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# Acoustic and visual surveys for bowhead whales in the western Beaufort and far northeastern Chukchi seas

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## ABSTRACT

Two types of passive-acoustic survey were conducted to investigate the seasonal occurrence of bowhead whales (*Balaena mysticetus*) in the western Beaufort and far northeastern Chukchi seas: (1) an over-winter (2003–04) survey using autonomous recorders deployed northeast of Barrow, Alaska, and (2) a summertime dipping-hydrophone survey along the 2005 NOAA Ocean Exploration (OE) cruise track northwest of Barrow. The longest continuous sampling period from the over-winter survey was 3 October 2003 to 12 May 2004. During that period, bowhead whale calls were recorded from 3 to 23 October, intermittently on 6–7 and 22–23 November, then not again until 25 March 2004. Bowhead calls were recorded almost every hour from 19 April to 12 May 2004, with a call rate peak on 30 April (ca. 9400 calls) and a few instances of patterned calling (or, “song”) detected in early May. Bowhead whale calls were never detected during the NOAA OE cruise, but calls of beluga whales (*Delphinapterus leucas*) were recorded at 3 of 16 acoustic stations. Opportunistic visual surveys for marine mammals were also conducted during the NOAA OE cruise from the ship (65 h) and helicopter (7.8 h), resulting in single sightings of bowhead whales (3–5 whales), beluga (16–20 whales), walrus (1), polar bear (2 = sow/cub), and 17 sightings of 87 ringed seals from the ship and 15 sightings of 67 ringed seals from the helicopter.

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## 1. Introduction

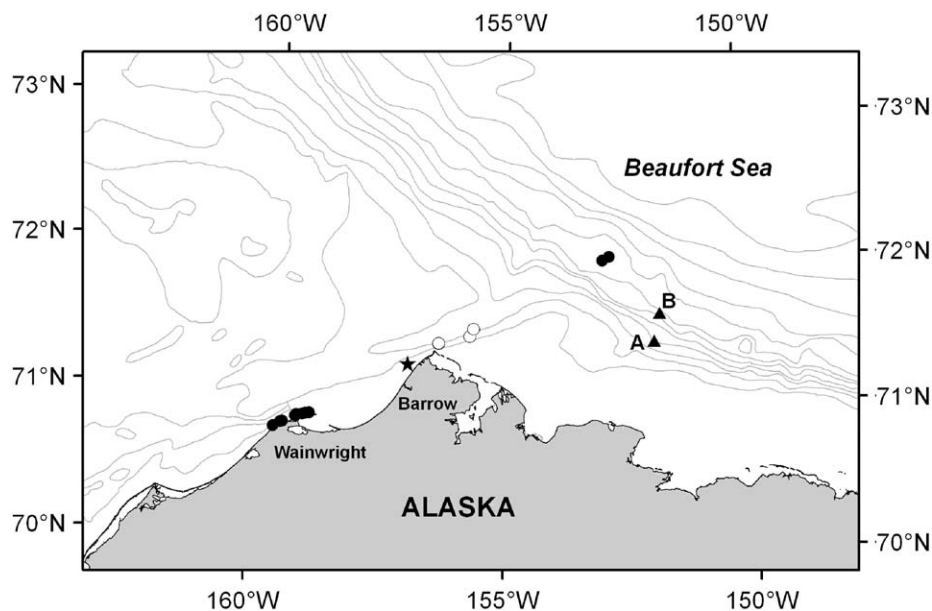
The Bering-Chukchi-Beaufort (BCB) population of bowhead whales migrates annually between wintering areas in the northern Bering Sea and summering areas in Canadian Beaufort Sea. Although there have been occasional opportunistic summertime sightings of bowhead whales near Barrow, Alaska, since the late 1970s (Moore, 1992), the bulk of the herd is thought to feed in Canadian waters from July through early September (Moore and Reeves, 1993; Rugh et al., 2003). Still, Alaskan Native hunters routinely report seeing bowheads near Barrow in July and August, ca. 5–15 whales were noted during opportunistic aerial surveys flown northeast and southwest of Barrow in July 1999 and July 2003, respectively (Moore unpublished data), and 30 bowheads were seen in the Chukchi Sea roughly 150 km southwest of Wainwright Alaska in early August 2007 (Sekiguchi, 2007). These summertime sightings could be the result of an expanding BCB bowhead population (George et al., 2004), climate-induced changes in habitat that influence whale distribution (e.g., Moore

and Laidre, 2006), more effort directed toward documenting local knowledge of bowhead whales (e.g., Noongwook, 2007), increased summertime survey effort, or all of the above. No matter the cause, the persistent reports of bowhead whales summering outside the Canadian Beaufort Sea are of keen interest to members of the International Whaling Commission-Scientific Committee (IWC-SC), the Alaska Eskimo Whaling Commission (AEWC), and the National Oceanic and Atmospheric Administration (NOAA), organizations responsible for their conservation and management.

Acoustic detection of whale calls has become a routine and comparatively cost-effective survey method for cetaceans, especially in remote habitats offshore Alaska (Moore et al., 2006). Thus, opportunities were sought to include passive-acoustic surveys on two on-going science programs in the western Arctic: (1) the National Science Foundation Western Arctic Shelf-Basin Interactions (NSF-SBI) project (Grebmeier and Harvey, 2005), and (2) the NOAA Ocean Exploration (OE) cruise. Sampling along the track of the NOAA OE cruise was of particular interest because it included waters near the Northwind Ridge and Chukchi Plateau (hereafter, Chukchi Borderland), an area suggested by Russian scientists as possible summering habitat for bowhead whales (Bogoslovskaya, 2003; Melnikov et al., 1998). Extant literature indicates the Chukchi Borderland may contain adequate prey to

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**Fig. 1.** Locations of two recorders (▲) deployed in early October 2003 in the Beaufort Sea. Recorder A was deployed at 71°28.3 N latitude, 151°56 W longitude in water 316 m deep, and recorder B was deployed at 71°39.3 N latitude, 151°48 W longitude in water 1258 m deep. Also shown are locations of bowhead whale sightings from opportunistic aerial surveys in July 1999 (light circles), July 2003 (dark circles) and at the outset of the NOAA OE survey (star) in late June 2005 (Moore unpublished). Please check the quality of Figs. 1 and 2.

support foraging bowhead whales, including large copepods (Ashjian et al., 2003; Hopcroft et al., 2005) and euphausiids advected to the Chukchi Sea from the northern Bering Sea (Maslowski et al., 2000; Shimada et al., 2004; Berline et al., 2008). Both copepods and euphausiids are commonly found in the stomachs of bowhead whales harvested at Barrow in autumn (Lowry et al., 2004).

The primary goal of both the NSF-SBI and NOAA OE acoustic surveys was the detection of bowhead whale calls. The SBI survey explored the possibility that bowhead whales remained in the western Beaufort Sea during winter, while the NOAA OE survey specifically addressed the question of bowhead whale summertime occurrence near the Chukchi Borderland. During the NOAA OE cruise, a first-ever visual survey for marine mammals to and near the Chukchi Borderland complemented the acoustic sampling, and a synopsis of all species seen along the cruise track is provided.

## 2. Materials and methods

### 2.1. Over-winter acoustic survey northeast of Barrow, Alaska

Three autonomous Acoustic Recording Packages (ARPs; hereafter, recorders) were deployed in the western Beaufort Sea in early October 2003 to provide continuous year-round sampling for cetacean calls within the 10–500 Hz frequency band (Wiggins, 2003). The recorders were placed near a SBI mooring array deployed for high-resolution sampling of physical oceanographic parameters along the Beaufort Sea slope, and in the vicinity of bowhead whale sightings in July 1999 and 2003 (Fig. 1). Although the transmission range of bowhead calls varies with the loudness of the call and ambient noise conditions, whales calling within ca. 20–30 km of the recorders would likely be detected. Unfortunately, recorder malfunction resulted in only two of the three instruments being recovered and both sampled only part of the year. Upon recovery, the internal hard drives from recorder 'A' and recorder 'B' were removed and the data downloaded for processing. Recorder A stored data only from 4 October 2003 to 29

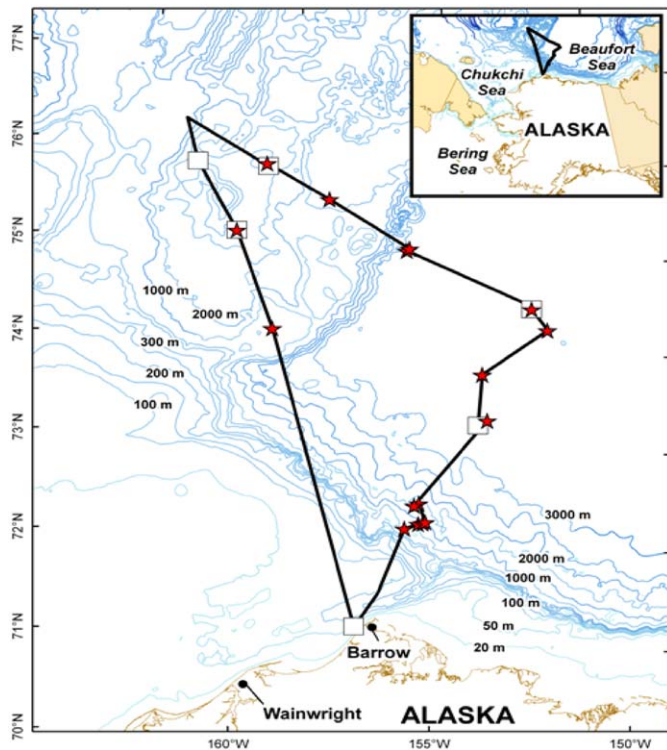
December 2003, whereas recorder B stored data from 3 October 2003 until 12 May 2004. Due to the focus on seasonal occurrence of bowhead whale calls, only data from recorder 'B' were analysed in detail. The available data files were split into 2-hour segments to facilitate processing, and 20 s spectrogram equalization was applied to remove long-term noise produced from sources such as sea ice and ships. To ensure accurate classification of signals, data files were then scanned visually for the presence of bowhead whale calls and a daily record of occurrence compiled.

### 2.2. Acoustic and visual survey along NOAA ocean exploration (OE) cruise track

Acoustic sampling was conducted from the sea ice at stations where other sampling activities were undertaken during the 2005 NOAA OE cruise (Fig. 2). Sampling was conducted from 28 June to 21 July at distances 100–400 m from the ship, by lowering an Offshore Acoustics<sup>1</sup> hydrophone (frequency range 10 Hz–40 kHz) roughly 10–12 m below the ice surface and recording the signals on a Sony TCD-D7<sup>1</sup> Digital Audio Tape (DAT) recorder.

Visual surveys for all marine mammals were conducted from the ship's bridge (ca. 20 m eye height) and the bridge tower (a.k.a. aloftcon; ca. 30 m eye height) aided by handheld binoculars. Observations were made over 360° when the ship was on station (usually ca. 1-h morning and afternoon watches) and over 180° looking forward during transit between stations (usually 1–2 h per watch), for a total of 65 h of shipboard visual survey. This effort was opportunistically augmented by sightings made by the ship's crew, especially bridge personnel trained in marine mammal identification and familiar with NOAA Platform of Opportunity Program (POP) forms. In addition, eight opportunistic aerial surveys (total = 7.8 h) were conducted using the ship's helicopter when weather and other ship operations permitted. Surveys were flown at 1500 m altitude on ~30 km radial transects to and from the ship with a single observer searching for marine mammals.

<sup>1</sup> Use of Trade Names does not constitute endorsement.



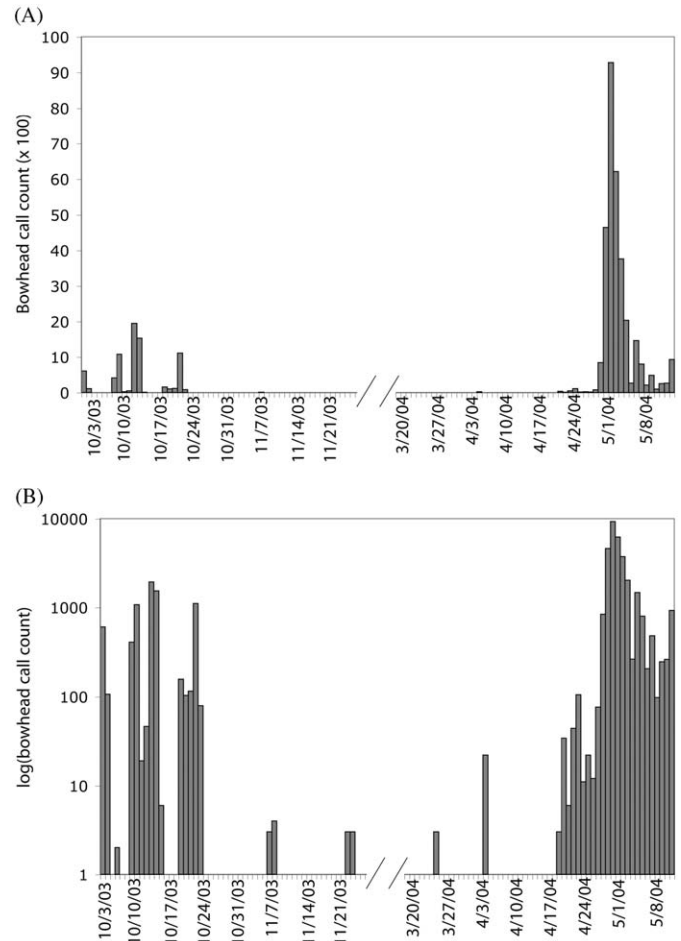
**Fig. 2.** Cruise track of the NOAA Ocean Exploration cruise, denoting passive acoustic sampling stations (stars) and opportunistic helicopter surveys (boxes) in search of bowhead whales, 27 June–23 July 2005.

### 3. Results and discussion

#### 3.1. Over-winter acoustic survey northeast of Barrow, Alaska

Bowhead whale calls were recorded at site B from 3 October (the day of deployment) through 23 October 2003, intermittently on 6–7 and 22–23 November 2003, then not until 25 March 2004 (Fig. 3). Calls were detected almost every hour during the last 3 weeks of recording (i.e. 19 April–12 May 2004), with a peak call rate (ca. 9400 calls) on 30 April. Call types included up- and down-swept and inflected signals generally in the 50–200 Hz frequency band (e.g., Fig. 4), as described by previous researchers (Cummings and Holliday, 1987; Clark and Johnson, 1984; Ljungblad et al., 1982). A few instances of patterned calling (or “song”) were found in early May 2004 (Fig. 5). Songs consisted of repeated frequency modulated sweeps and ‘grunts’ that continued for several minutes. Spectrograms of these call patterns looked very much like those shown for ‘song’ recorded during the bowhead spring migration near Barrow in the 1980s (Würsig and Clark, 1993; see Fig. 5.9).

Although sampling was limited to 7.5 months, bowhead calls were detected only during spring and autumn migration periods; that is, when whale are expected to be in the area. Surprisingly, gray whale (*Eschrichtius robustus*) calls were recorded throughout the 2003–04 winter (Stafford et al., 2007), so we are confident that if calling bowheads were in the vicinity of the recorder at site B, the calls would have been detected. It is noteworthy that the call rate for 30 April 2004 exceeded the peak count (ca. 5800 calls) on 27 April 1993, recorded from sites along the open-water lead system during bowhead whale spring migration past Barrow (Clark et al., 1996). This is surprising since the 1993 data were thought to represent ‘maximal rates’ due to the close proximity of the recording sites to the bowhead whale migratory corridor. The nearly double peak call rate recorded at site B suggests that the



**Fig. 3.** Bowhead whale call occurrence at site B: 3 October 2003–12 May 2004. Date on the X-axis and number of calls  $\times 100$  on the Y-axis (top); log (number of calls) on the Y-axis (bottom) to allow low call rates in November 2003 and March 2004 to be discernable.

Beaufort slope northeast of Barrow might represent a more central location in the migratory corridor, or may simply reflect an increase in the number of whales in 2004 compared to 1993 (George et al., 2004). Conversely, there was remarkable similarity between the 2 years in the timing of a 3-day pulse of high calling rates, with rates  $>3400$  calls/day from 27 to 29 April 1993 compared to  $>4800$  calls/day from 29 April through 2 May 2004.

#### 3.2. Acoustic and Visual Surveys along the NOAA ocean exploration (OE) cruise Track

Sixteen acoustic sampling periods (total = 30.5 h) were completed at 15 OE sea-ice stations (Table 1). Beluga calls were recorded at three stations, but no bowhead whale calls were detected anywhere along the cruise track. Even though recording sites were selected as far from the ship as safely possible, every recording contained underwater noise associated with on-going ship operations (e.g., fathometer, deck machinery). Those sounds, and listening to the footfalls of scientists walking on the sea ice and bubbles from the underwater divers, gave assurance that the acoustic equipment was working properly such that, based on call source levels (Cummings and Holliday, 1987), calling bowhead whales within ca. 20–30 km of the sampling stations would have been detected. What cannot be ruled out is the possibility that bowheads were present and silent, or fled the ship-associated underwater noise.

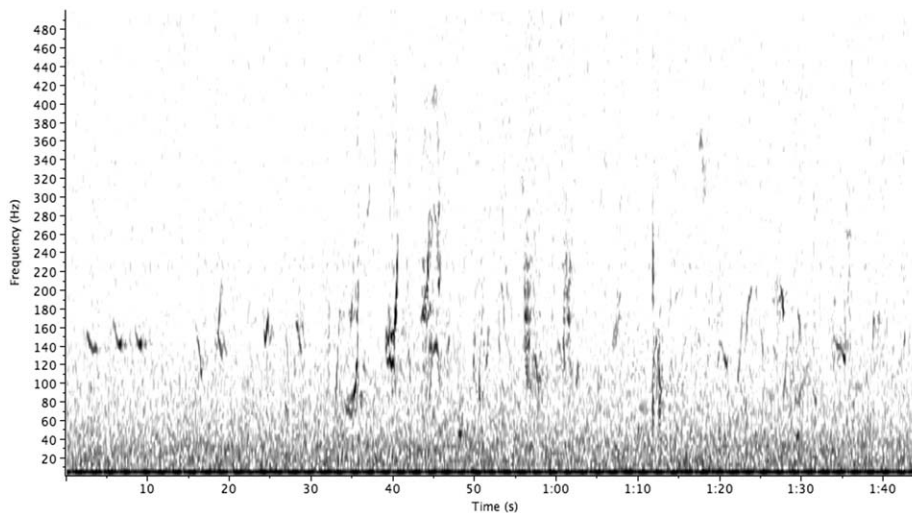


Fig. 4. Example bowhead whale 'up' and 'down sweep' calls recorded at site B on 1 May 2004. (256 pt FFT, 25% overlap, Hanning window).

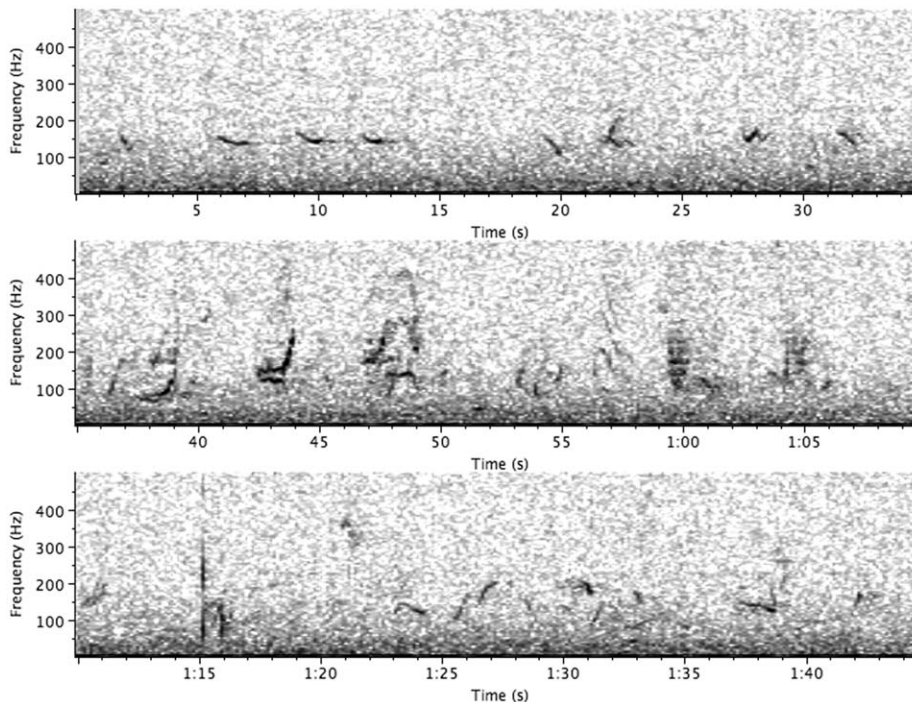


Fig. 5. Example spectrogram illustrating variation in bowhead calls and patterned call series that contain repetitive elements reminiscent of 'song' as described in Würsig and Clark (1993).

The only bowhead whale sighting was of a small group (3–5 whales) seen from the helicopter near Barrow on 27 June, just prior to the start of the NOAA OE cruise (Table 2). These whales were very near where bowheads were seen in July 1999 and 2003 (Fig. 2: ★), so their occurrence was not surprising. Other marine mammals seen during cruise included: beluga, ringed seals (*Phoca hispida*), walrus (*Odobenus rosmarus*) and polar bears (*Ursus maritimus*). Ringed seals were by far the most common marine mammals seen, with animals seen all along the cruise track. It was common for several seals (2–5) to remain near the ship when it was on station for sampling, sometimes even approaching divers.

#### 4. Conclusion

Passive acoustics provided an efficient and comparatively cost-efficient means to survey for bowhead whales over-winter 2003–04 and along the 2005 NOAA OE cruise track to a remote area of the Chukchi Sea. During the over-winter survey, bowhead calls were recorded only at times and in places where they would be expected based upon the annual migration of the BCB population. Based on recent summertime observations of bowhead whales near Barrow, the potential for prey availability near the Chukchi Borderland, and catches of bowhead whales north-west of Point Barrow (albeit later in the summer) during the

**Table 1**

Summary of acoustic recording effort, marine mammal (MM) detections and other sounds at 15 stations along the 2005 NOAA OE cruise track.

Date	Station	H	From HEALY	Marine mammal calls
28 June	2	2.0	200 m/port side	None
29 June	3	1.5	300 m/port side	None
30 June	3	2.0	300 m/port side	Beluga
01 July	3A	1.5	400 m/off stern	None
02 July	4	1.0	300 m/stern-brash ice	None
03 July	4A	2.0	250 m/stern-brash ice	Beluga
05 July	5	1.0	250 m/stern	None
07 July	6	1.5	100 m/bow	None
09 July	7	2.0	100 m/port stern	Beluga
11 July	8	2.5	300 m/off stern	None
13 July	9	2.0	200 m/off bow	None
14 July	9A	2.0	200 m/off bow	None
15 July	10	3.5	300 m/off stbd stern	None
16 July	11	2.0	200 m/off port stern	None
20 July	13	2.0	300 m/off port stern	None
21 July	14	2.0	100 m/off mid-port	None

Totals = 16 deployments; 30.5 h (H) recording; 3 detections of beluga calls.

**Table 2**

Summary of visual survey effort from the HEALY and helicopter (HELO), and number of sightings (number of animals) for bowhead whales, beluga, ringed seals, walrus and polar bears, June–July 2005.

Platform	Period (h)	Bow-head	Beluga	Ringed Seal	Walrus	Polar Bear
HEALY	27 June–22 July (65)	1 (3–5)	0	17 (87)	1 (1)	1 (2)
HELO	6–23 July (7.8)	0	1 (16–20)	15 (67)	0	0

Yankee commercial whaling period (Bockstoce and Botkin, 1983), it seemed plausible that bowheads would be seen or heard during the NOAA OE cruise. Indeed, the lack of bowhead detections in the NOAA OE survey area begs the question of why there are not more whales in the western Beaufort and northeastern Chukchi seas in summer, if the population has essentially 'recovered' in numbers since the end of commercial whaling roughly 100 years ago. Although provisional in nature due to the comparative brevity of sampling, the results of both acoustic surveys support the current paradigm that BCB bowhead whales migrate in spring and autumn between the northern Bering Sea and the Canadian Beaufort Sea, and do not occur outside this spatial and temporal range in large numbers. The conduct of additional passive acoustic sampling near the Borderland, if completed as planned in the final International Polar Year (2008–09), will provide the means to further assess bowhead whale presence/absence in that region.

## Acknowledgements

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## References

- Ashjian, C.J., Campbell, R.G., Welch, H.E., Butler, M., Van Keuren, D., 2003. Annual cycle in abundance, distribution, and size in relation to hydrography of important copepod species in the western Arctic Ocean. *Deep Sea Research I* 50, 1235–1261.
- Berline, L., Spitz, Y.H., Ashjian, C.J., Campbell, R.G., Maslowski, W., Moore, S.E., 2008. Euphausiid transport in the Western Arctic Ocean. *Marine Ecology Progress Series* 360, 163–178.
- Bockstoce, J.R. and Botkin, D.B., 1983. The historical status and reduction of the western arctic bowhead whale (*Balaena mysticetus*) population by the pelagic whaling industry, 1848–1914. Report of the International Whaling Commission (Special Issue 5), pp. 107–141.
- Bogoslovskaya, L., 2003. The bowhead whale off Chukotka: integration and scientific and traditional knowledge. In: McCartney, A.P. (Ed.), *Indigenous ways to the present: native whaling in the western Arctic*. Canadian Circumpolar Institute Press, Studies in Whaling No. 6, Edmonton, Canada, pp. 209–253.
- Clark, C.W., Johnson, J.H., 1984. The sounds of the bowhead whale, *Balaena mysticetus*, during the spring migrations of 1979 and 1980. *Canadian Journal of Zoology* 62, 1436–1441.
- Clark, C.W., Charif, R., Mitchell, S., Colby, J., 1996. Distribution and behaviour of the bowhead whale, *Balaena mysticetus*, based on analysis of acoustic data collected during the 1993 spring migration off Point Barrow, Alaska. Rep. International Whaling Commission 46, 541–552.
- Cummings, W.C., Holliday, D.V., 1987. Sounds and source levels from bowhead whales off Pt. Barrow, Alaska. *Journal of the Acoustical Society of America* 82, 814–821.
- George, J.C., Zeh, J., Suydam, R., Clark, C., 2004. Abundance and population trend (1978–2001) of western Arctic bowhead whales surveyed near Barrow, Alaska. *Marine Mammal Science* 20 (4), 755–773.
- Grebmeier, J.M., Harvey, H.R. (Eds.), 2005. The Western Arctic Shelf-Basin Interactions (SBI) Project. *Deep-Sea Research II* 52 (24–26), 3109–3576.
- Hopcroft, R.R., Clarke, C., Nelson, R.J., Raskoff, K.A., 2005. Zooplankton communities of the Arctic's Canada Basin: the contribution by smaller taxa. *Polar Biology* 28, 198–206.
- Ljungblad, D.K., Thompson, P.O., Moore, S.E., 1982. Underwater sounds recorded from migrating bowhead whales, *Balaena mysticetus*, in 1979. *Journal of the Acoustical Society of America* 71, 477–482.
- Lowry, L.F., Sheffield, G., George, J.C., 2004. Bowhead whale feeding in the Alaskan Beaufort Sea, based on stomach contents analyses. *Journal Cetacean Research and Management* 6 (3), 215–223.
- Maslowski, W., Newton, P., Schlosser, A., Semtner, A., Martinson, D., 2000. Modeling recent climate variability in the Arctic Ocean. *Geophysical Research Letters* 27 (23).
- Melnikov, V.V., Zelensky, M.A., Ainana, L.I., 1998. Observations on distribution and migration of bowhead whales (*Balaena mysticetus*) in the Bering and Chukchi Seas. Paper Sc/50/AS3 presented to the IWC-SC, available from <www.iwcoffice.org>.
- Moore, S.E., 1992. Summer records of bowhead whales in the northeastern Chukchi Sea. *Arctic* 45, 398–400.
- Moore, S.E., Laird, K.L., 2006. Trends in sea ice cover within habitats used by bowhead whales in the western Arctic. *Ecological Applications* 16 (4), 932–944.
- Moore, S.E., Reeves, R.R., 1993. Distribution and movement. In: Burns, J.J., Montague, J.J., Cowles, C.J. (Eds.), *The Bowhead Whale*. Special Publication No. 2, the Society for Marine Mammalogy. Allen Press, Lawrence, KS, pp. 313–386.
- Moore, S.E., Stafford, K.M., Mellinger, D.K., Hildebrand, J.A., 2006. Listening for large whales in the offshore waters of Alaska. *BioScience* 56 (1), 49–55.
- Noongwook, G., 2007. In: Huntington, H.P., George, J.C. (Eds.), *The Native Village of Savoonga, The Native Village of Gambell*. Traditional knowledge of the bowhead whale (*Balaena mysticetus*) around St. Lawrence Island, Alaska. *Arctic* 60 (1), 47–54.
- Rugh, D., Demaster, D., Rooney, A., Breiwick, J., Shelden, K., Moore, S., 2003. Bowhead whale (*Balaena mysticetus*) stock identity. *Journal Cetacean Research and Management* 5 (3), 267–280.
- Sekiguchi, K. 2007. Cruise Report: Oshoro Maru, OS180/Leg 3. University of Hawaii, Hilo, Hawaii, unpublished.
- Shimada, K., McLoughlin, F., Carmack, E., Proshutinsky, A., Nishino, S., Itoh, M., 2004. Penetration of the 1990s warm temperature anomaly of Atlantic Water in the Canadian Basin. *Geophysical Research Letters* 31 (20).
- Stafford, K.M., Moore, S.E., Spillane, M., Wiggins, S., 2007. Gray whale calls recorded near Barrow, Alaska throughout the winter of 2003–04. *Arctic* 60 2, 167–172.
- Wiggins, S., 2003. Autonomous Acoustic Recording Packages (ARPs) for long-term monitoring of whale sounds. *Marine Technology Society Journal* 37, 13–22.
- Würsig, B., Clark, C., 1993. Behavior. In: Burns, J.J., Montague, J.J., Cowles, C.J. (Eds.), *The Bowhead Whale*. Special Publication No. 2, The Society for Marine Mammalogy.