Review of Marine Mammal Monitoring and Mitigation Data and Outcomes for 2-D Seismic Surveys in the Canadian Beaufort Sea, 2006–2012

Prepared by

LGL LIMITED
environmental research associates

Prepared for

Fisheries and Oceans Canada

LGL Project FA0150
31 March 2018

Review of Marine Mammal Monitoring and Mitigation Data and Outcomes for 2-D Seismic Surveys in the Canadian Beaufort Sea, 2006–2012

Prepared by

Meike Holst, Valerie D. Moulton, Travis Gerwing, and Ross E. Harris

LGL Ltd., environmental research associates
388 Kenmount Road, PO Box 13248, Stn. A
St. John's, Newfoundland and Labrador A1B 4A5

Prepared for

Fisheries and Oceans Canada
501 University Crescent
Winnipeg, Manitoba R3T 2N6
Contract Authority: Jody Willis

LGL Project FA0150
31 March 2018

Suggested format for citation:

Holst, M., V.D. Moulton, T. Gerwing, and R.E. Harris. 2018. Review of Marine Mammal Monitoring and Mitigation Data and Outcomes for 2-D Seismic Surveys in the Canadian Beaufort Sea, 2006–2012. LGL Report FA0150. Report by LGL Limited, St. John’s, NL for Fisheries and Oceans Canada, Winnipeg, MB. 31 p.

Table of Contents

Page

List of Figures

Page

List of Tables

Summary

It has been recognized for some time that sound emitted from airguns, such as those used in offshore seismic surveys, affect marine mammals. To minimize potential effects of airgun sound on cetaceans and pinnipeds, seismic survey operators are required to coordinate and conduct marine mammal monitoring and mitigation programs which include pre-season spatial and temporal planning, visual watches by marine mammal observers (MMOs), shut downs of the airgun array under certain circumstances, and ramp up delays if marine mammals are seen in prescribed safety (shut down) zones by the MMOs. However, the extent to which these measures, individually and collectively, are successful in minimizing effects on marine mammals is still not well known. Here, we examine multiple years of MMO data collected during GX Technology Canada Ltd.'s 2-D seismic surveys in the Canadian Beaufort Sea as a means to examine the efficacy of the monitoring and mitigation measures employed during those programs. The results indicate that MMOs were able to detect bowhead whales within and beyond the designated safety zones (500–2500 m), when visibility permitted (daylight, no fog, and calm seas), and that two observers were more effective at detecting bowhead whales than a single observer. As expected, the data also showed that sea states >4 on the Beaufort wind force scale had a negative influence on sighting rates. Recommendations are made regarding future arctic seismic programs including the continued use of enhanced mitigation measures in areas where bowhead whales aggregate seasonally for foraging.

1.0 Introduction

It has been recognized for some time that sounds emitted from airguns, such as those used in offshore seismic surveys, affect marine mammals. Those potential effects include: masking of natural sounds, behavioural disturbance and, at least in theory, hearing impairment, or non-auditory physical or physiological effects (Richardson et al. 1995; Gordon et al. 2004; Nowacek et al. 2007; Southall et al. 2007; Weilgart 2007). General guidelines and specific measures have been developed in many international jurisdictions to mitigate those potential effects. In Canada, the "Statement of Canadian Practice with respect to the Mitigation of Seismic Sound in the Marine Environment" (SOCP), published by the federal department of Fisheries and Oceans Canada (DFO), specifies the minimum standards for the conduct of seismic surveys in Canadian marine waters (DFO 2008). However, more stringent monitoring and mitigation requirements have been developed and implemented in some Canadian areas of special concern, including the western Arctic, and in some cases with co-management partners. DFO, Central and Arctic Region, is seeking to examine existing marine mammal monitoring data collected during 2-D seismic surveys in the Canadian Beaufort Sea (CBS) across multiple years to determine whether monitoring and mitigation measures can be enhanced to further minimize the potential for effects on marine mammals.

During the open-water seasons of 2006, 2007, 2008, 2010, and 2012, GX Technology Canada Ltd (GXT) conducted 2-D seismic surveys in the CBS. The first four years of those surveys covered extensive areas of the offshore CBS; during 2012 the surveys were limited to a much smaller area offshore the Yukon coast, near the border with Alaska (Figure 1). Environmental assessments (EA) were prepared prior to each year of operations and included monitoring and mitigation plans to minimize potential effects on cetaceans, in particular bowhead whales (*Balaena mysticetus*) and beluga whales (*Delphinapterus leucas*) (LGL et al. 2006; LGL and Canning & Pitt 2007; LGL 2008; Upun-LGL 2010; GXT 2011). Those plans were developed with the input of DFO and local stakeholders, notably the Hunter and Trapper Committees (HTCs) of the Inuvialuit Settlement Region (ISR), who wanted to ensure that seismic operations did not affect their annual subsistence harvest of beluga whales. The Inuvialuit Environmental Impact Screening Committee (EISC) and the National Energy Board (NEB) separately screened the assessments; their responses included mitigation recommendations and conditions. The plans evolved each year, in some ways during the actual seismic program, and included pre-season planning, continuous visual watches by marine mammal observers (MMOs) during daylight, data recording procedures, and shut down of the airgun array and ramp up delays if marine mammals were detected by MMOs in the prescribed, region-specific safety (shut down) zones (SZ). Key mitigation measures for these 2-D seismic surveys not only included a conservative SZ, but also had enhanced mitigation measures in areas where foraging bowheads were aggregated.

Five species of marine mammals occur regularly in the CBS during late summer and autumn and could have been encountered during GXT's seismic programs—two species of whales (beluga and bowhead), two species of seals (ringed and bearded; *Pusa hispida* and *Erignathus barbatus*), and polar bear (*Ursus maritimus*). Gray whales (*Eschrichtius robustus*) also occur periodically in the CBS. Bowhead whales that occur in the CBS are from the Bering-Chukchi-Beaufort Sea population; this population is listed on Schedule 1 of the *Species at Risk Act* (*SARA*) as Special Concern and is also considered Special Concern by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC). The beluga whales in the study area are from the Eastern Beaufort Sea population which has no status under *SARA* and is listed as Not at Risk by COSEWIC. The polar bear is listed on Schedule 1 of *SARA* as Special Concern and is

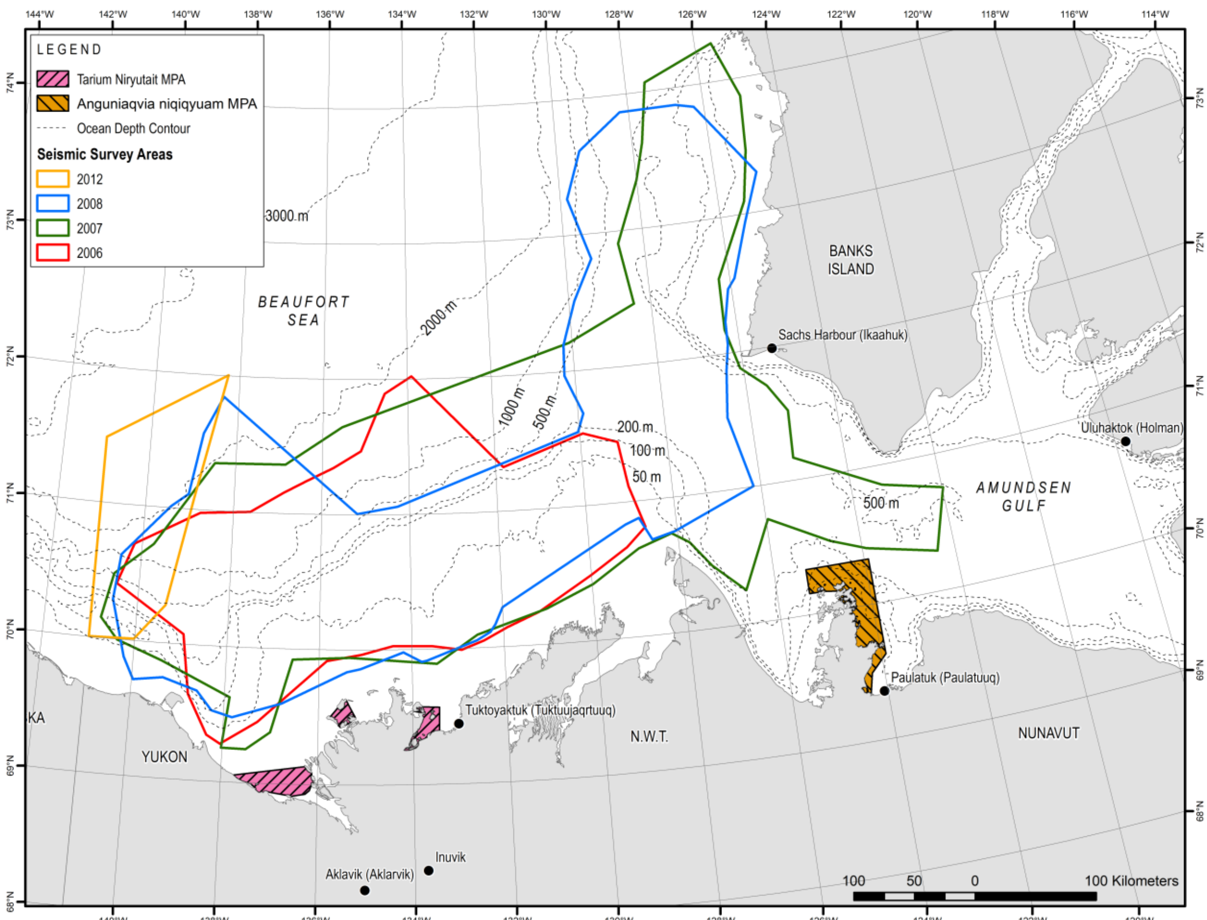


FIGURE 1. Boundaries of the seismic survey areas in the Canadian Beaufort Sea during 2006–2008 and 2012. Note that the Anguniaqvia niqiqyuam MPA was not established until 2016.

also considered Special Concern by COSEWIC. The gray whale and seals that occur in the region have no status under *SARA*. Ringed seals, bearded seals, and polar bears are resident in this region, but make local and extensive migratory movements within and beyond the CBS. They are often associated with sea ice when present.

During the period of GXT seismic programs, belugas and bowhead whales were expected to be foraging as well as migrating west out of the CBS to wintering areas in the Bering Sea. Most bowhead whales migrate westward from late August through mid or late October, and belugas begin to migrate west during August and September. Bowhead whales feed in several aggregation areas throughout the Beaufort Sea, and move to some extent between these areas during a season, and also exhibit fidelity to areas between years (Harwood et al. 2009; 2017). Aerial survey data have also shown seasonal variation in the location of the aggregation areas, as well as year-to-year variation (e.g., Richardson et al. 1987; Harwood and Smith 2002). A satellite telemetry study found that bowhead whales spend the greatest proportion of their time (59%) during late summer lingering (inferred to be foraging) in Canadian waters; they do this in relatively localized aggregation areas, using only 14.1% of the total area they travelled through in Canadian waters during August and September (Harwood et al. 2017).

Here we examine data gathered by MMOs during GXT's 2-D seismic surveys, across multiple years, to assess aspects of the outcomes and data produced by these programs, with the goal of examining the effectiveness of the monitoring and mitigation program to reduce potential negative effects of airgun sound on marine mammals. We explore three types of information collected by MMOs on the survey vessels during the course of regular operations in 2006–2009, focusing on (1) circumstances of airgun(s) shut downs for marine mammals; (2) behaviour of marine mammals recorded by MMOs; and (3) factors influencing MMO performance. Prior to this report, these data sets have not been analyzed across years or combined, and we seek through examination of multiple years of MMO data to elucidate trends and develop recommendations as to possible enhancements or modifications to monitoring and mitigation measures to further minimize the potential negative effects of airgun sound on marine mammals. Data gaps and ways to address those gaps to further develop standards and a knowledge base for decision making in the Canadian Arctic have also been identified.

2.0 Overview of 2-D Seismic Surveys and Monitoring Programs

During 2006–2012, GXT conducted five 2-D seismic surveys in the CBS. The design of GXT's 2-D seismic surveys were unique in that they were basin-wide surveys with widely and irregularly spaced survey lines designed to examine the basin-wide oil and gas bearing geology of the region. LGL Limited and Upun-LGL Limited were contracted by the operator to conduct the marine mammal monitoring programs in 2006, 2007, 2008, and 2012; these years form the basis of this report (Harris et al. 2007, 2008, 2009; GXT 2011).

2.1 Seismic Surveys

The initial three years of GXT's seismic programs in the CBS, 2006–2008, had extensive spatial coverage (see Figure 1). They were basin-wide surveys that ranged from the Alaska/Yukon maritime border in the west, to Amundsen Gulf in the east, and north to offshore northwestern Banks Island. The 2012 program, on the other hand, was limited to the waters offshore from the Yukon coast within Canadian waters but extended well west through the Canada-U.S. Disputed Zone and into the Alaskan Beaufort Sea. Table 1 presents summary information regarding each year's program.

The GXT 2-D seismic programs during 2006–2008 were conducted during the late summer and autumn periods, generally when the extent of open water was at its maximum for the year. Each year's program covered a large area of the CBS. Thus, a wide area was surveyed briefly as opposed to the repeated ensonification of a much smaller area as is typical of a 3-D seismic survey. The initial program in 2006 involved only the seismic source vessel (M/V *Discoverer*); there were no observations from a support vessel, but the M/V *Nunakput* delivered supplies and conducted crew transfers occasionally. The 2007 and 2008 seismic programs were carried out with the source vessel M/V *Binhai 517* and a support vessel, the M/V *Alex Gordon*. The *Alex Gordon'*s primary roles were to scout for ice, resupply the *Binhai*, facilitate crew changes, and provide an additional platform for marine mammal observations. The same airgun array was used during 2007 and 2008; the array was smaller during 2006 (Table 1).

TABLE 1. Summary of GXT Beaufort Sea 2-D seismic surveys conducted during 2006–2008 and 2012.

Year	2006	2007	2008	2012
Seismic Operations				
Area	Cdn Beaufort Sea	Cdn Beaufort Sea	Cdn Beaufort Sea	Offshore Yukon
Start Date	Aug 31	Aug 10	Aug 2	Oct 24
End Date	Oct 4	Oct 4	Oct 1	Nov 9
Total acquisition (km)	5069	5600	7174	224
Water Depth (m)				
Minimum	20	20	20	20
Maximum	2000	>3000	>2500	3000
Source Vessel (M/V)	*Discoverer*	*Binhai 517*	*Binhai 517*	*Geo Arctic*
Length (m)	72	60	60	81.8
Width (m)	16	15	15	14.8
Bridge Height asl (m)	11.6	6.3	6.3	10.8
Support Vessel (M/V)	No support vessel	*Alex Gordon*	*Alex Gordon*	*Polar Prince*
Length (m)		62.5	62.5	67.1
Width (m)		13.7	13.7	15
Bridge Height asl (m)		9.3	9.3	9.4
Airgun Array (standard operating conditions)				
Volume (in^3)	3320	4128	4128	4380
Number of airguns	36	32	32	26
Volume of smallest airgun	40	72	72	70
Source Level (dB re 1µPa @ 1 m rms)	236	239	239	221
Distance behind bridge (m)	144	104	104	100
Deployment depth (m)	8.5/6.5*	6.5	6.5	8.5

* Array depth was 8.5 m below the surface from August 31 to September 8, then was raised to 6.5 m for the rest of the program.

The 2012 seismic program occurred much later in the year, commencing in late October and continuing in Canadian waters into November before ice conditions forced the end of operations there. The total program in Canadian waters was much smaller than the programs conducted during 2006–2008. The seismic source vessel M/V *Geo Arctic* was accompanied by the support vessel M/V *Polar Prince*. The primary roles of the *Polar Prince* were to scout for ice, resupply the *Geo Arctic*, and provide an additional platform for marine mammal observations during daytime and nighttime.

2.2 Monitoring and Mitigation Measures

A Marine Mammal Mitigation and Monitoring Plan (MMMMP) was developed each year specifically for the CBS by the stakeholders, based initially on previous mitigation and monitoring programs conducted by LGL in the Alaskan Beaufort Sea. The mitigation strategy evolved over time, as more data and experience were gained, and with input from all of the stakeholders including GXT, DFO, the EISC, the Inuvialuit Fisheries Joint Management Committee (FJMC), and local community HTCs. The Beaufort-specific MMMMPs were designed to minimize the effects of seismic operations on bowhead and beluga whales, swimming polar bears and on subsistence hunting within the ISR. The MMMMPs consisted of four primary components: (1) spatial and temporal planning to avoid or enhance mitigation in sensitive times or areas, (2) vessel-based observations, mitigation and monitoring throughout the seismic survey area, (3) SZ monitoring and invoking shut down of the airgun array and ramp up delays, and (4) enhanced visibility requirements/additional mitigation measures in bowhead aggregation areas. The smallest airgun in the array was the only airgun used during line changes.

2.2.1 Vessel-based Mitigation and Monitoring

All MMOs received training, prior to and during the season, in the mitigation and monitoring procedures. Less experienced MMOs usually were teamed with experienced MMOs when on duty to facilitate continued learning. MMOs were onboard the source vessel (typically two biologists and two Inuvialuit technicians) and the support vessel (typically one biologist and one Inuvialuit technician) throughout each seismic program (except 2006 when there were no MMOs on the support vessel). MMOs aboard the source vessel watched for whales and other marine mammals during all daylight periods while airgun operations were underway, during the 30-min periods preceding ramp up, and during numerous daylight periods without airgun operations. The observers were responsible for implementing mitigation measures (see below) and documenting the numbers, distribution, and behaviour of marine mammals, as well as recording environmental data and seismic activity states. One to four observers were on watch at a time. Although one observer attempted to scan ~270° from their vantage point on board the vessel (i.e., bridge), two observers covered the area more thoroughly as each focused on one side of the vessel. Thus, observation effort with two observers was likely double that of one observer. Little effort occurred with more than two observers.

MMOs also conducted watches from the support vessel. The role of the MMO on the support vessel was to record information on marine mammal sightings and relay when a shut down species (bowhead, gray, beluga whale; and polar bear) was nearby and there was potential for a shut down. During 2007–2008, the support vessel typically sailed ~2–3 km ahead of the seismic source vessel. It is possible that some of the marine mammals detected by MMOs on one vessel were also reported by MMOs on the second vessel. In 2012, the *Geo Arctic* and *Polar Prince* were separated by >5 km for much of the seismic survey. The *Polar Prince* was at anchor 184.7 h (38.8%) of the total time spent in Canada.

Observations usually began at first light and continued past sunset. Except for 2012, MMOs did not conduct observations during periods of darkness. During the 2006–2008 monitoring programs, brief periods of darkness began in mid-August and there was ~11 hr of darkness each 24-hr period by early October. During the 2012 (October–November) monitoring program, there were ~7–11 hr of daylight per 24-hr period during which MMOs were on watch.

2.2.1.1 Spatial and Temporal Planning – Delay of Program Start

GXT planned data acquisition each year so that no survey lines near the primary beluga harvesting areas would be acquired until it was understood that the main part of the hunt was over.

2.2.1.2 Spatial and Temporal Planning – Maximizing Daylight Hours in Sensitive Areas

GXT timed the start of its seismic program each year to maximize the amount of surveying that would occur in bowhead aggregation areas during daylight hours. Seismic surveying was not permitted in bowhead whale aggregation areas during periods of darkness or poor visibility (e.g., fog).

2.2.1.3 Spatial and Temporal Planning – Avoidance of Beluga 1A Management Zones

GXT operations remained distant from the Beluga 1A Management Zones while the beluga hunt was active (i.e., ~19 km at the closest point of approach) and was timed so that it was well past the peak of the beluga hunting season which is usually 90% complete by the third week of July. A 22-km distance from shore of all 2-D seismic lines was also put in place to avoid interference with any coastal resource harvesting activities. The Beluga 1A Management Zones, which comprise the Tarium Niryutait Marine Protected Area (TNMPA; http://www.dfo-mpo.gc.ca/oceans/mpa-zpm/tarium-niryutait-eng.html), are key beluga harvesting areas for Inuvialuit hunters (https://fjmc.ca/co-management/maps/).

2.2.1.4 Shut Downs and Restarts

If a whale (or swimming polar bear) was seen within, or about to enter, the relevant SZ (see below), MMOs initiated a shut down of the airgun array. Shut downs were to be implemented for bowhead, beluga, and gray whales, as well as polar bears, even though these species were not listed as Endangered or Threatened on Schedule 1 of *SARA*. Shut downs typically occurred within less than 30 seconds (or within one or two "shots" from the airgun array) of the MMO instruction to the operators of the airguns.

The restart procedures following a shut down were modified during the course of the seismic programs during multiple years. In 2006 and 2007, it was permitted to restart the array at full volume without a ramp up, if (1) the array had been shut down for less than 20 min, and (2) the whale/polar bear was observed to depart the SZ. If the whale/polar bear was not observed to depart the SZ within 20 min, then the shut down continued. A restart without ramp up seldom occurred, as the typical procedure was for the ship to circle back to the point of the shut down and resume line shooting there; this could take several hours to complete, during which time no airguns, or a single small airgun, were in operation. Revised shut down/restart procedures were implemented beginning 27 August 2008, following discussions between DFO, GXT, and LGL. The airgun array could no longer resume activity at full volume without a preceding ramp up.

2.2.1.5 Ramp Ups

Airguns in the array were gradually activated until the full volume was obtained over an approximate 30-min period, thereby producing a gradual increase in sound level. That provided an opportunity for marine mammals to move away from the area before the airgun array reached maximum sound levels. Ramp up after a shut down could not begin until either (1) the whale/polar bear was observed outside the SZ, or (2) no whales/polar bears had been seen within a 30-min watch following the shut down.

2.2.1.6 Delay of Airgun Array Start Up

During daylight hours, MMOs conducted watches at least 30 min prior to the start of a ramp up. [Note that the airgun array could not be ramped up from a complete shut down if the entire SZ was not visible, such as during darkness or fog.] If the airgun(s) were silent for more than 20 min and a whale or swimming polar bear was sighted within or approaching the relevant SZ, airguns were not activated until the animal had left the SZ, or 30 min had passed, and the animal had not been re-sighted.

2.2.1.7 Airgun Operations Between Lines

Airguns often were shut down when transiting between seismic lines. Because the airgun array could not be ramped up from a complete shut down if the entire SZ was not visible, the smallest airgun in the array (40 in^3 during 2006; 72 in^3 during 2007 and 2008; 70 in^3 during 2012) was activated when the resumption of seismic activity was expected to occur during a period of poor visibility (e.g., darkness or fog). MMOs continued monitoring during periods of single airgun use and the airguns were ramped up from a single airgun before the start of the survey line.

2.2.2 Safety Zones

The size of the SZ varied among years and was based on acoustic modelling and subsequent sound source verification (SSV) measurements conducted by JASCO Research Ltd. Water depth, bottom type, and array volume all influenced the size of the SZ, which was based on a sound level threshold of 180 dB re 1 μPa_{rms}. The 180-dB threshold was used for cetaceans as it was also used at the time by the U.S. National Marine Fisheries Service (NMFS) (Southall et al. 2007). For the 2006 program, the initial zones were 1000 m (water depth >500 m) or 1150 m (water depth <500 m) for operating array volumes >40 in^3, and 100 m (water depth >500 m) or 300 m (water depth <500 m) for an operating array volume of 40 in^3, the smallest airgun in the array that year (see Harris et al. 2007). However, additional modelling done after the program finished indicated that the radius was likely as large as 2.2 km (Zykov et al. 2007a). During the 2012 program, the SZ were as large as 2.75 km (Matthews and MacGillivray 2012).

During the 2007 and 2008 seismic programs, the final results of the JASCO modelling studies were more complex spatial maps of safety radii covering the seismic survey areas in the CBS. The maps were used by MMOs aboard the source vessel to determine the appropriate SZ, based on the geographic position of the seismic vessel. For 2007 and 2008, the map outlined five zones with different 180 dB re 1 μPa_{rms} safety radii ranging from 500–2500 m, depending on water depth (Zykov et al. 2007b; MacGillivray et al. 2008). For 2008, the final results of the modelling studies also included 190 dB (for polar bears in the water) safety radii.

2.2.3 Bowhead Aggregation Areas

Bowheads are known to concentrate traditionally in certain general areas of the CBS during late summer and autumn, presumably where feeding conditions are good. However, the specific areas and timing of use of those areas vary from year to year and shift to some extent during a given season under the influence of prevailing winds and currents (see review in Harwood et al. 2017). Previous seismic programs in the CBS have demonstrated that feeding bowheads do not necessarily abandon a feeding area because of the presence of an operating seismic vessel (Miller et al. 2005; Harris et al. 2007). In fact, in many cases feeding bowheads do not move away in the presence of an approaching seismic vessel; the degree of avoidance varies among individuals. Shut downs mitigate the risk of marine mammals incurring hearing impairment (or potential physical effects) that may otherwise have been exposed, and also mitigate or moderate temporary or longer-term displacement from key feeding areas. However, the mitigation is most effective when the full SZ (based on acoustic modelling) is visible to MMOs, which means this mitigation measure is ineffective during darkness and at best, limited during times of poor visibility (e.g., fog, high sea states). It was thus part of the MMMMP that seismic surveying could not be conducted within known, inferred, or probable bowhead feeding areas (BAAs) during periods of darkness or when visibility was poor. To facilitate implementation of that mitigation measure, it was necessary to (1) define BAAs (i.e., what density of bowheads constitutes an aggregation), (2) document the real-time distribution of bowheads in these areas and the region, and (3) use the available distributional data to identify the location and spatial extent of the BAAs.

Once the BAAs were defined each year, they were plotted on the seismic survey charts and became another "feature" of the seismic survey's operating plan for that year. Having clearly defined areas where the full-visibility mitigation measure was in effect allowed the seismic operator a greater degree of certainty when developing their seismic survey strategy. In the Arctic, this is particularly important because seismic operators also have to consider sea ice conditions, the subsistence beluga hunt, other marine mammal shut downs, diminishing hours of daylight, and unpredictable weather conditions, all within a short operating season, typically August to early October (D. Kennedy, GXT, *in* Harwood et al. 2009).

In 2006, BAAs based on historical survey data were mapped prior to the start of the program. No seismic activity was to be permitted in those areas during periods of darkness or poor visibility. On 4 September 2006, an aerial survey was conducted by LGL and DFO to verify whether there was a BAA off the Tuktoyaktuk Peninsula. Since the strategy was just being developed in 2006, and the definition of a BAA was not yet clear or agreed to by all the stakeholders, the historical survey data were used to define BAAs throughout the 2006 season.

For the 2007 and 2008 programs, BAAs were clearly delineated early in the seismic season and agreed to by DFO, GXT, and other stakeholders. During August 2007 and 2008, DFO flew aerial surveys of much of the southern CBS to document the distribution of bowhead whales, with funding for the surveys from government, land-claim organizations, and industry. The BAAs for each of those years were identified using the year-specific aerial survey data (Figure 2) and were forwarded to MMOs aboard the seismic vessel during August of each year. MMOs applied the BAA-specific mitigation measures when seismic acquisition occurred there (Harris et al. 2008, 2009; Joynt and Harwood 2009; Smith et al. 2013). During the brief periods in August before the aerial survey results were available, the 2007 program used the historical BAAs, and the 2008 program used the 2007 BAAs. The ship-based MMOs documented a BAA offshore from the northwestern coast of Banks Island, beyond DFO's aerial survey coverage, during the 2007 program. That BAA was included in the 2008 program.

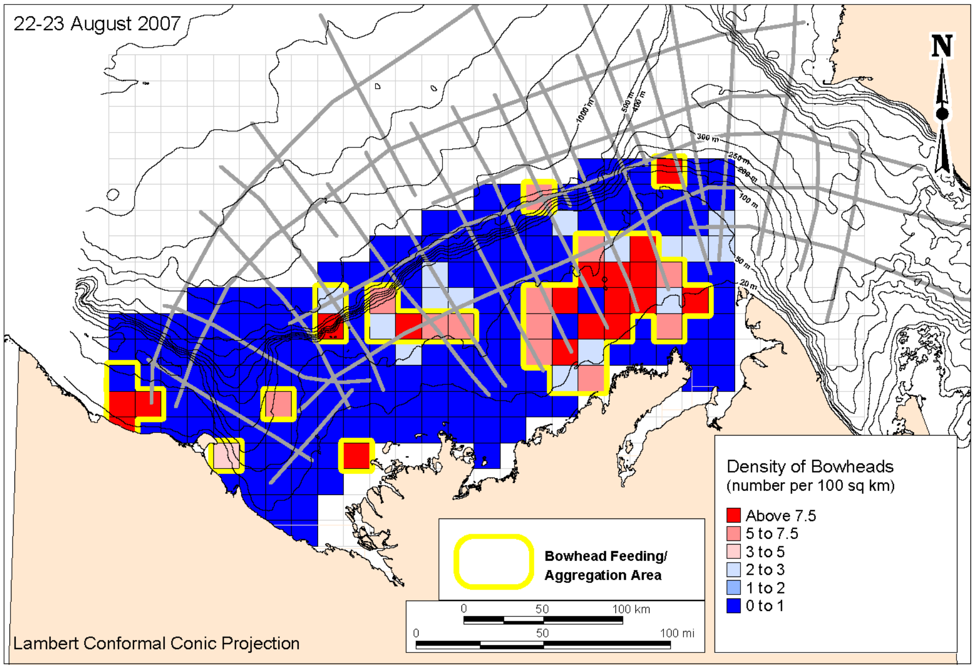


FIGURE 2. Example of bowhead aggregation/feeding areas for 2007, based on aerial surveys conducted by DFO on 22 and 23 August 2007 (LGL Limited 2008). Gray lines depict GXT's planned seismic survey lines.

BAA-specific mitigation measures included:

- at least two MMOs on watch simultaneously during seismic activity;
- no seismic activity was permitted when, in the opinion of any MMO on duty, the full SZ was not visible (e.g., during fog or darkness); and
- the airgun array was shut down if, in the opinion of any MMO on duty, the sea state was such that bowhead whales could not readily be detected.

2.3 Summary of Monitoring Effort

Overall, during all four programs (2006–2008, 2012), a total of 1418 h of MMO observations took place from the support vessels, and 2539 h occurred from the seismic vessels (Table 2). Of the total observation effort from the seismic vessels, most effort (65%) occurred when the full airgun array was operational, 13% took place when the airgun array was operating at less than full power, and 22% occurred when no airguns were active (Table 2). Observation effort was lowest in 2012, as little effort occurred in Canadian waters (Table 2). Approximately 46% of observations from the seismic vessels were made by one observer, and 49% were made by two observers; these proportions were similar during all seismic and non-seismic periods (Figure 3). Overall, most observation effort from the support vessels (80%) was conducted by a single observer; two observers were on watch for 19% of the time, with more than two observers on watch for the remaining effort (Figure 3).

TABLE 2. Marine mammal observer effort (in hours) from the seismic and support vessels during various seismic activity states.

Year	Effort (h)[1]						
	Seismic Vessel						Support Vessel
	No Airguns	Single Airgun	Ramp Up	Unknown Volume	Full Array	Total Effort	
2006	121.2	32.2	19.4	6.2	295.5	474.5	N.A.
2007	219.4	125.3	22.9	9.3	567.1	944	730.5
2008	178.6	61.7	32.1	5.3	769.7	1047.4	591.1
2012	44.1	9.8	4.1	8.5	6.6	73.1	96.2[2]
Totals	563.3	229.0	78.5	29.3	1638.9	2539	1417.8
Percentages	22.2%	9.0%	3.1%	1.2%	64.5%	100%	100%

N.A. = not available; no support vessel during 2006.

1 Not standardized by number of MMOs on watch.

2 During daylight. An additional 45 h and 47.7 h of observational effort occurred during darkness and at anchor during daylight, respectively.

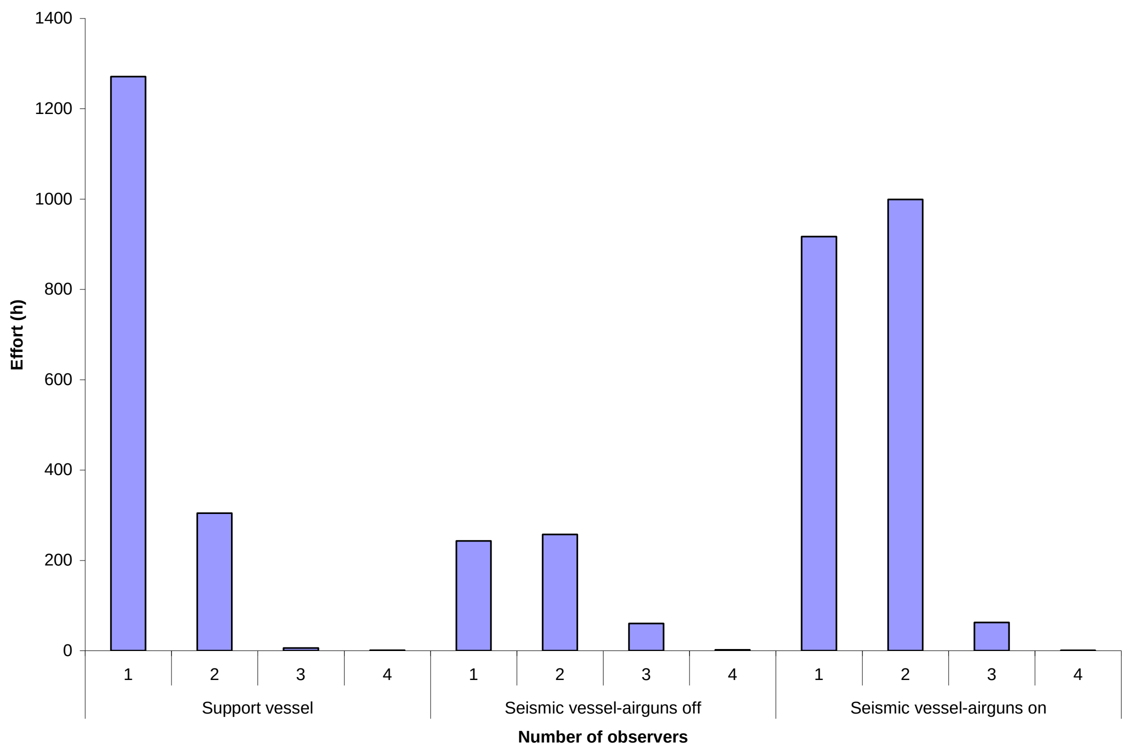


FIGURE 3. Number of observers on watch from the seismic and support vessels during the Beaufort Sea seismic programs conducted in 2006–2008 and 2012.

2.4 Summary of Marine Mammal Sightings

During all programs combined, the most frequently sighted marine mammal was the bowhead whale (762 sightings), followed by the ringed seal (534 sightings), bearded seal (86), and beluga whale (18) (Table 3). In addition, one walrus, a group of four gray whales (the same group was seen from both the source and seismic vessels), and six sightings of eight polar bears were made (Table 3). The remaining sightings were of unidentified whales (38) and unidentified seals (147). Approximately 44% of all bowhead whale sightings were made from the support vessels, 37% occurred from the seismic vessel when the full array was operating, and 13% were made from the seismic vessel when no airguns were active (Table 3). Half of all ringed seal sightings were made from the support vessel; 25% were made during full-array operations, and 17% were made from the seismic vessel when no airguns were active (Table 3). Most sightings were made in water <100 m deep, where seismic surveying and observational effort were also concentrated.

TABLE 3. Number of initial marine mammal sightings (and individuals) from the support and seismic vessels during various seismic activity states.

Year	Species	Number of Sightings (Individuals)							Combined Total
		Seismic Vessel						Support Vessel	
		No Airguns	Single Airgun	Ramp Up	Unknown Volume	Full Array	Total Seismic		
2006[1]									
	Bowhead Whale	4 (9)	6 (6)	2 (2)	1 (1)	52 (88)	65 (106)	N.A.	65 (106)
	Beluga Whale	1 (5)	0	1 (4)	0	0	2 (9)	N.A.	2 (9)
	Ringed Seal	8 (10)	0	0	0	6 (6)	14 (16)	N.A.	14 (16)
	Bearded Seal	2 (2)	0	0	0	0	2 (2)	N.A.	2 (2)
	Unidentified Seal	0	0	0	0	2 (2)	2 (2)	N.A.	2 (2)
2007[2]									
	Bowhead Whale	78 (136)	26 (48)	6 (8)	2 (2)	100 (185)	212 (379)	125 (182)	337 (561)
	Beluga Whale	0	0	0	0	4 (16)	4 (16)	8 (95)	12 (111)
	Gray Whale	0	0	0	0	1 (4)*	1 (4)	1 (4)*	2 (8)
	Unidentified Whale	1 (1)	2 (2)	0	0	4 (4)	7 (7)	23 (29)	30 (36)
	Ringed Seal	52 (144)	27 (35)	12 (18)	4 (16)	70 (235)	165 (448)	186 (432)	351 (880)
	Bearded Seal	8 (9)	10 (11)	0	0	7 (7)	25 (27)	29 (59)	54 (86)
	Unidentified Seal	22 (83)	5 (5)	1 (1)	1 (1)	15 (16)	44 (106)	49 (99)	93 (205)
	Walrus	0	0	0	1 (1)	0	1 (1)	0	1 (1)
	Polar Bear	0	0	0	1 (1)	0	1 (1)	3 (5)	4 (6)
2008[3]									
	Bowhead Whale	20 (29)	2 (6)	1 (2)	0	128 (235)	151 (272)	209 (255)	360 (527)
	Beluga Whale	1 (10)	0	0	0	2 (8)	3 (18)	0	3 (18)
	Unidentified Whale	1 (1)	0	1 (1)	2 (2)	0	4 (4)	4 (5)	8 (9)
	Ringed Seal	28 (35)	5 (5)	4 (5)	0	56 (92)	93 (137)	72 (162)	165 (299)
	Bearded Seal	7 (7)	0	2 (2)	0	11 (12)	20 (21)	9 (9)	29 (30)
	Unidentified Seal	5 (5)	2 (2)	0	2 (2)	19 (25)	28 (34)	24 (26)	52 (60)
	Polar Bear	0	0	0	0	0	0	2 (2)	2 (2)
2012[4]									
	Beluga Whale	0	0	0	0	0	0	1 (1)	1 (1)
	Ringed Seal	2 (2)	0	0	0	0	2 (2)	2 (2)	4 (4)
	Bearded Seal	0	0	0	0	0	0	1 (1)	1 (1)
Overall									
	Bowhead Whale	102 (174)	34 (60)	9 (12)	3 (3)	280 (508)	428 (757)	334 (437)	762 (1194)
	Beluga Whale	2 (15)	0 (0)	1 (4)	0 (0)	6 (24)	9 (43)	9 (96)	18 (139)
	Gray Whale	0 (0)	0 (0)	0 (0)	0 (0)	1 (4)*	1 (4)	1 (4)*	2 (8)
	Unidentified Whale	2 (2)	2 (2)	1 (1)	2 (2)	4 (4)	11 (11)	27 (34)	38 (45)
	Ringed Seal	90 (191)	32 (40)	16 (23)	4 (16)	132 (333)	274 (603)	260 (596)	534 (1199)
	Bearded Seal	17 (18)	10 (11)	2 (2)	0 (0)	18 (19)	47 (50)	39 (69)	86 (119)
	Unidentified Seal	27 (88)	7 (7)	1 (1)	3 (3)	36 (43)	74 (142)	73 (125)	147 (267)
	Walrus	0 (0)	0 (0)	0 (0)	1 (1)	0 (0)	1 (1)	0 (0)	1 (1)
	Polar Bear	0 (0)	0 (0)	0 (0)	1 (1)	0 (0)	1 (1)	5 (7)	6 (8)

*Same group seen from seismic and support vessel. N.A. = not applicable; no support vessel in 2006.

[1] Harris et al. (2007). [2] Harris et al. (2008). [3] Harris et al. (2009). [4] Smith et al. (2013).

3.0 Methods

Details of airgun array shut downs, cetacean behaviours recorded by MMOs, and "MMO performance" from the four program years were analyzed as outlined in the scope of work provided by DFO. We focused our analyses on bowhead whales and data from 2006–2008, since limited sample size precluded quantitatively examining the other species and bowheads in 2012. Bowheads were the most frequently sighted marine mammal during the 2006–2008 monitoring programs (see Table 3). There were relatively few sightings of beluga whales (n=18) so these data are discussed qualitatively as are data for polar bears. There were numerous sightings of ringed seals (and fewer sightings of bearded seals), but there were no mitigation requirements specific to seals. Data analyses focus on the 2006–2008 monitoring programs because of the limited monitoring effort and number of marine mammal sightings made in 2012.

3.1 Shut downs and Ramp up Delays

Data are summarized regarding shut downs for bowhead whales, looking for patterns in seismic state (e.g., full array, one airgun), location (within/outside bowhead aggregation areas, within/approaching the SZ), bowhead group size, bowhead movement relative to the source vessel, bowhead behaviour, water depth, initial sighting distance, and number of MMOs on watch. Additionally, information on shut downs that were implemented for beluga whales and polar bears are summarized. Details of delays in ramp up that occurred during the monitoring programs are presented.

3.2 Bowhead Whale Behaviour

It was difficult for MMOs to collect detailed behavioural data, whether at the time of a shut down or even during most other periods. The combination of a limited time period available to observe a whale as the ship sailed on (thus no extended behavioural observations), and the need to keep a constant watch of the SZ, meant that MMOs could devote limited effort to recording observations. Typically, only one or two behavioural codes were recorded during most sightings. During most shut downs, the bowhead simply dove and was not re-sighted. Data on bowhead behaviour other than during shut downs are summarized for:

- sightings made within and beyond the SZ;
- sightings made from the source vs. support vessel; and
- group size from the source vs. support vessel.

3.3 MMO Performance: Factors Affecting Sighting Distances and Rates

We conducted tests for statistically significant differences in bowhead whale sighting rates and distances relative to factors that are known or suspected to influence these rates (e.g., number of observers, sea state, etc.) independent of the individual MMO conducting the watch. Sighting distances and rates are affected by a suite of related factors that must be considered when conducting comparative analyses. A key factor for observations conducted during a seismic survey is whether airguns are active or inactive. Lower sighting rates and greater sighting distances are expected if bowhead whales were avoiding airgun array sound. Environmental factors like sea state and fog/precipitation (i.e., visibility) can negatively affect sighting rates and distances by making it more difficult for MMOs to consistently and reliably detect marine mammals. Natural factors like location (i.e., within or outside a BAA, water depth) and date would also likely affect sighting rates and possibly distances. The type of vessel (seismic versus support), the height of the MMO's viewing location above sea level, and number of MMOs on watch may also influence sighting rates and distances. It is important to account for the influences of these factors when comparing how effective an individual MMO was at detecting bowhead whales. The experience level of the MMO conducting the watch may also affect how many whales and at what distance they are detected, but was not examined.

3.3.1 Sighting Distances

In addition to summarizing sighting distance data (radial distance between the observer and initial sighting), Mann-Whitney *U* tests were performed to compare sighting distances recorded in various Beaufort wind force (Bf) conditions, time of day, vessels, and activity states (seismic periods from source vessel, non-seismic periods from source vessel, support vessel whether airguns were operating nearby or not, ramp up). Initial sighting distances of bowheads (distance at which an animal was first seen) were compared during the three different vessel activities (seismic periods, non-seismic periods, support vessel) in Bf >4 (i.e., 5–8) and Bf ≤4. Four 6-hr periods were chosen for time of day: morning (00:00 to 06:00); midday (06:00 to 12:00); afternoon (12:00 to 18:00); and night (18:00 to 24:00). Vessel type included two categories: source vessel and support vessel. Periods when visibility was <3.5 km (~20% of all effort) were excluded from the sighting distance data.

3.3.2 Sighting Rates

Two approaches were used to test for statistical differences in bowhead whale sighting rates relative to factors that are known or suspected to influence these rates. First, a permutational multivariate analysis of variance (PERMANOVA) was performed using the software PRIMER V7 to identify which variables were statistically correlated with bowhead whale sighting rates. However, this required that data were standardized by number of observers and that only sea state conditions Beaufort 0–4 were used. As such, observer number and Bf could not be properly assessed in this analysis. Therefore, regression analyses were used to explore the relationships between whale sighting rates and Bf and number of observers. The details of each analysis, as well as the standardization used, are provided below.

As the number of observers and observer hours varied between vessels, we standardized whale sighting rates by dividing the number of whales observed by the number of hours searched (number of observers multiplied by the number of hours searched). We excluded sighting data from periods when Bf >4, visibility was <3.5 km, and vessel speed was <3 or >5 kt. Multivariate statistics were then used to examine the data. While multivariate statistics are normally run using multiple response variables, they can be used to examine single response variables (Anderson et al. 2008; Clarke and Gorley 2015) that are either biological or abiotic (Gerwing et al. 2015a,b, 2016, 2017). Here, the response variable was bowhead whale sighting rate, which was derived using a resemblance matrix constructed using Euclidian distances from sighting rates. The data from which the resemblance matrix was calculated was visually evaluated using shade plots to determine if the data required a transformation, while the spread of dependent variables were evaluated using draftsman plots. Based on examination of the shade and draftsman plots, no transformations were required or applied either to dependent or independent variables. A PERMANOVA was then conducted, using 9999 permutations, quantifying correlations between sighting rates and the variables of interest. The independent variables included: Type of Vessel (Support, Source), Year (2006, 2007, 2008), and Seismic Activity (Seismic, No Seismic). For the source vessel, 'Seismic' included effort when the full array was in operation; for the support vessel, 'Seismic' included effort when the source vessel was operating its airguns within 5 km of the support vessel. We denoted statistical significance as $\alpha = 0.1$ in all analyses.

To determine if sighting rates varied in relation to the number of observers or Bf, regressions were fit using Minitab V17. For the number of observers, data were standardized by the total observation effort in hours (e.g., effort was doubled if two observers were on watch). For these analyses the entire dataset was included, retaining data from all sea state conditions and all observer numbers. In all cases linear, quadratic, and polynomial regression equations were attempted; however, only quadratic equations produced results that were significant or approached significance; therefore, we only present and discuss the quadratic equations here. Scatter plots are presented alongside the regression equations to better visualize the data.

4.0 Results

4.1 Shut Downs and Ramp up Delays

Below is a summary of the number of shut downs and ramp up delays that were implemented during the seismic programs.

4.1.1 Shut Downs of the Airgun Array

There was a total of 44 shut downs during the four monitoring programs; 37 of these occurred for bowhead whales sighted in the SZ (Table 4). In 2006, there were three shut downs for bowhead whales. In 2007, there were 15 shut downs—13 for bowhead whales (one of these was for two sightings at the same time), one for a polar bear in the water, and one for restricted visibility (fog) in a BAA. In 2008, there were 26 shut downs; 21 occurred for bowhead whales, two for beluga whales, and three for restricted visibility in a BAA. No shut downs were necessary in 2012.

Most shut downs for bowhead whales (26 of 37 or 70.3%) occurred when two observers were on watch. Approximately half of all shut downs for bowheads (19 out of 37) occurred between midnight and noon, with most of those shut downs (14 of 19) occurring between 05:30 and 11:30; all other sightings occurred between 13:45 and 21:46. Most shut downs for bowheads (22 of 37) occurred during August; 15 shut downs were implemented during September.

In addition, five shut downs took place during periods of fog when the MMOs did not have full visibility of the SZ (i.e., when visibility was <3.5 km), and two shut downs occurred during rainy conditions when visibility was >3.5 km. The most frequently-recorded (13 of 37) Bf during shut downs involving bowhead whale sightings was 5, followed by Bf = 1 and Bf = 4 (both 7 of 37).

Thirteen of 37 shut downs (35.1%) occurred for bowhead sightings within the SZ within BAAs identified in 2007 and 2008—nine of these in 2007 and four in 2008. Twenty-one occurred outside of BAAs, four in 2007 and 17 in 2008, and three occurred in 2006 as the mitigation strategy was being developed (Figure 4).

TABLE 4. Shut downs implemented for bowhead whales during the 2006, 2007, and 2008 GXT 2-D seismic surveys in the Beaufort Sea.

Initial or Subsequent Sighting	Seismic State	Aggreg. Area	No of MMOs on watch	Long	Lat	Local Date & Time	Water depth (m)	Wind force	Visibility (km)	Precipit-ation	Number of whales	Move-ment	Initial behaviour	Sighting distance (m)	CPA (m)	Final safety zone (m)
Subsequent	Full Array	UN	2	137.2	70.1	9/05/06 9:47	51	5	10	None	4	SA	SW	920	1059	1150
Initial	Full Array	UN	2	130.5	20.9	9/19/06 10:23	45	2	10	None	2	PE	BL	493	636	1150
Subsequent	Full Array	UN	2	131.0	70.7	9/22/06 19:08	40	4	10	None	1	SA	BL	920	984	1150
Subsequent	Full Array	No	1	132.3	70.8	8/15/07 19:25	57	1	10	None	1	UN	BL	1229	1320	2000
Initial	Full Array	No	1	129.6	71.3	8/16/07 13:50	49	5	10	Rain	1	SA	BL	692	783	1500
Initial	Full Array	Yes	2	130.0	71.0	8/21/07 17:14	40	2	10	None	1	SA	UN	1223	1314	1500
Initial	Full Array	Yes	3	129.9	70.9	8/22/07 0:00	32	1	10	None	1	SA	BL	880	936	1500
Initial	Full Array	Yes	1	129.9	70.8	8/22/07 5:43	30	2	10	None	1	SP	SW	150	221	1500
Initial	Full Array	Yes	2	129.7	70.6	8/22/07 13:45	23	1	10	None	1	SA	BL	1223	1278	1500
Initial	Ramp Up	Yes	1	130.4	70.5	8/22/07 18:26	26	2	10	None	1	UN	UN	UN	UN	1500
Subsequent	Full Array	Yes	2	130.6	70.7	8/23/07 1:26	36	3	10	None	1	ST	BL	1223	1314	1500
Subsequent	Full Array	Yes	2	130.6	70.7	8/23/07 1:26	36	3	10	None	1	ST	BL	692	783	1500
Subsequent	Full Array	Yes	1	130.8	70.9	8/23/07 9:04	47	5	10	None	1	SA	BL	1229	1233	1500
Subsequent	Full Array	Yes	3	131.2	70.5	8/24/07 17:13	44	1	10	None	1	NO	UN	1229	1320	1500
Initial	Full Array	Yes	3	131.2	70.5	8/24/07 20:47	44	1	10	None	1	PE	UN	1229	1333	1500
Subsequent	Full Array	No	3	125.8	74.0	9/14/07 14:52	51	5	10	None	1	UN	BL	2023	2076	1500
Initial	Full Array	No	2	125.7	73.9	9/16/07 7:39	49	4	2	Fog	1	SP	BL	688	745	1500
Subsequent	Full Array	No	1	134.0	70.6	8/03/08 1:20	22	3	>3.5	None	1	SA	BL	1229	1304	1500
Subsequent	Full Array	No	2	133.5	70.8	8/13/08 11:15	72	6	>3.5	None	1	ST	BL	482	541	1500
Initial	Full Array	No	2	131.1	71.1	8/14/08 0:55	64	5	>3.5	None	1	UN	BL	692	749	1500
Initial	Full Array	No	2	131.0	71.2	8/14/08 1:33	59	5	>3.5	None	1	UN	BL	1229	1284	1500
Initial	Full Array	No	2	131.4	71.1	8/14/08 10:17	61	5	>3.5	None	1	SP	BL	1229	1284	1500
Initial	Full Array	No	2	129.6	71.3	8/14/08 20:54	52	5	>3.5	None	2	SA	BL	1229	1320	1500
Subsequent	Full Array	No	2	129.4	71.4	8/14/08 21:57	56	5	>3.5	None	4	SP	BL	1229	1284	1500
Subsequent	Full Array	Yes	2	129.9	71.1	8/16/08 17:50	43	5	<3.5	Fog	2	SA	BL	1229	1329	1500
Initial	Full Array	Yes	2	130.0	71.1	8/16/08 18:29	44	5	<3.5	Fog	2	SA	BL	692	749	1500
Subsequent	Full Array	No	1	134.0	70.3	8/18/08 15:33	45	4	>3.5	None	2	SA	BL	1229	1320	1500
Initial	Full Array	No	2	126.8	73.4	8/28/08 10:23	127	4	>3.5	None	2	SP	BL	1063	1118	1500
Initial	Full Array	No	2	128.9	71.4	9/02/08 6:13	97	2	<3.5	Fog	1	SA	BL	1063	1068	1500
Initial	Full Array	No	2	128.9	71.1	9/02/08 10:03	46	1	<3.5	Fog	1	UN	SW	150	245	1500
Subsequent	Full Array	No	2	133.1	70.4	9/08/08 18:01	38	6	>3.5	Rain	1	UN	BL	1229	1284	1500
Subsequent	Full Array	No	2	132.8	70.3	9/11/08 15:58	37	1	>3.5	None	1	SA	BL	1063	1154	1500
Initial	Full Array	No	2	133.4	70.2	9/11/08 18:53	37	UN	>3.5	None	1	SA	SW	692	749	1500
Initial	Full Array	No	2	137.5	70.0	9/12/08 21:46	74	5	>3.5	None	3	SA	BL	692	749	2000
Initial	Full Array	Yes	2	137.8	69.6	9/13/08 10:12	65	4	>3.5	None	1	SA	BL	1458	1512	2000
Initial	Full Array	No	2	138.6	70.0	9/15/08 10:24	263	4	>3.5	None	2	SA	BL	1458	1512	1500
Subsequent	Full Array	Yes	2	137.8	69.5	9/16/08 9:04	54	4	>3.5	None	2	SA	BL	1229	1320	2000
Initial	Full Array	No	2	136.8	70.1	9/23/08 11:19	22	5	>3.5	None	1	UN	BL	885	976	1500

Note:
UN = unknown or not recorded. Long = longitude. Lat = latitude. Local Date & Time = month/day/year. CPA = closest point of approach to the airgun array. Movement: SA = swim away from vessel. PE = swim perpendicular to vessel. SP = swim parallel to vessel. ST = swim toward vessel. NO = no movement relative to vessel. Initial behaviour: SW = swim. BL = blow. One shut down (on 23 August 2007) is reported twice in the table, as it involved two separate sightings.

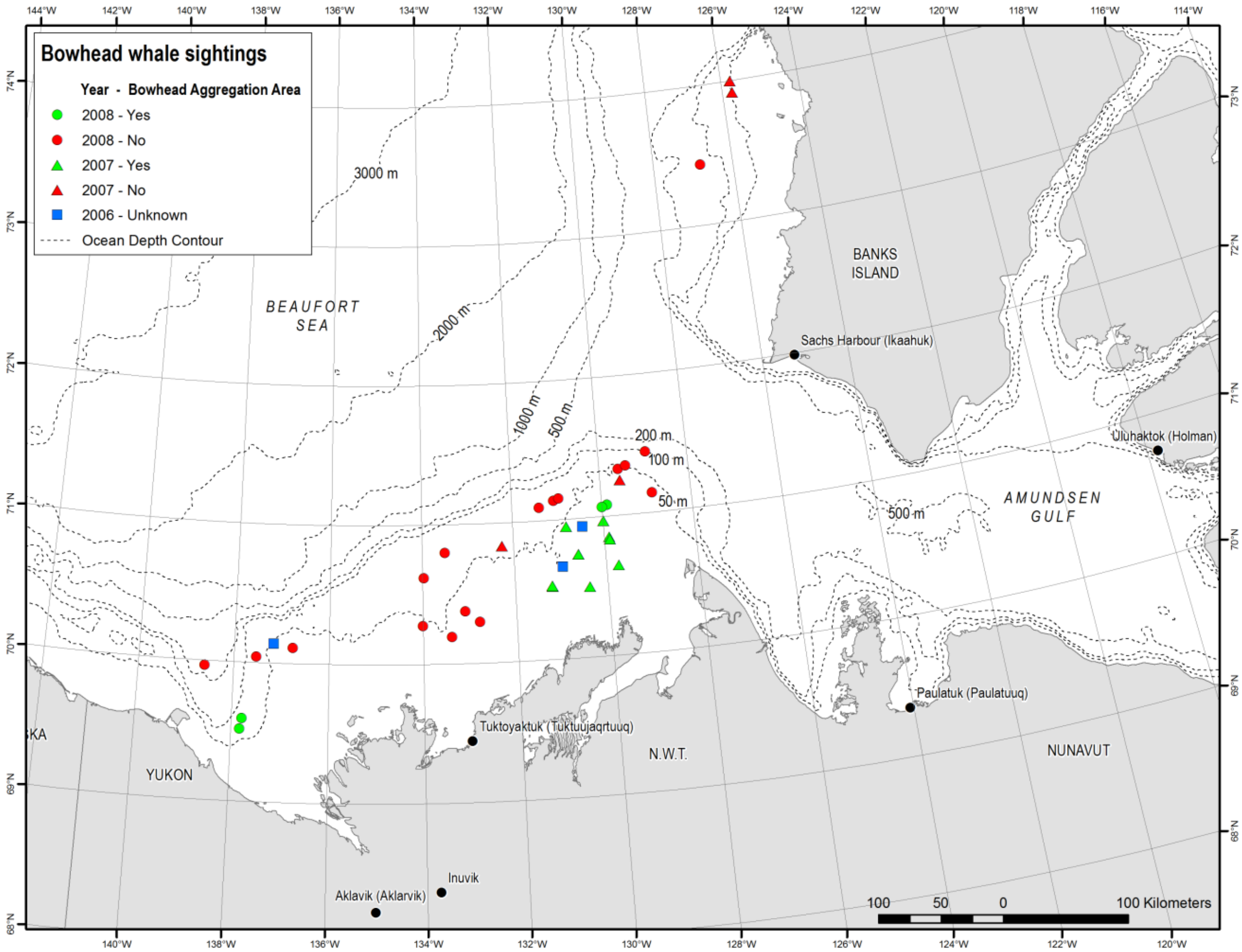


FIGURE 4. Locations of bowhead whale sightings in 2006–2008 that resulted in a shut down of the airgun array. Also shown is whether a sighting was located within (yes) or outside (no) of a Bowhead Aggregation Area (BAA).

MMOs were typically unable to obtain detailed behavioural data on the animal after a shut down was invoked. In most cases, however, the animal was not seen again after a shut down. On several (6) occasions, the same group/individual was resighted outside of the SZ several minutes after the airgun array was shut down. Although 92% of the shut downs were successfully implemented within less than a minute of the initial SZ sighting, three shut downs were delayed for up to 3 min.

In addition to the shut downs for bowhead whales, there were two shut downs for beluga whales during the 2008 program, and one in 2007 for a polar bear swimming in the water. On 12 August 2008, a group of six belugas was seen at a distance of 1230 m while the vessel was operating its full array. On 13 August 2008, two belugas were seen ~1458 m away. The SZ was 1500 m for both sightings. The polar bear was seen 330 m from the vessel on 18 September 2007 while the full airgun array was in operation. Shut downs for restricted visibility due to fog were implemented in 2007 (one shut down) and 2008 (three shut downs).

4.1.2 Delayed Ramp Ups

There were two delayed ramp ups both of which occurred during the 2008 program. One delayed ramp up occurred because a bowhead whale was detected within the SZ on 14 September; this event occurred outside of a BAA. The whale was seen again 10 min after the initial sighting and not seen again thereafter; ramp up was delayed for 40 min. The other delayed ramp up occurred on 14 August because fog restricted the visibility within the SZ in a designated BAA.

4.2 Bowhead Whale Behaviour

A summary of bowhead whale behaviour is presented below, including information regarding where initial sightings were made relative to the vessels and group size.

4.2.1 Movement Relative to the Vessel

Bowhead whales were seen swimming away, toward, parallel, and/or perpendicular to the vessel during non-seismic and seismic periods from the seismic vessels and from the support vessels (Figure 5). The most frequently-recorded movement (57% of sightings) relative to both types of vessels was 'swimming away' from the vessel; 'swimming away' was the most frequently recorded movement during non-seismic and seismic periods, within and beyond the SZ. Whales were seen 'swimming toward' the support vessels, as well as toward the seismic vessels within the SZ when airguns were operating and when beyond the SZ with the airguns off (Figure 5). However, bowheads were not observed swimming toward the seismic vessel when they were outside the SZ and airguns were on.

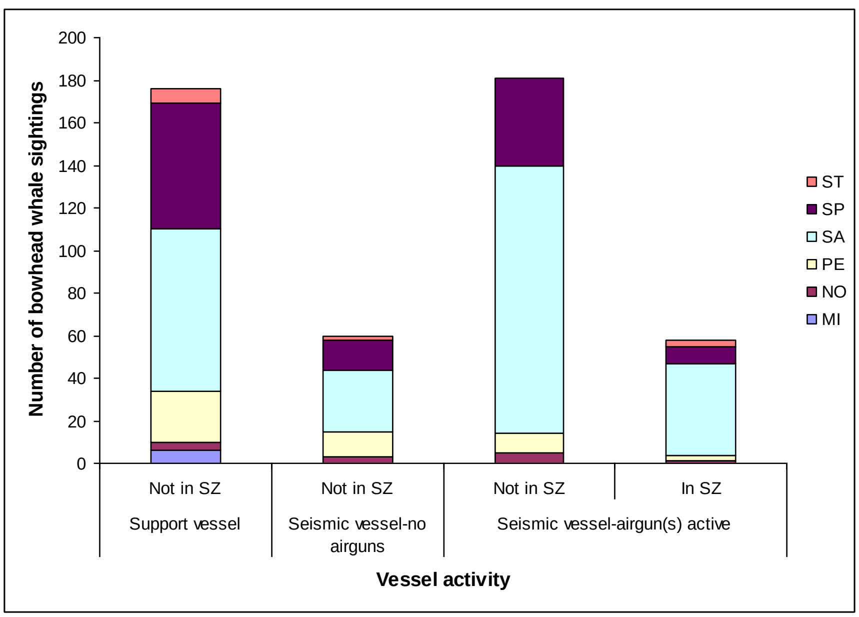


FIGURE 5. Movement of bowhead whales (number of sightings) relative to the support and seismic vessels (within and beyond the safety zone [SZ]). For non-seismic periods, 'Not in SZ' refers to sightings at any distance. SA = swimming away; ST = swimming toward; SP = swimming parallel; PE = swimming perpendicular; NO = no movement observed relative to vessel; MI = milling.

4.2.2 Group Size

The mean group size for bowhead whales sighted from the support vessels was 1.3 (n = 384; sd = 0.7; range 1–10); it was 1.8 (n = 125; sd = 1.1; range: 1–7) from the seismic vessels when the airguns were off. When the airguns were active, the mean group size was also 1.8 (n = 460; sd = 1.3; range: 1–10); it was slightly greater for animals seen outside of the SZ (1.9; n = 383; sd = 1.3; range: 1–10) than within the SZ (1.6; n = 78; sd = 1.1; range: 1–6).

4.3 MMO Performance: Factors Affecting Sighting Distances and Rates

This section examines how factors such as sea state, seismic activity, and number of observers affect bowhead whale sighting distances and rates.

4.3.1 Sighting Distances

Sighting distances during various sea states, time of day, and vessel types and activities were examined to determine how these factors influence the initial sighting distance of bowhead whales.

4.3.1.1 Beaufort Wind Force

To examine whether sea state affected sighting distance or whether sighting distances during all sea states could be pooled for the ensuing comparisons, initial sighting distances were compared during three different seismic activity states in various Bf categories. The initial sighting distances for bowhead whales were not significantly different for three different activity states (i.e., full airgun array, source vessel without seismic, and support vessel) when two different sea state conditions (Bf >4 and Bf ≤4) were compared using Kruskal-Wallis tests for each activity state. The test statistics were as follows: full array (x^2 = 0.001, df = 1, p = 0.98), no seismic (x^2 = 0.021, df = 1, p = 0.88), and support vessel (x^2 = 1.223, df = 1, p = 0.27). Thus, for the remaining comparisons, initial sighting distances during all Bf conditions were included in the analyses.

4.3.1.2 Seismic Activity

Although seismic activity does not necessarily affect MMO performance, it may affect sighting distances, so this factor needed to be examined as well. Sighting distances were compared during four different seismic activities. Bowhead whales were seen initially, on average, farther from the source vessel when the full array was operating (μ = 3056 m) and at the closest initial distance (μ = 1777 m) from the support vessel (Figure 6). The average initial sighting distance during ramp up (μ = 2516 m) was greater than that for non-seismic periods (μ = 2011 m), but smaller than for full seismic. Initial sighting distance during ramp up was only statistically significant when compared with initial sighting distance recorded during non-seismic periods (U = 273.5, p = 0.04) but not when compared with seismic periods (U = 1164.5, p = 0.95). However, the sample size during ramp up was based on only nine sightings (Figure 6). The average initial sighting distance was also significantly greater during seismic with the full array compared with non-seismic periods from the source vessel (U = 8296.5, p <0.00001). The average initial sighting distance during non-seismic periods from the source vessel and that from the support vessel were not statistically significantly different (U = 20,925, p = 0.5).

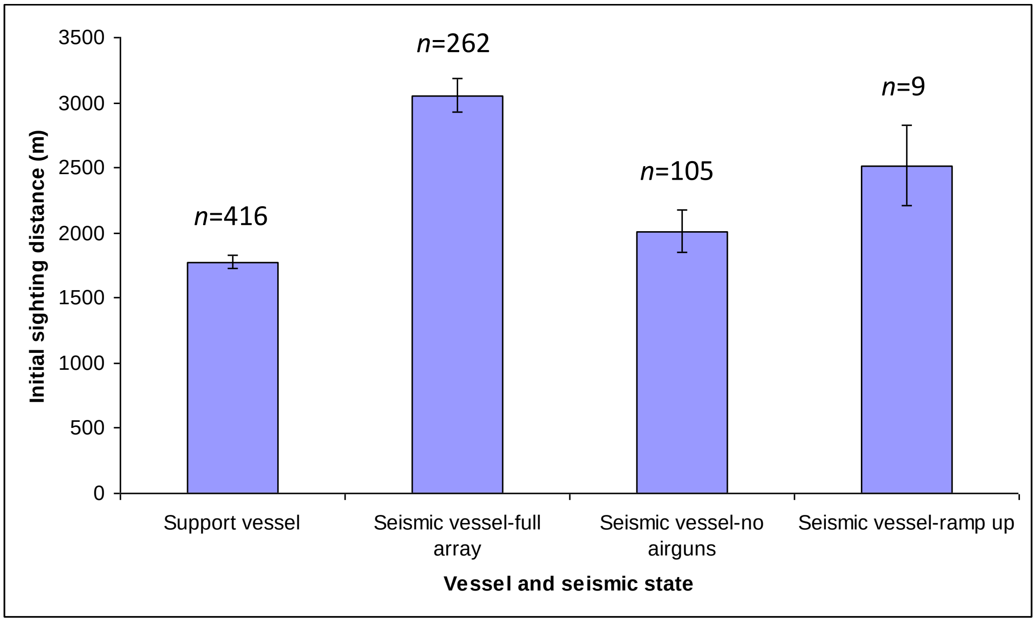


FIGURE 6. Average initial sighting distances for bowhead whales seen from the support (during all seismic states) and seismic vessels during various seismic states.

4.3.1.3 Time of Day

The influences of time of day on sighting distances were examined for 6-hr time intervals. Average initial sighting distances differed by time of day from both the support and seismic vessels, with initial sighting distances occurring closer to the vessels during 'night' (00:00 to 06:00); however, no observations were made during the dark. Average initial sighting distances were significantly lower during night versus during the midday period (12:00 to 18:00) from the support vessel (U = 1124.5, n_1 = 28, n_2 = 109, p = 0.03; μ = 1358 vs. 1715 m), the seismic vessel with the full airgun array active (U = 480, n_1 = 22, n_2 = 82, p = 0.008; μ = 1961 vs. 3595 m), and the seismic vessel without airguns active (U = 35, n_1 = 5, n_2 = 32, p = 0. 048; μ = 968 vs. 2600 m). Generally, initial sighting distances from the seismic vessel were greater during midday (12:00 to 18:00; μ = 3316 m) than during the morning (06:00 to 12:00; μ = 2629 m) or during the afternoon (18:00 to 24:00; μ = 2463 m), but sighting distances during midday, morning and afternoon were similar from the support vessel (μ = 1715 m, 1733 m, 1878 m, respectively).

4.3.1.4 Vessel Type

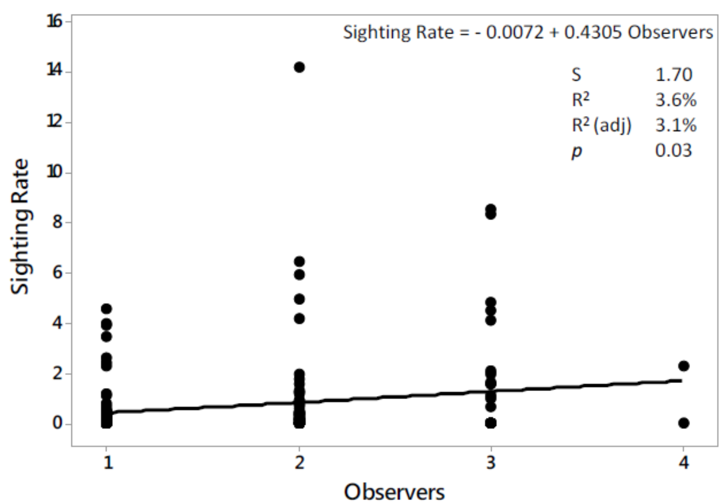
When comparing sighting distances from the support and source vessels, only data during non-seismic periods were used for the source vessel. As noted above, the average initial sighting distances were similar from the support vessels (μ = 1777 m) and seismic vessels during non-seismic periods (μ = 2011 m) (U = 20,925, n_1 = 105, n_2 = 416, p = 0.5). The average initial sighting distances did not differ significantly between the two different seismic vessels during non-seismic periods (*Discoverer*, μ = 2625 m; *Binhai*, μ = 1980 m; U = 189, n_1 = 5, n_2 = 100, p = 0.4), but the sample size for sightings from the *Discoverer* in 2006 was small. However, the average initial sighting distances did differ significantly between the two different seismic vessels when the full airgun array was active even though average sighting distances were similar (*Discoverer*, 2940 m; *Binhai*, 3082 m; U = 4131, n_1 = 48, n_2 = 214,

p = 0.02). Also, sighting distances during full airgun array operations may have been influenced by the higher source level of the array operated by the *Binhai* (see Table 1).

4.3.2 Sighting Rates

The relationships between number of observers and sighting rate, as well as Bf and sighting rate, were examined using scatter plots and a PERMANOVA test (Figure 7). The number of observers was significantly correlated (p = 0.03) with sighting rates (with sighting rates increasing with number of observers), and the Bf was marginally correlated with sighting rates (p = 0.08), with highest sighting rates occurring during BF 2, 3, and 4 (Figure 7). The PERMANOVA found that Year was the only single variable that was marginally statistically significant when comparing sighting rates (Table 5). The interaction between year and vessel type was significant.

A



B

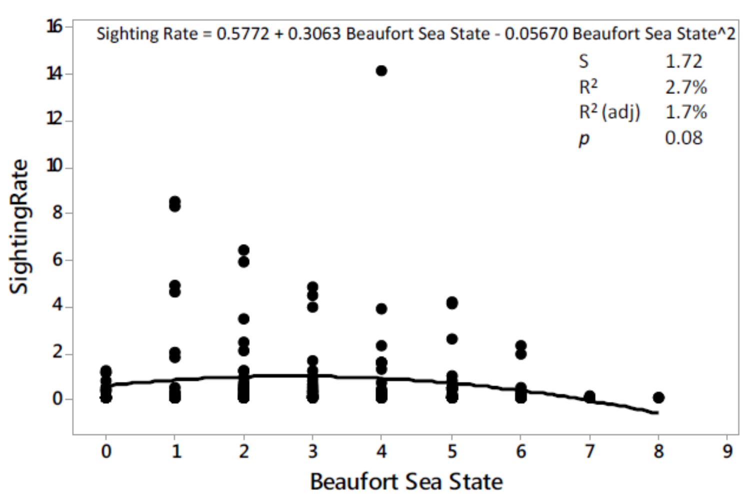


FIGURE 7. Relationships between (A) Number of Observers and Sighting Rate (Sightings per hour) of bowhead whales, and (B) Bf and Sighting Rate of bowhead whales.

TABLE 5. Results of the PERMANOVA to examine variables that affect bowhead whale sighting rates.

Source	df	MS	Pseudo-F	Unique Permutations	*p*
Year	2	8.56	2.52	9944	0.08
Vessel Type	1	0.02	0.001	9930	0.97
Seismic Activity	1	0.15	0.10	9360	0.80
Year X Vessel Type	1	15.63	4.61	9784	0.03
Year X Seismic Activity	2	0.56	0.16	9956	0.85
Vessel Type X Seismic Activity	1	0.02	0.01	7243	0.94
Year X Vessel Type X Seismic Activity	1	2.01	0.59	9842	0.43
Residual	754	3.39			
Total	763				

5.0 Discussion

Our objectives were to standardize and examine the available CBS MMO data to (1) summarize monitoring and mitigation measures and outcomes during the 2006–2008 seismic programs, (2) identify data gaps and information needs to enhance future shipboard mitigation efforts, and (3) make suggestions for consideration to enhance monitoring and mitigation for future seismic programs in the Canadian Arctic.

5.1 Vessel-based Visual Monitoring by MMOs

Marine mammal observers were central to the MMMMP. The effectiveness of MMOs at detecting bowheads was investigated by looking at sighting distances and sighting rates. Both are likely influenced by a number of factors, including number of MMOs on watch, the visual acuity and dedication of each MMO or MMO team on watch, fatigue, sea state (Bf), visibility (e.g., fog, precipitation), and location (e.g., within or outside of a BAA). Because so many interacting variables and levels of variables were at play, the sample sizes for each combination of factors were not always adequate for analysis. Hence, it was not possible to quantify the influence of all contributing factors despite the seemingly large data set.

Likewise, there were limitations in the collection and analysis of bowhead whale behavioural data. Observations of bowhead whale behaviour, and movements relative to the ships, were very limited because the MMOs had to remain vigilant of the SZ while the ship continued sailing. It was difficult to make behavioural observations (particularly prolonged observations) in the field. Available data indicated that bowhead whales were more frequently observed swimming away from the vessels during periods of airgun operations.

5.1.1 Sighting Rates

Typically, there were four MMOs aboard the source vessel and two aboard the support vessel. At any one time, from one to four MMOs were on watch simultaneously on the source vessel (usually one or two), and one or two on watch on the support ship (usually one). The number of observers on watch significantly affected sighting rates, with rates being highest when more observers were on watch. Not surprisingly, more search effort increased the chances of making a sighting.

Sighting rates were highest when the Bf was 2–4 and declined at higher Bf. The expectation was that sighting rates would be highest in the calmest conditions, i.e., during Bf 0 and 1. However, observation effort during Bf 0–1 was limited; small sample size likely played a factor in lower than expected rates during those conditions.

Based on the findings of a PERMANOVA analysis, the number of observers on watch, Bf, and Year were the only variables that were found to be significantly correlated with sighting rates. There were no statistically significant differences in sighting rates between different seismic states or vessel types (support versus seismic vessels).

5.1.2 Sighting Distances

The sighting distance results indicate that MMOs were able to detect bowhead whales at distances within and beyond the SZ, and thus were able to monitor even the largest SZ (2500 m) effectively when visibility (e.g., no fog) permitted. This was accomplished even from the comparatively low bridge height of the M/V *Binhai* 517 (6.3 m) and typically with Bf ≥4. Although the observation platform of the *Binhai* was not as high as that of the *Discoverer*, initial sighting distances were greater from the *Binhai*, possibly because the vessel operated a larger source array. Bf was not significantly correlated with sighting distance.

The average initial sighting distances from the source vessel to bowheads were statistically significantly greater during seismic operations compared with non-seismic periods. Thus, bowheads were staying farther away from the source vessel when the airgun array was operating. This is expected, as whales were likely avoiding the strongest underwater sound. Temporary avoidance of sound sources such as these is a well-documented response in bowheads (Richardson et al. 1995, 1999; Miller et al. 2005). During non-seismic periods, however, average initial sighting distances were similar from the source and support vessels.

5.1.3 MMO Experience Level and Observation Location

The MMO experience level was not assessed; however, a study funded by ESRF collected data during summer 2017 off southern Nova Scotia and Newfoundland to investigate (in part) how experience level affects marine mammal detection rates. The results of that study will be available later this year (Smith et al. in prep.). There were likely differences in sighting distances and sighting rates among the MMOs in the CBS, but this was difficult to reliably assess with the data set because of the multitude of other factors at play. Even with the quantity of data, sample sizes were small when trying to tease apart the influence of sea states, visibility, seismic states, bridge heights, etc. Needless to say, selection of experienced and properly trained MMOs are essential to the effectiveness of the monitoring program. For example, Stone (2015) compared MMOs with and without prior relevant experience in data collected during seismic surveys operating within the United Kingdom continental shelf from 1994 until 2010 and found that experienced MMOs had higher visual sighting rates, could detect animals at greater distances, and recorded a wider range of behaviours than MMOs without experience.

There are limitations to the number of MMOs that can be accommodated on a working ship and on the bridge where MMO observations are typically conducted. Our data show that having a crew of four MMOs aboard the seismic vessel, working in alternating shifts of two, was more effective than when an MMO was on watch alone. However, as MMOs on board the support vessels often did not need to alert the MMOs on the source vessel to marine mammals approaching their location, MMOs on the support vessels may be redundant and could likely be eliminated in favour of additional observers on the source vessel, given adequate bunk space.

5.1.4 Annual Variability

Sighting rates showed great variability as data were collected over several years, from different platforms, and within as well as outside of BAAs. When data were evaluated separately for each year (as shown in the annual monitoring reports), there was variation in the results. In 2006, average initial sighting distances did not differ between seismic and non-seismic periods, and sighting rates were actually higher when the airgun array was active (Harris et al. 2007). However, those results may have been biased because observer effort was limited during non-seismic periods. In 2007, average initial sighting distances were farther during seismic than non-seismic periods, and sighting rates were lower during seismic than non-seismic periods (Harris et al. 2008). Average initial sighting distances and sighting rates were similar during seismic and non-seismic periods during 2008 (Harris et al. 2009). Here, we have shown that over the course of three programs (i.e., considering three years of combined data), average initial sighting distances were statistically significantly greater during seismic than non-seismic periods. As such, the collection and analysis of multiple years of monitoring data including data during non-seismic periods, serves to strengthen the conclusions which can be made.

The fact that sighting distances were greater during seismic operations suggests that feeding bowheads remained within the area of seismic operations but showed localized avoidance (~1 km) of the active airgun array. Baleen whales hear well at frequencies below 1 kHz (Richardson et al. 1995; Ketten 2000), where most of the energy from airgun pulses is focused. However, sighting rates were not correlated with seismic activity. This suggests that feeding bowheads remained within the area of seismic operations, as has been shown during previous studies (Miller et al. 2005; Harris et al. 2007), presumably because moving away from an area with prey has greater cost to the whales than avoiding the disturbance.

5.2 Mitigation Measures

5.2.1 Shut Downs

There were a total of 326 sightings of bowheads from the source vessel when the airgun array was active, 37 of which led to shut downs, the remainder were sightings beyond the SZ. Most shut downs occurred when two observers were on watch and for single whales. The majority of times, the animal(s) dove and was not seen again after a shut down, or it was seen to swim away. Most shut downs occurred during August, corresponding to the period when bowhead sighting numbers were the highest.

Shut downs occurred both within and outside of BAAs defined for the GXT marine mammal monitoring programs. Just over half of the 37 shut downs for bowheads detected within the SZ during periods airguns were active occurred outside of BAAs (four in 2007 and 17 in 2008). Thirteen of 37 shut downs (35.1%) occurred for bowhead sightings within the SZ within BAAs identified in 2007 and 2008—nine of these in 2007 and four in 2008. As a reminder, three shut downs for bowheads occurred in 2006 as the mitigation strategy was being developed (see Figure 4). Ideally, for 100% mitigation effectiveness of the BAAs, all bowhead shut downs would have occurred in identified BAAs. However, 100% efficacy should not be expected for two key reasons: (1) BAAs are challenging to define in a given year, particularly given logistical constraints in conducting aerial surveys, and (2) bowheads are known to move between feeding areas within a given late summer season. The occurrence of shut downs for bowheads outside of the BAAs likely occurs when/if the entire foraging region is not covered by the aerial surveys which are flown to define the BAAs, due to logistics, cost, weather or shifting locations of the zooplankton concentrations which attract the whales. This appears to have been particularly problematic in 2008, and much less so in 2007 (see Figure 4, prevalence of red symbols, by year). In addition, based on satellite telemetry data, bowheads do spend almost a quarter of their time, moving between BAAs and in/out of the region (i.e., 22%, tagged whales, in Harwood et al. 2017), and therefore are at times seen by MMOs outside of the BAAs.

All but one shut down occurred when bowhead whales were detected within the SZ; in 2007, one shut down was implemented for a bowhead whale outside of the SZ, as a precautionary measure. Sixteen of 37 shut downs occurred for subsequent rather than initial sightings. For operational reasons, it is likely that animals were at times exposed to one or two pulses from the airgun array with sound levels exceeding the 180 dB level (i.e., the acoustic criterion in place at the time for the safety zone), before a shut down was successfully implemented.

The 180-dB threshold is no longer used by the U.S. NMFS (NMFS 2016, 2018). The current U.S. thresholds for permanent threshold shift (PTS) onset or Level A Harassment (injury) for marine mammals for impulsive sounds use dual metrics of cumulative sound exposure level (SEL_{cum} over 24 hr) and peak sound pressure levels or SPL_{flat} (NMFS 2016, 2018). Also, those thresholds vary among groups of marine mammals with different hearing characteristics; bowhead whales are low-frequency cetaceans (NMFS 2016, 2018)[1].

It is apparent from the number of shut downs in 2007 and 2008 that bowhead whales (in contrast to beluga whales) tend not to actively avoid the seismic ship since they regularly enter the SZ, and presumably they do this regardless of the time of day or weather/sea or sky conditions. Had greater proportions of the seismic surveys in 2007 and 2008 been allowed in bowhead whale feeding habitat during night time or during periods with little or no visibility, the ability of MMOs to implement mitigation measures (i.e., ramp up delays and shut downs) would have been absent or compromised, and these particular whales would have likely been exposed to sound levels exceeding 180 dB. The shut downs generally occurred in areas where whales aggregated, indicating that the mitigation strategy to place restrictions within feeding areas was in theory effective at minimizing the number of bowheads exposed to airgun pulses with sound levels >180 dB.

[1] The PTS onset threshold for low-frequency cetaceans and impulsive sounds is 219 dB SPL_{flat} or 183 dB SEL_{cum} over 24 hours, whichever results in the largest isopleth (see Table 4 in NMFS 2018).

It was essential that shut downs be implemented quickly when bowhead whales or swimming polar bears were involved. Consequently, the ship and airgun crews were made aware of the requirements of the MMMMP and the authority of the MMOs during meetings prior and during the programs. The shut down process was initiated by the MMO(s) on duty, who told the ship crew on the bridge to shut down the airgun array. The bridge then phoned the airgun crew, who were on the airgun deck (below the bridge), and passed on the order to shut down. The bridge crew then confirmed to the MMO(s) on duty that the airguns were off. In virtually all cases, this process was fast and reliable and most shut downs were implemented quickly and effectively. We know of very few occasions when the shut down was not immediate.

5.2.2 Ramp Ups

Ramp up is a standard mitigation measure that is used to alert marine mammals in a seismic survey area of increasing sound levels. Use of the ramp up procedure is based on the assumption that some marine mammals will move away from the airgun sounds before sound levels are reached that could potentially cause hearing impairment or injury. However, some authors (e.g., Weilgart 2007) have suggested that ramping up could be harmful if animals habituate to the gradual increase in sound and remain in the area until injurious levels are reached.

Few observations were made during ramp up – it is likely that as intended, ramp ups did alert marine mammals to the impending seismic operations. In 2006, sighting distances were the greatest during ramp up, but overall for all programs, the mean sighting distance during ramp up was greater than during non-seismic periods but less than during operation with the full array. However, given the infrequency and short durations of ramp ups (approximately 30 min each), there are insufficient data to assess this procedure's effectiveness. Results from an examination of MMO data collected during eight seismic surveys offshore Newfoundland suggest that the effectiveness of ramping up varies with species (and likely circumstances) and may be largely ineffective for some odontocetes (Moulton and Holst 2010). Based on sighting distances, ramp up (over a 30-min period) appeared to be effective at deterring some species from the immediate area around the seismic vessel. Mysticetes were observed significantly farther from the seismic vessel during ramp up compared with periods when the airguns were silent. In particular, significant differences in sighting distances during ramp up were detected for blue whales. However, as the sample size of blue whale sightings during ramp up periods was small ($n = 5$), the results should be interpreted with caution. Sighting distances of delphinids and toothed whales during periods when the airgun array was ramping up were similar to distances during non-seismic periods.

5.2.3 Bowhead Aggregation Areas

BAAs were used as a mitigation tool during each of the 2006–2008 programs. BAAs were defined, mapped and sometimes redefined by DFO, either prior to or during each year's seismic program, using the most recent and reliable aerial survey data available at the time. Within a defined BAA, at least two MMOs had to be on watch at all times the airgun(s) were active and the airgun array had to be shut down if the full SZ was not visible (e.g., during darkness, periods of fog and/or compromised visibility). Our analyses show that sighting rates were greater when two MMOs were on watch versus one. Consequently, having two MMOs on watch simultaneously undoubtedly increased the detection of bowheads within BAAs and thus the implementation of shut downs when required. This indicates that the additional monitoring and mitigation requirements in the BAA were useful and necessary.

As noted previously, the accurate identification and mapping of BAAs on the basis of one set of aerial surveys early in the season is not ideal; this is in part because defined BAAs are only as good as the aerial survey data they are based on, and because the distribution of whales can/does shift as the season progresses. The aerial survey associated with the 2007 program was done without temporal or spatial interruption and within 48 hr (Harwood et al. 2009), and thus provided the most useful survey data for mitigation in that year. In contrast, the 2008 aerial survey was interrupted spatially and temporally by weather, with substantial gaps in coverage especially off the Yukon coast and Mackenzie Delta. Optimally, the survey would provide complete coverage of known or expected BAAs, be completed without spatial or temporal interruptions and in a short time window, and be repeated several times during the same season to refine and document any changes in the use and distribution of BAAs. However, weather, budget, and logistical constraints come into play.

The CBS is one of the few marine areas in Canada that has had geophysical exploration and where documented and defined areas of traditional cetacean foraging activity are relatively well known. With this historic knowledge, combined with contemporary knowledge, it is essential that mitigation measures are designed to minimize effects on these whales during important feeding periods. The requirement of using two MMOs on watch within the BAAs and prohibiting airgun operations during periods when the full SZ is not visible is logical and recommended to continue in future years. Ideally, aerial surveys would be conducted before seismic surveying begins (typically in early August) and replicated at strategic intervals throughout the seismic season (e.g., mid-August, end of August, and mid-September) to document and refine BAAs. This, however, would be quite costly and historically, the seismic proponent has typically been responsible for funding aerial surveys (in full or in part) related to seismic surveys in the CBS. As a suggestion, seismic proponents, if required to fund aerial surveys in the future, could be given the option of conducting replicated aerial surveys for BAAs <u>or</u> implementing BAA-precautionary mitigation measures (i.e., using two MMOs on watch and only conducting seismic surveys when the full SZ is visible) throughout the seismic survey area, regardless of the survey location in nearshore areas (i.e., <200 m water depth) where BAAs are known to occur. The near 24-hr of daylight throughout August when most seismic surveying has historically occurred would minimize the amount of downtime during which seismic surveying would not be permitted. Aerial survey requirements would be determined by regulators, with input from co-management groups, local stakeholders, and the seismic proponent prior to the start of the seismic season, preferably during the EA process and with regard to the target survey area.

6.0 Data Gaps

We note that it was not required or often possible to collect whale behaviour and movement data during the mitigation and monitoring program, but this is an area that could be expanded in future programs. Detailed records of behaviour and movements were not a priority of the marine mammal monitoring and mitigation programs and are not always practical to collect. The nature of the seismic program, moving along pre-defined survey lines at set speeds, does not make it easy to follow bowhead whales and obtain prolonged observations of series of behaviours. However, if it is of interest to gather that information during future Arctic seismic programs, then other recording methods can be explored such as behavioural observations from aircraft or unmanned aerial vehicles (UAV; i.e., drones). UAVs have been used to successfully document bowhead whale behaviour in the eastern Canadian arctic (Koski et al. 2016; Fortune et al. 2017).

7.0 Summary and Recommendations

Despite the seemingly large dataset it was difficult to assess some aspects of the effectiveness of various monitoring and mitigation measures. That was in large part because of the number and complexity of environmental and observer variables at play and, regarding behaviour and movements, limited data. Based on our initial analyses, it is apparent that poor sea states (i.e., >Bf 4), decrease sightability, and that having more than one observer on watch significantly increased sighting rates for bowhead whales. Future monitoring and mitigation programs should take into account what additional data needs might be, and what additional data could be collected to address those questions. Our recommendations based on 2006–2008 Beaufort Sea data presented in this report include:

(1) The use of two MMOs on watch at all times airgun(s) are active and during the pre ramp up watch. The data collected in this report demonstrate that two observers detected more whales than one observer. Given the 24-hr of summer daylight in the Arctic, this would require six MMOs on the seismic source vessel. The total number of MMOs could be reduced if seismic surveys continue into the fall when daylight hours decrease. Typically, an MMO should not be on watch for more than eight hours per 24-hr period. Of note, we do not recommend placing MMOs on the support vessel because the monitoring results indicate that given the typical separation distance between the support and seismic source vessels, the MMOs on the support vessel serve minimal purpose relative to monitoring and mitigation objectives.

(2) Aerial surveys should be conducted before seismic surveying begins (typically in early August) and replicated at strategic intervals throughout the seismic season. Otherwise see (3) below.

(3) Seismic proponents should be consulted and potentially given the option of conducting replicated aerial surveys as outlined in (2) or implementing BAA-precautionary mitigation measures (i.e., using two MMOs on watch at all times the airgun(s) are active and only conducting seismic surveys when the full SZ is visible) throughout thee seismic survey area, regardless of the survey location, in nearshore areas (<200 m water depth) where BAAs are known to occur. We acknowledge, however, that this decision ultimately is in the purview of the regulator.

(4) The enhanced mitigation measure of prohibiting airgun operations within a BAA during periods when the full SZ is not visible should continue. The determination of whether the SZ is fully visible should consider the influences of precipitation and fog, encroaching darkness, and sea state conditions. The data presented in this report demonstrated that bowhead sighting rates were higher when sea state was Bf 4 or less.

(5) Ensure that the MMMMP and the authority of the MMOs are discussed with and made clear to the ship and seismic crews prior to and during the program, and that a clear and effective protocol for communication between the bridge and airgun deck is established. This will ensure timely shut downs for marine mammals detected within the SZ.

(6) Marine mammal monitoring and mitigation data should be collected consistently across seismic surveys to readily enable multi-year analyses of data. We have demonstrated that trends in bowhead whale response to airgun activity become evident when analyzing multiple years of combined data versus a single year of data.

(7) The preparation of comprehensive technical reports of the marine mammal monitoring results should continue with review by DFO. These reports should be made publically available and the findings should be incorporated into subsequent EAs.

Although the findings presented in this report focused on bowhead whales, the monitoring and mitigation measures (see Section 2.2) established for beluga whales, other cetaceans, and polar bears, which have been developed over many years, also are recommended. Particularly, the shut down of airguns for polar bears detected in water (versus on ice) as this is not directly included in the SOCP. We would also highlight the need for stakeholder engagement, as GXT and DFO had done, especially prior to seismic surveying to assist with monitoring and mitigation planning.

8.0 Acknowledgements

The vessel-based monitoring was funded by GX Technology Corporation (GXT) via a contract to LGL Limited and Upun-LGL Limited. We thank Joe Gagliardi, Dean Kennedy, and Rob Pitt of GXT for their substantial support and assistance during the planning and conduct of the projects. The onboard client representatives, and crews of the M/V *Discoverer*, M/V *Binhai 517* and M/V *Alex Gordon*, were most helpful, and we thank the crews especially for their diligence in implementing the mitigation procedures.

The marine mammal mitigation and monitoring programs were successful in large part because of the skill and diligence of the MMOs: Raymond Ettagiak (Tuktoyaktuk), Colin Gordon (Aklavik), Roger Memorana (Ulukhaktok), Ricky Joe (Aklavik), Leonard Gordon (Aklavik), Vernon Amos (Inuvik), Preston Carpenter and Jeff Kuptana (Sachs Harbour), Nick Engelmann, Tony Douglas, Tom Plath, Marina Milligan, Bruce Di Labio, Andrea Hunter (LGL), Andrew Davis (LGL), and Patrick Abgrall (LGL).

Input from regulators and regional stakeholders helped in the development and refinement of the mitigation and monitoring procedures including the HTCs of the six Inuvialuit communities, DFO (Lois Harwood, Amanda Joynt), the Inuvialuit EISC, and the FJMC (A. Hoyt, Louie Porta). Aklak Air of Inuvik provided the aircraft for the aerial surveys; Ken Dalton of Aklak was of great assistance making these arrangements, often on short notice.

The acoustic transmission measurements and modelling were carried out by JASCO Research of Victoria, BC. We thank Dave Hannay, Alex MacGillivray, Caitlin O’Neill, Rob Racca, Holly Sneddon, and Mikhail Zykov and for their input and assistance.

Numerous people at LGL assisted with the data analyses and reporting of these projects, in addition to those who served as MMOs, these people were: Mark Fitzgerald and Ted Elliott especially for their data analyses and mapping expertise, Heather Patterson, Meaghan Jankowski, Anne Wright, and Dr. W. John Richardson and Dr. Rolph Davis for senior review and guidance. We thank Lois Harwood, Jody Willis, Dean Kennedy, and Rob Pitt for reviewing the report and providing helpful feedback. Jody Willis was the contract authority.

9.0 Literature Cited

Anderson, M., R.N. Gorley, and R.K. Clarke. 2008. Permanova+ for Primer: Guide to software and statistical methods. PRIMER-E Ltd., Plymouth, United Kingdom.

Clarke, K.R. and R.N. Gorley. 2015. PRIMER v7: user manual/tutorial Primer-E Ltd, Plymouth, United Kingdom.

DFO (Fisheries and Oceans Canada). 2008. Statement of Canadian Practice with respect to the Mitigation of Seismic Sound in the Marine Environment. Accessed on 20 April 2018 at http://www.dfo-mpo.gc.ca/oceans/publications/seismic-sismique/index-eng.html.

Fortune, S.M.E., W.R. Koski, J.W. Higdon, A.W. Trites, M.F. Baumgartner, and S.H. Ferguson. 2017. Evidence of molting and the function of "rock-nosing" behavior in bowhead whales in the eastern Canadian Arctic. PLoS ONE 12(11): e0186156. 15 p.

Gerwing, T.G., A.M.A. Gerwing, D. Drolet, M.A. Barbeau, and D.J. Hamilton. 2015a. Spatiotemporal variation in biotic and abiotic features of eight intertidal mudflats in the Upper Bay of Fundy, Canada. North. Nat. 22(12):1-44.

Gerwing, T.G., D. Drolet, M.A. Barbeau, D.J. Hamilton, and A.M.A. Gerwing. 2015b. Resilience of an intertidal infaunal community to winter stressors. J. Sea Res. 97:40-49.

Gerwing, T.G., D. Drolet, D.J. Hamilton, and M.A. Barbeau. 2016. Relative importance of biotic and abiotic forces on the composition and dynamics of a soft-sediment intertidal community. PLoS One 11(1): 11:e0147098.

Gerwing, T.G., A.M.A. Gerwing, K. Cox, F. Juanes, and S.E. Dudas. 2017. Relationship between apparent redox potential discontinuity (aRPD) depth and environmental variables in soft-sediment habitats. Int. J. Sed. Res. 32(4):472-480.

Gordon, J., D. Gillespie, J. Potter, A. Frantzis, M.P. Simmonds, R. Swift, and D. Thompson. 2004. A review of the effects of seismic surveys on marine mammals. Mar. Technol. Soc. J. 37(4):16-34.

GXT. 2011. Project Description for the proposed GX Technology 2011 Beaufort Span Offshore 2-D Marine Seismic Program. Rep. from GX Technology Canada Ltd. with support from Upun-LGL Limited and LGL Limited.

Harris, R.E., T. Elliott, and R.A. Davis. 2007. Results of mitigation and monitoring program, Beaufort Span 2-D marine seismic program, open-water season 2006. LGL Rep. TA4319-1. Rep. from LGL Ltd., King City, ON, for GX Technology Corp., Houston, TX. iv + 48 p.

Harris, R.E., A. Lewin, A. Hunter, M. Fitzgerald, A.R. Davis, R.E. Elliott and R.A. Davis. 2008. Marine mammal mitigation and monitoring for GX Technology's Canadian Beaufort Span 2-D marine seismic program, open-water season 2007. LGL Report TA4460-1-3. Report by LGL Ltd., King City, ON for GX Technology Corp., Houston, TX. xiii + 99 p.

Harris, R.E., A. Lewin, P. Abgrall, M. Fitzgerald and D. Hauser. 2009. Marine mammal mitigation and monitoring for GX Technology's Canadian Beaufort Span 2-D marine seismic program, open-water 2008. LGL Report TA4460-2A. Report by LGL Ltd., King City, ON for GX Technology Corp., Houston, TX. xiv + 99 p.

Harwood, L.A. and T.G. Smith. 2002. Whales of the Inuvialuit Settlement Region in Canada's Western Arctic: An overview and outlook. Arctic 55(Suppl. 1):77-93.

Harwood, L., A. Joynt, D. Kennedy, R. Pitt, and S. Moore. 2009. Spatial restrictions and temporal planning as measures to mitigate potential effects of seismic noise on cetaceans: a working example from the Canadian Beaufort Sea, 2007-2008. DFO Can. Sci. Advis. Sec. Res. Doc. 2009/040. iv + 14 p.

Harwood, L.A., L.T. Quakenbush, R.J. Small, J.C. George, J. Pokiak, C. Pokiak, M.P. Heide-Jorgensen, E.V. Lea, and H. Brower. 2017. Movements and inferred foraging by bowhead whales in the Canadian Beaufort Sea during August and September, 2006-12. Arctic 70(2): 161-176.

Joynt, A. and L.A. Harwood. 2009. A review of the practices used to mitigate the effects of seismic noise on whales as applied in the Beaufort Sea from 2006-2009; a case study for adaptive management. Poster presented at the 18th Biennial Conference on the Biology of Marine Mammals, Quebec City, Canada. October 13-16, 2009.

Ketten, D.R. 2000. Cetacean ears. p. 43-108 In: W.W.L. Au, A.N. Popper, and R.R. Fay (eds.) Hearing by Whales and Dolphins. Springer-Verlag, New York, NY.

Koski, W.R., S. Fortune, T. Seitz, S.H. Ferguson and B. LeBlanc. 2016. Preliminary Field Report: Demonstration of Small Unmanned Aerial Systems (sUAS) to Conduct Photo-identification and Feeding Behaviour Studies of Bowhead Whales. Confidential assessment report to World Wildlife Fund by LGL Limited, King City, ON, University of British Columbia, Vancouver, BC, and VDOS Global, Corvallis, OR.

LGL Limited. 2008. Environmental Assessment of GX Technology's Beaufort Span 2-D Marine Seismic Program, Open-water Season 2008. LGL Rep. TA4460-2a. Rep. from LGL Limited, St. John's, NL and King City, ON for GX Technology Canada Ltd., Calgary, AB. 173 p. + appendices.

LGL Limited and Canning & Pitt Associates. 2007. Environmental assessment of GX Technology's Beaufort Span 2-D marine seismic program, open-water season 2007. LGL Project TA4460-2. Report by LGL Limited, King City, ON, and Canning & Pitt Associates, St. John's, NL for GX Technology Corporation, Houston, Texas. 158 p. + appendices.

LGL Limited, Inuvialuit Environmental & Geotechnical Inc, and Canning & Pitt Associates. 2006. Environmental assessment of GX Technology's Beaufort Span 2-D marine seismic program, open-water season 2006/2007. LGL Rep. TA4319-2. Rep. by LGL Limited, King City, ON, IEG, Inuvik, NT, and Canning & Pitt Associates, St. John's, NL for GX Technology Corporation, Houston, Texas. 154 p. + appendices.

MacGillivray, A., M. Zykov, D. Hannay, R. Racca, and M. Laurinollli. 2008. GX Technology Corporation – Final report on underwater acoustic modeling and field measurements for GX Technology's 2007 Beaufort Span seismic program. Report from JASCO Research, Victoria, BC, for GX Technology, Houston, TX. 43 p.

Matthews, M-N.R. and A.O. MacGillivray. 2012. ION Beaufort Span 2012 Acoustic Modeling: Distances to rms SPL Thresholds for a 4380 in^3 airgun array towed at a depth of 12 m. JASCO Document 00464, Version 1.0. Technical report by JASCO Applied Sciences for LGL Alaska Research Associates Inc. v + 19 p.

Miller, G.W., V.D. Moulton, R.A. Davis, M. Holst, P. Millman, A. MacGillivray, and D. Hannay. 2005. Monitoring seismic effects on marine mammals—southeastern Beaufort Sea, 2001-2002. p. 511-542 In: S.L. Armsworthy, P.J. Cranford, and K. Lee (eds.), Offshore Oil and Gas Environmental Effects Monitoring/Approaches and Technologies. Battelle Press, Columbus, OH.

Moulton, V.D. and M. Holst. 2010. Effects of seismic survey sound on cetaceans in the northwest Atlantic. Environmental Studies Research Funds Report No. 182. 28 p.

NMFS (National Marine Fisheries Service). 2016. Technical guidance for assessing the effects of anthropogenic sound on marine mammal hearing: underwater acoustic thresholds for onset of permanent and temporary threshold shifts. U.S. Dept. of Commer., NOAA. 178 p.

NMFS. 2018. 2018 revision to: technical guidance for assessing the effects of anthropogenic sound on marine mammal hearing (version 2.0). Underwater thresholds for onset of permanent and temporary threshold shifts. Office of Protected Resources Nat. Mar. Fish. Serv., Silver Spring, MD. 167 p.

Nowacek, D.P., L.H. Thorne, D.W. Johnston, and P.L. Tyack. 2007. Responses of cetaceans to anthropogenic noise. Mamm. Rev. 37(2):81-115.

Richardson, W.J., R.A. Davis, C.R. Evans, D.K. Ljungblad, and P. Norton. 1987. Summer distribution of bowhead whales, *Balaena mysticetus*, relative to oil industry activities in the Canadian Beaufort Sea, 1980-84. Arctic 40(2):93-104.

Richardson, W.J., C.R. Greene, Jr., C.I. Malme, and D.H. Thomson. 1995. Marine mammals and noise. San Diego, CA: Academic Press.

Richardson, W.J., G.W. Miller, and C.R. Greene, Jr. 1999. Displacement of migrating bowhead whales by sounds from seismic surveys in shallow waters of the Beaufort Sea. J. Acoust. Soc. Am. 106(4, Pt. 2):2281 (Abstract).

Smith, H.R., P. Abgrall, and V.D. Moulton. 2013. Marine Mammal Mitigation and Monitoring for GX Technology's Canadian Beaufort Span 2-D Marine Seismic Program: October and November, 2012. Upun-LGL Rep. No. UA0011-01. Rep. by Upun-LGL Limited, Inuvik, NT, for GX Technology Canada Ltd., Calgary, AB. 33 p.

Smith, H.R., D.P. Zitterbart, M. Flau, O. Boebel, and V.D. Moulton (in preparation) Comparison of marine mammal detections made using visual, acoustic and thermal-imaging methods offshore in Atlantic Canada.

Southall, B.L., A.E. Bowles, W.T. Ellison, J.J. Finneran, R.L. Gentry, C.R. Greene Jr., D. Kastak, D.R. Ketten, J.H. Miller, P.E. Nachtigall, W.J. Richardson, J.A. Thomas, and P.L. Tyack. 2007. Marine mammal noise exposure criteria: initial scientific recommendations. Aquat. Mamm. 33(4):411-522.

Stone, C.J. 2015. Marine mammal observations during seismic surveys from 1994-2010. JNCC report, No. 463a. 64 p.

Weilgart, L.S. 2007. A brief review of known effects of noise on marine mammals. Int. J. Comp. Psych. 20:159-168.

Upun-LGL Limited. 2010. Environmental Assessment for the Proposed GX Technology Beaufort Span Canada West 2010 2-D Seismic Program. Upun-LGL Rep. UA0004-2. Rep. from Upun-LGL Limited, Inuvik, NT and LGL Limited, King City, ON for GX Technology Canada Ltd., Calgary, AB. 194 p. + appendices.

Zykov, M., R. Racca, and A. MacGillivray. 2007a. Characterization of noise emissions from GX Technology Corporation's 2006 seismic survey in Alaskan Chukchi Sea and Canadian Beaufort Sea. Acoustics Levels Estimate Modeling Report. Report from JASCO Research, Victoria, BC, for GX Technology, Houston, TX. 29 p.

Zykov, M., D. Hannay, and R. Racca. 2007b. Mapping of pre-season estimates of safety radii for GX Technology Corporation's Seismic Exploration Program in the Beaufort Sea 2007. Report from JASCO Research Ltd., Victoria, BC, for GX Technology, Houston, TX. 21 p.