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Perspective

Narwhals and seismic exploration: Is seismic noise increasing the risk of ice entrapments?

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ABSTRACT

There is great interest in exploring and exploiting hydrocarbon resources in the Arctic, and one of the main methods of locating and assessing such resources is seismic survey. Marine seismic surveys involve the use of airguns that introduce high-energy noise to the Arctic's largely pristine underwater acoustic environment. Narwhals may be particularly sensitive to this noise but so far no studies have addressed the question of direct effects of high-energy airgun pulses on these animals. We are concerned about the possibility that three large recent ice entrapments were causally linked to seismic survey activities. On these occasions narwhals remained in coastal summering areas until well into the fall and early winter season, delaying their annual offshore migration and becoming lethally entrapped by rapidly forming fast ice. About 1000 narwhals died in an ice entrapment in Canada in 2008 and about 100 in two entrapments in Northwest Greenland in 2009–10. We conclude that studies of the direct effects of seismic surveys on narwhals are urgently needed and should ideally precede further seismic surveys in narwhal habitats.

Contents

Some of the largest unexplored geological basins for hydrocarbon development are located in offshore seasonally ice-covered shelf-areas of the Arctic (Gautier et al., 2009; Schenk, 2010). With the prospects for a continued reduction in extent and thickness of sea ice (Perovich and Richter-Menge, 2009), these areas are of increasing interest to the oil and gas industry. On the shelf areas of East and West Greenland alone, it has been estimated that >20 million barrels of undiscovered oil might exist and would be potentially recoverable (Gautier et al., 2009). The prospect of large-scale untapped but accessible hydrocarbon resources in a country with a stable political system has fueled interest in oil and gas exploration in Greenland. Both offshore seismic surveys and exploratory drilling have taken place in West Greenland since 2007 and licensing for areas of East Greenland is expected to take place in 2012 (http://www.bmp.gl/petroleum/).

The underwater environment in the Arctic often has high background sound levels from activity of icebergs, sea ice, wind, waves, and wildlife, but there has been, until recently, relatively little noise of anthropogenic origin (Carey and Evans, 2011; Moore et al., 2012). Despite opening of the Northwest and Northeast Passages (Arctic Marine Shipping Assessment, 2009), the level of shipping activity remains low and is largely limited to the open-water season. Therefore the underwater acoustic environment in much of the Arctic is still nearly pristine, without the chronic noise from shipping, drilling, seismic exploration and sonar. In Baffin Bay large-scale industrial seismic surveys were only recently initiated.

Arctic marine mammals use underwater sounds to locate prey, detect and avoid predators, find openings in sea ice for breathing, and to communicate and maintain contact (Richardson et al.,

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1995). Historically, cetaceans and pinnipeds that live year-round in the Arctic have been exposed to very limited amounts of anthropogenic sound and there is no reason to believe that these animals have become desensitized or habituated to such noise. In fact, there is published evidence of dramatic responses to ship noise by belugas (*Delphinapterus leucas*) and narwhals (*Monodon monoceros*) (Finley et al., 1990; Cosens and Dueck, 1993; Lesage et al., 1999) and to airgun pulses by bowhead whales (*Balaena mysticetus*) (Richardson et al., 1995; Blackwell et al., 2010). The effects of anthropogenic noise on several temperate-region species have been studied (Wright et al., 2007; Rolland et al., 2012) but few studies have addressed this issue for Arctic marine mammals. Depending on the type and level of the sound as well as its spatial and temporal character, the impacts on marine mammals may include short- or long-term changes in behavior (i.e. disruption of feeding activity, avoidance, shifts in habitat-use patterns), physical damage to hearing abilities, and masking of important signals. Change in calling behavior is a commonly detected effect of noise exposure.

The narwhal, primarily found in the Atlantic sector of the Arctic with the largest numbers centered in Baffin Bay and adjoining waters (Richard et al., 2010; Heide-Jørgensen et al., 2010), is of particular concern. Narwhals are skittish, highly sensitive to human activities and easily disturbed by approaching boats, even in areas without hunting. Hunting of narwhals in several areas of West Greenland continues to be conducted from kayaks because the whales react with long submergence times and often simply disappear when pursued by boats with noisy outboard engines. No direct studies have been conducted of the effects of seismic airgun noise on narwhals but they are known to react at long distances to underwater noise from vessels, with and without ice-breaking (Finley et al., 1990). The reactions of narwhals to approaching vessels include long-distance displacement, even at relatively low received sound levels (94–105 dB re 1 μPa; 20–1000 Hz). This responsiveness at such long distances is exceptional in the literature on marine mammal disturbance (see Richardson et al., 1995). It should be noted however that recent studies indicate that some other species also react to noise at long distances (e.g. Risch et al., 2012). The responsiveness of narwhals confirmed by the paucity of sightings obtained from vessels passing through areas known (from hunting returns and aerial surveys) to have high densities of narwhals (Heide-Jørgensen et al., 2010; GINR unpublished data). In particular, observers on active seismic survey vessels rarely if ever encounter narwhals, even when surveying areas where narwhals are known to occur (Lang and Mactavish, 2011). It is likely that the animals disappear before the survey vessels are within the observers' range of visual detection.

The sounds produced by narwhals span a wide range of frequencies, from <300 Hz to >150 kHz (Miller et al., 1995), and the low-frequency sounds of seismic surveys are likely to overlap in frequency with at least a portion of the narwhal's vocal repertoire. It is uncertain at what distance from an operating seismic airgun array the sound pressure received by the narwhals would elicit a behavioral or physiological response. The received level would depend not only on distance but, perhaps more critically, on the size of the array and other factors. It is a combination of distance (to the airguns) and received level (at the whale) that is likely to elicit a response.

Although narwhals dive to depths exceeding 1000 m (maximum recorded depth was 1900 m; Laidre et al., 2003), they are not considered fast swimmers. Based on contraction times, dominance of slow-twitch muscle fibers and exceptionally high myoglobin concentrations, narwhals have been characterized as slow, aerobic swimmers (Williams et al., 2010). Observations of narwhals instrumented 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 and Heide-Jørgensen, 1995; Heide-Jørgensen and Dietz, 1995). These values are among the slowest reported for any marine mammal (Williams, 2009).

The usual escape response of narwhals exposed to killer whales (*Orcinus orca*) or Inuit hunters involves prolonged submergence and entry into dense pack ice, if this is available (Williams et al., 2010; Laidre et al., 2006). In other words, they tend to hide or flee slowly and cryptically to avoid predators. Their observed response to an icebreaker was similar (Finley et al., 1990) and this is in contrast to the responses of other cetaceans with locomotor muscles divided equally into slow-twitch and fast-twitch fiber types, allowing for high-speed movement away from a disturbance (Ponganis and Pierce, 1978). Narwhals make long-distance migrations in the spring and autumn (>3000 km per year), moving between coastal summering grounds (Heide-Jørgensen et al., 2003) and winter feeding areas in the pack ice (Laidre et al., 2004). Such migrations across areas with few predators require endurance swimming (Williams et al., 2010). In summary, narwhals adhere to strict migratory schedules and routes with a high degree of site fidelity to specific localities (Heide-Jørgensen et al., in press). They live in an environment with strong seasonal variability in habitat conditions, have few predators, and are rarely exposed to human disturbances except during the short periods when they are hunted along the edges of fast ice and in open water.

Narwhals remain in the Arctic or sub-Arctic throughout the year. Although they spend approximately half of the year in dense pack ice and have done so for centuries (and presumably for millennia), they are still susceptible to ice entrapment. At intervals, large numbers succumb in this way during the winter (February through April). Ice entrapments are caused by a sudden freeze-up during periods of stable but high atmospheric pressure (Egede, 1788; Porsild, 1918; Siegstad and Heide-Jørgensen, 1994). Ice entrapments are well documented in West Greenland and to some extent also in Canada as these are major events in the lives of people living in Arctic communities. The Disko Bay area of West Greenland has long been the area with the highest incidence of narwhal ice entrapment, and it was the site of the largest such event on record: more than 1000 whales died in a February 1915 ice entrapment in Disko Bay (Porsild, 1918). This bay typically provides excellent feeding conditions for narwhals, and sea ice coverage is highly variable according to the changing strength of the warm Atlantic water and the cold polar currents that meet there. During certain weather conditions in winter, hunters are "on the lookout" for ice-entrapped whales at sites where entrapments are to some extent predictable based on local experience and knowledge. This situation, specifically the high level of local interest and consequent vigilance by people, gives us confidence in asserting that ice entrapments of narwhals occur mainly between February and March and most often in the Disko Bay region of West Greenland. There are few historical records of entrapments north of Disko Bay, none from Qaanaaq (Northwest Greenland) and few from winter in the Canadian high Arctic (Fig. 1).

Three recent ice entrapments of narwhals occurred in summering areas outside the normal range of ice-entrapment events. Two of these took place in the autumn in locations where entrapments of narwhals had not been reported previously. In November 2008 thousands of narwhals were seen moving quickly through the freezing seas near the community of Pond Inlet (northern Baffin Island, Canada) a few days before being entrapped (Watt and Ferguson, 2011). Some of the whales apparently avoided entrapment. However, after the ice had frozen solid, local residents discovered about 1000 narwhals at breathing holes about 50 km from open water. During late September and early October 2008, 2D seismic surveys (m/v Geolog Dmitriy Nalivkin) were underway

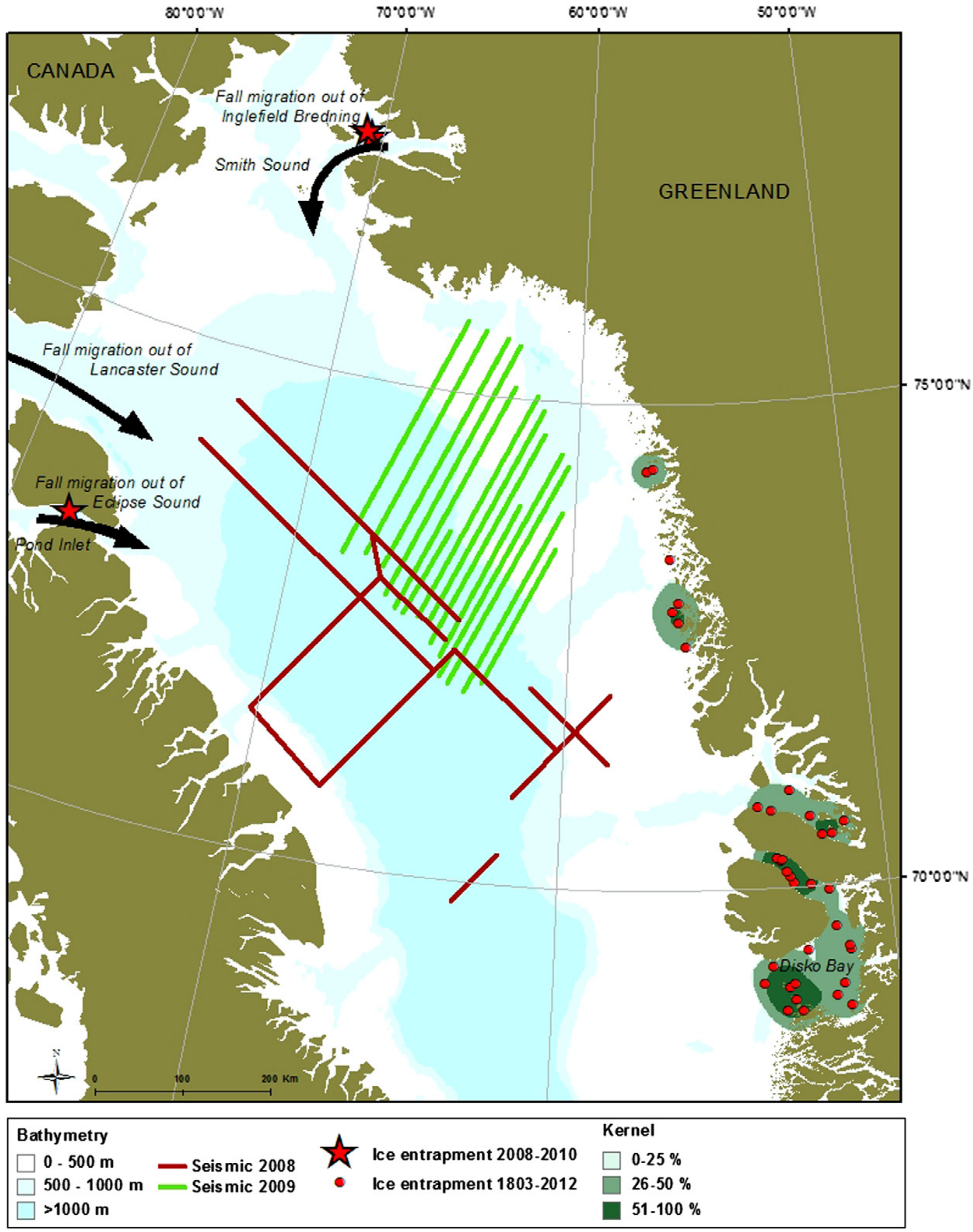

Fig. 1. Tracks of seismic survey operations in northern Baffin Bay during September–October 2008 and 2009. Historical ice entrapments in West Greenland are indicated with red dots and shown with kernel home ranges in green. Three recent entrapments are shown with red stars in Canada (November 2008) and Northwest Greenland (November 2009, February 2010). Major fall migration routes of narwhals exiting Lancaster and Eclipse sounds in Canada and Inglefield Bredning in Northwest Greenland are shown with black arrows. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

in Baffin Bay at the time when narwhals would normally be moving out of Pond Inlet and Lancaster Sound and starting their southward migration in Baffin Bay (Fig. 1). This seismic vessel normally operates with four arrays of up to 37 airguns with a combined maximum volume of 4200 inch^3 and a pressure of 2000 psi.

Two other unusual, and similarly lethal, incidents occurred in November 2009 and February 2010 in Inglefield Bredning, involving 30–100 and 50–100 narwhals, respectively (Laidre et al., 2011). Similar to 2008, seismic activity (m/v Bergen Surveyor) was taking place in northern Baffin Bay in September–October 2009, i.e. at the time when narwhals would normally be moving out of their summering area in Inglefield Bredning. This vessel operates with an airgun arrangement (4 arrays with 12 two-gun clusters and source energy of 3460–4210 inch^3) similar to that used by m/v Geolog Dmitriy Nalivkin and both vessels deploy airgun arrays with more than enough power to produce pulses that would be audible in the entire Baffin Bay. We have no records of previous seismic surveys as late in the year as late September–October in northern Baffin Bay.

Narwhals that have spent the summer in and near Pond Inlet usually depart the fjord system around the 25th of September and head towards their wintering grounds in central Baffin Bay (Heide-Jørgensen et al., 2002; Fig. 2). The large number that remained in Pond Inlet during freeze-up in November 2008 was exceptional. Inglefield Bredning is an important summering ground for narwhals (Heide-Jørgensen et al., 2010) but the whales always leave the area in late September-early October (Born, 1986). Although the migratory destination of this population of narwhals is still not known with certainty, the narwhals traditionally move south and abandon Smith Sound for the winter (Finley and Renaud, 1980; Richard et al., 1998).

The areas where ice entrapments of narwhals usually occur along West Greenland (shown as kernel ranges in Fig. 1) are characterized by mobile pack ice where leads and cracks in most winters provide open spaces for air-breathing mammals. However, the coastal areas in northern Baffin Bay where the narwhals were entrapped 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. Narwhals inhabit areas where climate imposes strong forcing on the habitat conditions, meaning the conditions can change from suitable (ice-free or unconsolidated pack ice) to unsuitable (solid and continuous ice cover) over short timescales. It has been speculated that, with climate change, later freeze-up on the summering grounds will delay the departure of narwhals from these areas and make them increasingly vulnerable to rapid freeze-up and ice-entrapment late in the fall (Laidre et al., 2011). This suggestion is inconsistent with the tight schedule of narwhal fall migrations; for decades, the whales have been observed to depart their summering grounds well ahead of the formation of fast-ice (Dietz and Heide-Jørgensen, 1995; Dietz et al., 2008; Heide-Jørgensen et al., 2003).

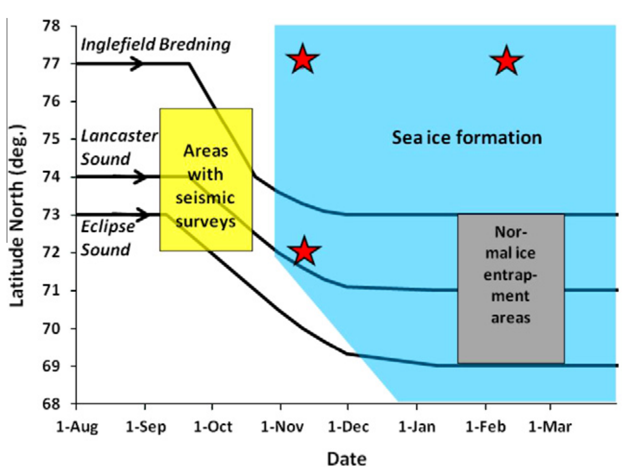

Fig. 2. Generalized model of autumn sea ice development with latitude (y-axis) and date (x-axis) in Baffin Bay. The fall migration of narwhals from three summering areas (Inglefield Bredning, Lancaster Sound and Eclipse Sound, see Fig. 1) from high latitudes towards lower latitudes is shown with black lines, and the normal latitude and season for ice entrapments of narwhals are shown as the gray box, with the three unusual entrapment events in 2008 and 2009–10 indicated with red stars in areas and seasons where entrapments have generally not been reported before. The seismic surveys (yellow square) happened just after the narwhals normally would have begun to depart from their summering grounds and while they would have been heading towards wintering areas in central Baffin Bay. For background data see Dietz et al. (2008) and Heide-Jørgensen et al. (in press). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Low-frequency sounds from airguns can be transmitted over long distances. For example, Nieukirk et al. (2012) monitored seismic activity from moored stations along the mid-North Atlantic and documented sounds from seismic survey vessels located >3000 km away. Airgun sounds were recorded in Fram Strait, off northeastern Greenland, year-round, even during the winter when the area was ice covered and no seismic exploration was being conducted locally (Moore et al., 2012). The seismic surveys conducted in Baffin Bay in 2008 and 2009 were in a relatively deep basin (500–2000 m). The airgun pulses from the >3000 inch^3 industrial seismic arrays would have ensonified the underwater environment of most of the northern part of Baffin Bay during the early part of the narwhal fall migration, and 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 parts of the period.

The general proximity in space and time of the seismic survey activity and the 2008 and 2009–10 ice entrapments leads us to propose as a possibility that there was a causal connection, with the seismic surveys in 2008 and 2009 interrupting the outmigration of narwhals and prompting them to return to the summering grounds which would eventually be covered with fast ice. Although direct proof of such a connection is not possible in retrospect and would be difficult even in a "real-time" situation, we believe a very cautious approach to seismic surveys in narwhal habitats is warranted. This remains true even if, as an alternative hypothesis, the recent entrapments are considered stochastic events, possibly more related to climate change than to the disruptive effects of industrial activity within the Baffin Bay region.

Persistent disturbance of narwhals (and other acoustically sensitive Arctic species) could disrupt important behavior, cause the animals to abandon important summering areas, and change their migration patterns. As they leave the summering grounds, narwhals are generally heading towards winter feeding grounds, and disturbance could cause them either to return and risk ice entrapment or to move to wintering areas that are sub-optimal for feeding. Considering that narwhals already appear to be approaching their physiological capacity and may have little flexibility to adjust their swimming and diving behavior (Williams et al., 2010), it seems critical that the whales are not disturbed to such an extent that their basic annual cycle is disrupted.

We conclude that extreme caution should be taken by companies and agencies involved in planning and conducting marine seismic surveys in or in close proximity to narwhal summering grounds and migratory routes. We also identify as an urgent research priority specific studies on the effects of seismic airgun noise on narwhals (and belugas). Such studies should include assessment of the effects of airgun noise on escape movements (dosis response experiments), migratory movements, diving activity, vocalizations and, if possible, heart rate changes during long dives. Given the uncertainty in relation to potential population effects of seismic noise, it is also recommended to monitor the population trends of exposed narwhal populations carefully.

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