's 2010 guidelines.

6.5 The soft-start

The soft-start is defined as the time that airguns commence shooting till the time that full operational power is obtained. Power must be built up slowly from a low energy start-up (e.g. starting with the smallest airgun in the array and gradually adding in others) over at least 20 minutes to give adequate time for marine mammals to leave the area. This build-up of power must occur in uniform stages to provide a constant increase in output. The duration of the pre-shooting search (at least 30 minutes) and the soft-start procedure (at least 20 minutes) must be factored into the survey design.

General advice to follow for soft-starts:

• To minimise additional noise in the marine environment, a soft-start (from commencement of soft-start to commencement of the line) should not be significantly longer than 20 minutes (for example, soft-starts greater than 40 minutes are considered to be excessive, and an explanation should be provided within the weekly MMSO report to MLSA).

• Where possible, soft-starts should be planned so that they commence within daylight hours.

• Once the soft-start has been performed and the airguns are at full power the survey line must start immediately. Operators must avoid unnecessary firing at full power before commencement of the line.

• If, for any reason, firing of the airguns has stopped and not restarted for at least 10 minutes, then a pre-shooting search and 20 minute soft-start must be carried out (the requirement for a pre-shooting search only applies if there for some extraordinary reason was no MMSO on duty and observing at this time, and if the break in firing occurred during the hours of daylight). After any unplanned break in firing for less than 10 minutes the MMSO should make a visual assessment for marine mammals (not a pre-shooting search) within 500 metres of the centre of the airgun array. If a marine mammal is detected whilst the airguns are not firing the MMSO should advise to delay commencement, as per the pre-shooting search, delay and soft start instructions above. If no marine mammals are present then they can advise to commence firing the airguns. If possible the mitigation gun should remain firing when otherwise the entire array is shut down (requirement beyond JNCC's 2010 guidelines).

• When time-sharing, where two or more vessels are operating in adjacent areas and take turns to shoot to avoid causing seismic interference with each other, the soft-start and delay procedures for each vessel must be communicated to, and applied on, all the vessels involved in the surveying.

6.6 Soft-start requirements for site survey or Vertical Seismic Profiling (VSP)

Surveys should be planned so that, whenever possible, the soft-start procedures for site surveys and Vertical Seismic Profiles (VSPs) commence during daylight hours. For ultra-high resolution site surveys that only use a 'mini-airgun' (single airgun with a volume of less than 10 in^3) there is no requirement to perform a soft-start; however, a pre-shooting search should still be conducted before its use.

For site surveys and VSPs, a number of options are available to effect a soft-start:

• The standard method, where power is built up slowly from a low energy start-up (e.g. starting with the smallest airgun in the array and gradually adding in others) over at least 20 minutes to give adequate time for marine mammals to leave the vicinity.

• As the relationship between acoustic output and pressure of the air contained in the airgun is close to linear and most site surveys / VSP operations use only a small number of airguns, a soft-start can be achieved by slowly increasing the air pressure in 500 psi steps. The time from initial airgun start up to full power should be at least 20 minutes.

• Over a minimum time period of 20 minutes the airguns should be fired at an increasing frequency until the desired firing frequency is reached.

6.7 Soft-starts and airgun testing

Individual airguns, or the whole array, may need testing; the airguns may be tested at varying power levels. The following guidance is provided to clarify when a soft-start is required:

• If the intention is to test all airguns at full power then a 20 minute soft-start is required.

• If the intention is to test a single airgun on low power then a soft-start is not required.

• If the intention is to test a single airgun, or a number of guns on high power, the airgun or airguns should be fired at lower power first, and the power then increased to the level of the required test; this should be carried out over a time period proportional to the number of guns being tested and ideally not exceed 20 minutes in duration.

MMSOs must maintain a watch as outlined in the pre-shooting search guidance before any instances of gun testing.

7 Line change

Seismic data is usually collected along predetermined survey lines. Line change is the term used to describe the activity of turning the vessel at the end of one line prior to commencement of the next line. Depending upon the type of seismic survey being undertaken, the time for a line change can vary. Line changes are not necessary for all types of seismic surveys, for example, in certain regional surveys where there is a significant distance between the lines, and for VSP operations.

The guidance relating to line change depends upon the airgun volume.

7.1 Seismic surveys with an airgun volume of 500 in^3 or more

If the line change time is expected to be greater than 20 minutes, airgun firing should be terminated at the end of the line and a full 20 minute soft-start undertaken before the next line. A pre-shooting search should also be undertaken during the scheduled line change, and the soft-start delayed if marine mammals are seen within 500 metres of the centre of the airgun array.

7.2 Seismic surveys with an airgun volume of 180 in^3 or less (site surveys)

If the line change time is expected to be greater than 40 minutes, airgun firing should be terminated at the end of the line and a full 20 minute soft-start undertaken before the next line. The pre-shooting search should also be undertaken during the scheduled line change, and the soft-start delayed if marine mammals are seen within 500 metres of the centre of the airgun array.

If the line change time is expected to be less than 40 minutes, airgun firing can be reduced to the mitigation gun or continue during the turn, but in the latter case the Shot Point Interval (SPI) should be increased (longer duration between shots) and the source level decreased. Ideally, the SPI should not exceed 5 minutes during the turn.

Depending upon the duration of the line turns and the nature of seismic survey it may be necessary to vary the soft-start procedures. If an applicant determines that an effective line change cannot be achieved using the above methods it must be explained and alternatives described in the EIA.

7.3 Undershoot operations

During an undershoot operation, one vessel is employed to tow the seismic source and a second vessel used to tow the hydrophone array in order to facilitate shooting under platforms or other obstructions. It is recommended that MMSOs are positioned on the source vessel. Pre-shooting search and soft-start procedures should still be followed prior to undertaking an undershoot operation.

8 Passive Acoustic Monitoring (PAM)

Visual observation is an ineffective mitigation tool during periods of darkness or poor visibility or during periods when the sea state is not conducive to visual mitigation (i.e. sea state above 3), as it will not be possible to detect marine mammals in the vicinity of airgun sources. Under such conditions, PAM is considered to be the only currently available mitigation technique that can be used to detect marine mammals, although the systems have their limitations and can only be used to detect vocalising species of marine mammals.

9 Use of PAM as a mitigation tool

PAM can provide a useful supplement to visual observations undertaken by MMSOs and JNCC recommends that it is used as a mitigation tool when commenting on applications for survey approval. However, in many cases it is not as accurate as visual observations for determining range, and this will mean that the mitigation zone will reflect the range accuracy of the system. Although, at present it is not possible to express the range accuracy of most PAM systems in numerical terms, this example serves to illustrate that it is in the operator’s best interests to use the most accurate system available, and for the PAM operative to factor in a realistic estimate of the range accuracy.

Some PAM systems do not have a reliable range determination facility or can only calculate the range for some species. In such cases, the detection of a confirmed cetacean vocalisation should still be used to initiate postponement of the soft-start if the PAM operator is able to make a judgement about the range of the animals from the airgun source, because of their experience gained in differentiating between distant and close vocalisations. In the absence of PAM systems capable of range determination, this expert judgement will constitute the basis for deciding whether an area is free from cetaceans prior to the soft-start.

In all cases where PAM is employed, a description of the system, its sensitivity, species covered and an explanation on how the applicant intends to deploy PAM to greatest effect should be included in the EIA for survey consent.

10 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 MLSA for evaluation and approval.

11 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 purpose of the second task is to improve the knowledge on temporal and spatial distribution of marine mammals and seabirds in Greenland waters.

If the activity as described in the project scope, and in combination with other planned or ongoing human activities, is considered by DCE, based on the best information available at the time, to have no potential for significant impacts on the environment, even though some negative effects may well remain, the applicant will be requested to submit an Environmental Mitigation Assessment (EMA) report.

A3) An overview of mitigation requirements in place for seismic surveys in New Zealand

In conjunction with international and domestic stakeholders representing industry, operators, observers and marine scientists, New Zealand's Department of Conservation developed the 2013 Code of Conduct for Minimising Acoustic Disturbance to Marine Mammals from Seismic Survey Operations (the Code; DOC 2013) to provide effective, practical mitigation measures for minimising acoustic disturbance of marine mammals during seismic surveys. The Code aims to minimise impacts through a range of required mitigation measures, while still providing for seismic survey operations to be conducted. It applies to all marine seismic survey operations in New Zealand continental waters (from the coast to the outer edge of the 200 nm exclusive economic zone, and includes the extended continental shelf). Under the Exclusive Economic Zone and Continental Shelf (Environmental Effects – Permitted Activities) Regulations 2013, seismic surveying is a permitted activity within EEZ waters provided the Code is complied with. The Environmental Protection Authority is responsible for monitoring seismic surveys within the EEZ to determine compliance with the Code. The code presents higher mitigation standards for 36 Species of Concern, a list which includes all baleen whales and most toothed whales encountered in New Zealand. The following marine seismic survey operations are recognised as being subject to the Code in New Zealand continental waters:

1. Level 1 surveys (>427 in^3) primarily include large-scale geophysical investigations that would routinely be employed in oil and gas exploration activities with dedicated marine seismic survey vessels, but may also apply to other studies using high-power acoustic sources. This level features the most stringent requirements for marine mammal protection, and is the main focus of the Code.

2. Level 2 surveys (151–426 in^3) provides for lower scale seismic investigations often associated with scientific research. As these survey programmes are normally conducted from smaller, sometimes multi-mode platforms using moderate power seismic sources or smaller seismic source arrays, the risks to marine mammals are decreased. Therefore the mitigation procedures are reduced accordingly.

3. Borehole seismic surveying (also referred to as vertical seismic profiling) is a specific survey activity related to offshore oil and gas well-bore investigations. Such operations are by necessity limited to a small geographic area and may be conducted from static platforms. Borehole seismic surveys may be determined to be within any of the above levels according to the acoustic source power employed.

The following summarises the specific requirements for each survey type:

1.1 Level 1 surveys (>427 in^3)

1.1.1 Pre-survey planning

No person may carry out a Level 1 marine seismic survey unless they have submitted to the Director-General a written Marine Mammal Impact Assessment (MMIA) not less than one month before commencing the survey. When planning to operate in areas of identified sensitivity, proponents should develop adaptive management procedures to ensure that survey activities can be modified to respond to unforeseen circumstances and minimise risks of negative impacts by incorporating additional mitigative measures. In all circumstances, the provisions of the Code must be considered as the minimum required.

1.1.2 Observer requirements

For all Level 1 surveys the minimum qualified observer requirements are:

• At all times there will be at least two qualified Marine Mammal Observers (MMOs) on board, and

• At all times there will be at least two qualified Passive Acoustic Monitoring (PAM) operators on board.

• At all times while the acoustic source is in the water, at least one qualified MMO (during daylight hours) and at least one qualified PAM operator will maintain watches for marine mammals. Observations by qualified observers are also encouraged at all other times where practical and possible.

If the PAM system has malfunctioned or become damaged, operations may continue for 20 minutes without PAM while the PAM operator diagnoses the issue. If the diagnosis indicates that the PAM gear must be repaired to solve the problem, operations may continue for an additional 2 hours without PAM monitoring as long as all of the following conditions are met:

• It is daylight hours and the sea state is less than or equal to Beaufort 4.

• No marine mammals were detected solely by PAM in the relevant mitigation zones in the previous 2 hours.

• Two MMOs maintain watch at all times during operations when PAM is not operational.

• DOC is notified via email as soon as practicable with the time and location in which operations began without an active PAM system.

• Operations with an active source, but without an active PAM system, do not exceed a cumulative total of 4 hours in any 24 hour period.

1.1.3 Pre-start observations

Normal requirements

A Level 1 acoustic source can only be activated if it is within the specified operational area, and no marine mammals have been observed or detected in the relevant mitigation zones as outlined in section 1.1.4.

The source cannot be activated during daylight hours unless:

• At least one qualified MMO has continuously made visual observations all around the source for the presence of marine mammals, from the bridge (or preferably an even higher vantage point) using both binoculars and the naked eye, and no marine mammals (other than fur seals) have been observed in the relevant mitigation zone for at least 30 minutes, and no fur seals have been observed in the relevant mitigation zones for at least 10 minutes, and

• Passive Acoustic Monitoring for the presence of marine mammals has been carried out by a qualified PAM operator for at least 30 minutes before activation and no vocalising cetaceans have been detected in the relevant mitigation zones.

The source cannot be activated during night-time hours or poor sighting conditions unless:

• Passive Acoustic Monitoring for the presence of marine mammals has been carried out by a qualified PAM operator for at least 30 minutes before activation and no vocalising cetaceans have been detected in the relevant mitigation zones.

Additional requirements for start-up in a new location in poor sighting conditions

In addition to the normal pre-start observation requirements outlined above, when arriving at a new location in the survey programme for the first time, the initial acoustic source activation must not be undertaken at night or during poor sighting conditions unless either:

• MMOs have undertaken observations within 20 nautical miles of the planned start up position for at least the last 2 hours of good sighting conditions preceding proposed operations, and no marine mammals have been detected; or

• Where there have been fewer than 2 hours of good sighting conditions preceding proposed operations (within 20 nautical miles of the planned start up position), the source may be activated if:

  – PAM monitoring has been conducted for 2 hours immediately preceding proposed operations, and

  – Two MMOs have conducted visual monitoring in the 2 hours immediately preceding proposed operations, and

  – No Species of Concern have been sighted during visual monitoring or detected during acoustic monitoring in the relevant mitigation zones in the 2 hours immediately preceding proposed operations, and

  – No fur seals have been sighted during visual monitoring in the relevant mitigation zone in the 10 minutes immediately preceding proposed operations, and

  – No other marine mammals have been sighted during visual monitoring or detected during acoustic monitoring in the relevant mitigation zones in the 30 minutes immediately preceding proposed operations.

1.1.4 Delayed starts and shutdowns

Species of Concern with calves within a mitigation zone of 1.5 km

If, during pre-start observations or while a Level 1 acoustic source is activated (which includes soft starts), a qualified observer detects at least one cetacean with a calf within 1.5 km of the source, start-up will be delayed or the source will be shut down and not be reactivated until:

• A qualified observer confirms the group has moved to a point that is more than 1.5 km from the source, or

• Despite continuous observation, 30 minutes has elapsed since the last detection of the group within 1.5 km of the source, and the mitigation zone remains clear.

Species of Concern within a mitigation zone of 1 km

If, during pre-start observations or while a Level 1 acoustic source is activated (which includes soft starts), a qualified observer detects a Species of Concern within 1 km of the source, start-up will be delayed or the source will be shut down and not reactivated until:

• A qualified observer confirms the Species of Concern has moved to a point that is more than 1 km from the source, or

• Despite continuous observation, 30 minutes has elapsed since the last detection of the Species of Concern within 1 km of the source, and the mitigation zone remains clear.

Other Marine Mammals within a mitigation zone of 200 m

If, during pre-start observations prior to initiation of a Level 1 acoustic source soft start, a qualified observer detects a marine mammal within 200 m of the source, start-up will be delayed until:

• A qualified observer confirms the marine mammal has moved to a point that is more than 200 m from the source, or

• Despite continuous observation, 10 minutes has passed since the last detection of a New Zealand fur seal within 200 m of the source and 30 minutes has elapsed since the last detection of any other marine mammal within 200 m of the source, and the mitigation zone remains clear.

If all mammals detected within the relevant mitigation zones are observed moving beyond the respective areas, there will be no further delays to initiation of soft start.

2.1 Level 2 surveys (151–426 in^3)

Requirements for Level 2 surveys are broadly similar to those required for Level 1 with some differences:

• PAM is likely to be a requirement for Level 2 surveys in the future when mandatory regulations are being considered. However, at this stage under the Code it remains an optional consideration for Level 2 surveys. Unlike the Level 1 requirements, if the PAM system has malfunctioned or become damaged, operations may continue in the absence of PAM while repairs are conducted.

• The requirements for pre-start observations are as for Level 1 if PAM is used. If PAM is not used, start up can be initiated and active surveys may proceed at night or during poor sighting conditions only if:

- There have not been more than 3 marine mammal instigated shutdowns or delayed starts in the previous 24 hours of active survey operations in good sighting conditions, or

- If active survey operations were not conducted in the previous 24 hours, MMOs have undertaken observations within a radius of 20 nm of the proposed start-up position for at least the last 2 hours of good sighting conditions during the daylight hours preceding proposed operations and no marine mammals have been detected.

• The mitigation zones for Level 2 differ from Level 1 in the following with delayed starts and shutdowns to take place when:

- Species of Concern with calves are within a mitigation zone of 1 km (rather than 1.5 km for Level 1), and/or
- Species of Concern are within a mitigation zone of 600 m (rather than 1 km for Level 1).

3.1 Borehole seismic surveys

Requirements for borehole seismic surveys vary from those required for Level 1 with some differences:

• Observer requirements and pre-start observation requirements depend on the capacity of the acoustic source being used for the borehole seismic survey, and shall comply with the requirements for the applicable Level 1 or 2 survey.

• It is recognised that soft start may not be possible with the alternative acoustic source technologies that may be used for borehole seismic surveys. Where possible, initial activation of the acoustic source must involve the gradual increase of the source's power over a period of at least 20 minutes and no more than 40 minutes, unless the source is being reactivated after a break in firing less than 10 minutes before that time. In the case of borehole seismic surveying, activation of the acoustic source at least once within sequential 10 minute periods shall be regarded as continuous operation.

• Delayed start and shutdown requirements shall depend on the capacity of the acoustic source being used for the borehole seismic survey, and shall comply with the requirements for the applicable Level 1 or 2 survey.

A4) Comparison of mitigation requirements in Canada and Greenland with New Zealand

The following table provides a comparison of the key provisions of guidelines for reducing disturbance to marine mammals during seismic surveying currently in place for Canada, Greenland and New Zealand. Those provisions deemed to be more precautionary are shaded green. Blank cells signify the provision is not considered or is not given unambiguous elaboration.

Provision	New Zealand	Canada	Greenland
Mitigation addresses effects on individuals (rather than populations)	For all marine mammal species	Only for SARA Schedule 1 species	For all marine mammal species
Higher mitigation standards for certain species	36 Species of Concern	SARA Schedule 1 species	Protection zones specified for beluga, narwhal, bowhead whale, northern right whale & walrus
Higher mitigation standards for larger arrays	Mandatory PAM and larger mitigation zones for Level 1 (>427 in^3) vs. Level 2 (151–426 in^3)	Regular MMO watch required if source level ≥ 229 dB re 1 µPa @ 1m	Only during line change
Adaptive management procedures required in certain areas	Additional mitigative measures for Areas of Ecological Importance	Avoid displacing non-SARA species from breeding, feeding, nursing or migrating habitats if no alternatives exist	Pre-shooting search extended in waters >200m deep
Adaptive management procedures required for certain behavioural states	Avoid surveys where Species of Concern are likely to be breeding, calving, resting, feeding or migrating	Avoid displacing SARA Schedule 1 species from breeding, feeding, nursing or migrating	

Mitigation zones vary by species	More stringent for Species of Concern (especially for groups with calves)		
Impact Assessment reporting requirements	Marine Mammal Impact Assessment	Environmental Assessment	Environmental Impact Assessment
MMO required when source in water during daylight	From 2 qualified MMOs on board	If source level ≥ 229 dB re 1 µPa @ 1m; otherwise only for ≥ 30 min prior to survey	From 2 MMSOs on board
PAM operator required when source in water	From 2 PAM operators on board (for Level 1)	For ≥ 30 min prior to survey if visibility <500m and in critical habitat for endangered or threatened SARA cetaceans	During night-time start-up or sea states > 3
Provisions for failure of PAM system	Only 2 hours possible without PAM (for Level 1)		
Soft-starts required	Over 20-40 mins	Over at least 20 mins	Over 20 mins
Soft-starts required after break in firing	Only if >10 mins	Only if >30 mins	Only if >5 mins
Shut-down between lines	Strongly encouraged	Either complete shut-down (subsequent soft-start required if ≥ 30 mins) or only single source element (subsequent soft-start not required)	Output should be reduced to mitigation gun; soft-start required if transit time > 20 mins (for arrays ≥500 in^3) or >40 mins (for arrays ≤180 in^3)
Delayed starts in response to detection of marine mammal	30 min delay when within 200-1500m	30 min delay when within 500m for any	20 min delay when within 500m;

	(varies according to Species of Concern); monitored for ≥30 min prior to survey	cetacean or SARA Schedule 1 species; monitored for ≥30 min prior to survey	monitored for 30 min (if < 200m deep) or 60 min (if > 200m deep) prior to survey
Shut-downs in response to detection of marine mammal	When within 200-1500 m (varies according to Species of Concern)	When within 500m for SARA Schedule 1 species	Output reduced to mitigation (smallest) airgun if marine mammal seen within 200m
Consideration of multiple surveys/arrays	Mitigation applied according to combined capacities of arrays	Additional or modified mitigation measures	Model of expected cumulative noise exposure in EIA
Modelling of noise propagation	Only for surveys in Area of Ecological Importance or Marine Mammal Sanctuary		For all surveys
Separate standards for vertical seismic profiling	Varies according to volume of acoustic source		Soft-starts required if ≥10 in^3

A5) References

New Zealand Department of Conservation, 2013. 2013 code of conduct for minimising acoustic disturbance to marine mammals from seismic survey operations. Report prepared by New Zealand Department of Conservation, Wellington. 36 pages. Available at: http://www.doc.govt.nz/Documents/conservation/native-animals/marine-mammals/seismic-survey-code-of-conduct.pdf (accessed 09/06/15).

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