# Bowhead whale springtime song off West Greenland

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(Received 13 February 2008; revised 30 July 2008; accepted 31 July 2008)

Three songs were recorded from bowhead whales (*Balaena mysticetus*) in Disko Bay, West Greenland, during 59 h of recordings via sonobuoys deployed on seven days between 5 and 14 April 2007. Song elements were defined by units following the protocol of previous description of bowhead whale song. The two most prominent songs were loud, complex, and repeated in long bouts on multiple recording days while the third song was much simpler and recorded on only one day. Bowhead whale simple calls and faint song elements were also recorded using digital audio tape recorders and a dipping hydrophone deployed from the sea ice approximately 100–150 km southwest of Disko Bay on three separate days suggesting that song is also produced in the central portion of Baffin Bay in winter. Songs recorded in Disko Bay are from an area where approximately 85% of the whales have been determined to be adult females. Although it is not known which sex was singing, we speculate that, as in humpback whales (*Megaptera novaeangliae*), male bowhead whales may sing to mediate sexual competition or mate selection behaviors. This is the first detailed description of springtime songs for bowhead whales in the eastern Arctic.
 [DOI: 10.1121/1.2980443]

PACS number(s): 43.80.Ka, 43.30.Sf [WWA] Pages: 3315–3323

## I. INTRODUCTION

Bowhead whales (*Balaena mysticetus*) occur off the coast of West Greenland in early spring, with the population estimated at roughly 1200 ($CV$=0.3) individuals (Heide-Jørgensen *et al.*, 2007). From February to May, a large proportion of this population concentrates in and near Disko Bay, where they feed intensively on dense layers of epibenthic copepods (Laidre *et al.*, 2007) before migrating across Baffin Bay to the eastern Canadian Arctic in May and June (Heide-Jørgensen *et al.*, 2003). Whales demonstrate highly predictable arrival and departure dates each spring, following observations as far back as the 1700s (Eschricht and Reinhardt, 1861). Satellite tagging studies have revealed strong site fidelity to the region south of Disko Island and have demonstrated that bowhead whales wintering off the west coast of Greenland and summering in the eastern Canadian Arctic likely consists of a single population (Heide-Jørgensen *et al.*, 2003, 2006). Bowheads exhibit considerable sex and age-class segregation across this geographic range, as first noted by commercial whalers (e.g., Southwell, 1898). For example, genetic studies to date show that over 85% of the whales in Disko Bay are adult females, and given they are not accompanied by calves they are either resting or pregnant (Heide-Jørgensen *et al.*, 2007). On the contrary, whales occupying Foxe Basin and northwestern Hudson Bay are nursing females, calves, and subadults (Cosens and Blouw, 2003).

There are few detailed descriptions of calls produced by bowhead whales in the eastern Arctic (Richardson *et al.*, 1995). Conversely, bowhead whale calls have been well described for the western Arctic population (Ljungblad *et al.*, 1980; Ljungblad *et al.*, 1982; Clark and Johnson, 1984; Cummings and Holliday, 1987). Würsig and Clark (1993) compiled results from over 5000 h of recordings obtained from ice-based hydrophone arrays during the 1980s (George *et al.*, 2004) and roughly 500 h of recordings obtained from sonobuoys in the northern Bering, Chukchi and Beaufort Seas (Ljungblad *et al.*, 1986; Würsig *et al.*, 1985). Three types of sounds summarized the acoustic repertoire of bowhead whales in the western Arctic: (1) percussive slaps, blows, gunshot, and crunch sounds; (2) simple frequency-modulated (FM) and complex amplitude-modulated (AM) calls given in no particular order, and (3) long patterned sequences of calls (often called "units" or "notes"), hereafter referred to as song.

In the western Arctic, bowhead songs were usually recorded before mid-May during the initial phase of the spring migration past Barrow, AK (Würsig and Clark, 1993). Songs consisted of one to three themes that include repeated phrases comprised of one to five units. Compared to simple FM and AM calls, which often last only 1–2 s, calls that

comprise songs are longer, exhibit a broader frequency range and much greater FM and AM variations. Songs recorded during the spring migration were usually about a minute long, but song bouts sometimes lasted hours. Usually only one whale of the number within range of the hydrophone array would sing at a time; when that whale stopped, another often began to sing (Cummings and Holliday, 1987). Songs produced by various whales in the same season were similar, but interannual variability in songs was pronounced. For example, distinct bowhead songs were described for each of six springs (1979, 1980, 1982, 1985, 1986, and 1988), with complexity ranging from two to three units lasting a few minutes (Ljungblad *et al.*, 1982), to three to five units, some of which show harmonically unrelated features produced simultaneously and continued for hours (Würsig and Clark, 1993; Fig. 5.9). Singing whales were never observed, so sex, size, and behavior for these animals are unknown.

Despite considerable sampling effort, no records of singing were reported from western Arctic bowhead whales in summer or autumn, causing Würsig and Clark (1993) to speculate that singing is a male breeding display used, as in humpback whales (*Megaptera novaeangliae*), to either attract females or deter rival males (e.g., Cerchio *et al.*, 2001). Modeling estimates based on measurements of fetuses and ovaries from bowheads harvested in Alaska indicate that conception occurs between 2 March and 14 April (Reese *et al.*, 2001). So, songs recorded near Barrow in late April and early May were assumed to be from males singing "late" in the season, resulting in shorter and less frequent songs, again as reported for humpback whales toward the end of the mating season. From autumn recordings of bowhead whales migrating across the Alaskan Beaufort Sea, Blackwell *et al.*, (2007) reported simple or complex calls that were repeated every 2–5 s, for roughly 73 s (range 14 s–5.5 min), with two notable extremes being "call sequences" that lasted 30 and 50 min. Although different from song, in that the call sequences were comprised of recognizable FM and AM calls, this calling behavior exhibited some songlike complexity in calling rate, frequency content, and occasionally included alternating call sequences between at least two whales. Thus, it would appear that bowhead whale calling behavior is more variable than as summarized in Würsig and Clark (1993).

In April 2007, calls and songs of bowhead whales were recorded in Disko Bay, West Greenland. Disko Bay lies at the boundary between the high Arctic waters of Baffin Bay and the sub-Arctic waters of southwest Greenland. Annual sea ice reaches maximum extent in March, and then retreats in April and May such that the bay is ice-free by June. Recordings were made via sonobuoys deployed in open-water areas among drifting sea ice, often near bowheads (2–3 km distances) that were presumably feeding (Laidre *et al.*, 2007). The spectacular call sequences received at the nearby research station are described here.

## II. METHODS

### A. Recording protocol

Seven ANSSQ-57A type sonobuoys were deployed in 80%–90% ice cover roughly 1 km off the southwest coast of

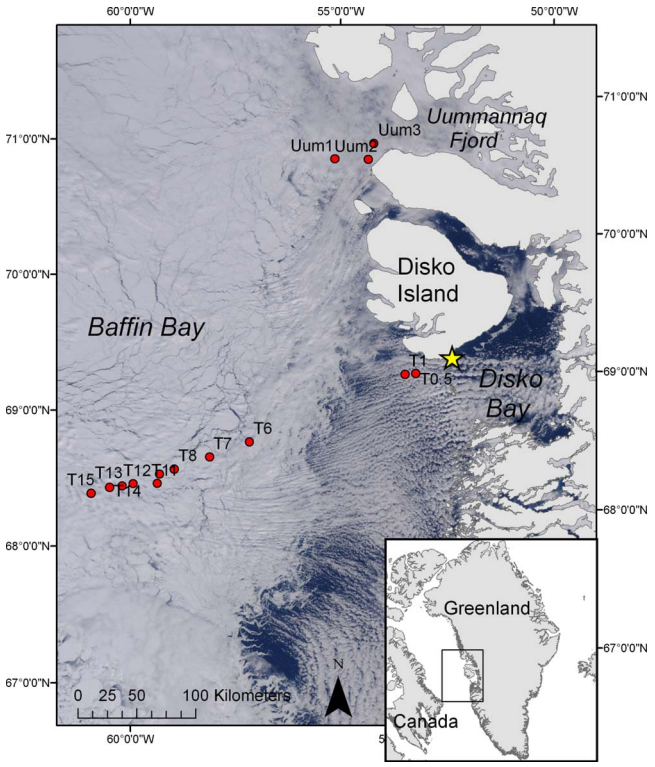


FIG. 1. (Color online) Map of Disko Bay and recording locations in Disko Bay, Uummannaq fjord, and along the hydrographic line. Sonobuoys were deployed <1 km directly offshore (star) from the town of Qeqertarsuaq and signals were received at the Arctic Station, University of Copenhagen. Sea ice conditions from 13 April 2006 were obtained from the MODIS Aqua satellite.

Disko Island, near the town of Qeqertarsuaq, between 5 and 14 April 2007 (Fig. 1, Table I). Sonobuoys are passive acoustic listening systems that contain a hydrophone, signal processing electronics, and a VHF transmitter (Thomas *et al.*, 1986). Signals from the sonobuoy were received by a VHF antenna mounted on the roof of the field station and connected to a laptop computer continuously recording in the laboratory. Hydrophone deployment was set at 122 m depth and all seven instruments recorded sounds from 10 Hz to 20 kHz for roughly 8–9 h. Data were recorded to an external hard drive as wav files for later analysis.

Recordings in sea ice cover >95% were also made at 11 locations that ranged from ~75 to 300 km offshore from Disko Island. These locations were coincident with a line of hydrographic stations and were therefore opportunistic. Recordings were made using a Sony TCD-D7 digital audio tape (DAT) recorder attached to a dipping hydrophone (Offshore Acoustics: frequency response of 10 Hz—40 kHz). Stations were accessed via a Bell 222 helicopter (Fig. 1) and concurrent oceanographic conditions (CTD casts) were made during recordings sessions. Recordings (~12 h) were made after the helicopter engines had shut down by deploying the hydrophone to 10 m depth through an open-water lead or a hole bored in the ice. The total time recorded at each station varied with conditions and battery failure of equipment (temperatures <−25 °C); however, recordings from each station lasted at least 20 min and in some cases up to 45 min.

TABLE I. Summary of acoustic sampling effort via sonobuoys (sb) in Disko Bay and on-ice via hydrophone (h) in Davis Strait and Uummannaq Fjord (Fig. 1).

| Date | | Start | End | Sample description | Song type recorded |
|---|---|---|---|---|---|
| 5 April | sb | 1720 | 0200 | Bowhead and beluga calls | Faint warble |
| 6 April | sb | 1703 | 0200 | Bowhead and beluga calls | Warble, faint screechy |
| 7 April | sb | 1643 | 0120 | Bowhead only | Screechy, faint warble, 3+ animals overlapping at times |
| 8 April | sb | 1212 | 2030 | Bowhead | Warble and check mark |
| 9 April | sb | 1836 | 0310 | Bowhead | Warble, screechy, overlapping multiple animals |
| 10 April | sb | 2009 | 0500 | Bowhead | Faint warble, 2+overlapping throughout the recording |
| 14 April | sb | 2020 | 0510 | Bowhead | Warble |
| 9 April T7 | h | 1045 | 1130 | Bowhead | Warble |
| 5 April T8 | h | 1346 | 1354 | Bowhead and bearded seal | Faint |
| 9 April T11 | h | 1656 | 1724 | Bowhead and bearded seal | Faint |
| 9 April T12 | h | 1505 | 1525 | Nothing obvious | |
| 9 April T14 | h | 1400 | 1419 | Narwhal | Clicks |
| 9 April T15 | h | 1244 | 1321 | Narwhal | Clicks and cries |
| 14 April U1 | h | 1335 | 1442 | Narwhal and bearded seal | Clicks and whistles, song |
| 14 April U2 | h | 1619 | 1707 | Narwhal and bearded seal | Clicks and whistles, song |
| 15 April U3 | h | 1340 | 1540 | Narwhal and bearded seal | Clicks and whistles, song |

### B. Data analysis

All 59 h of acoustic data from the sonobuoy recordings were displayed as spectrograms [4096 point fast Fourier transform (FFT), 50% overlap] and visually examined for bowhead whale calls using Raven (Charif *et al.*, 2007). Data were also played back as audio files to help characterize the call types and song notes, units, and themes. Time-frequency measurements were made in Raven (same FFT and overlap as above). The DAT tapes (~6 h) from the dipping hydrophone stations were digitized as 10 min long wav files and were both listened to in real time for bowhead whale sounds and displayed as spectrograms as above.

### C. Song classification

Song elements were classified as aurally distinct units (Würsig and Clark, 1993). Each song is composed of multiple units always repeated in the same order. We used onomatopoetic names for the two most common songs as this was more evocative of the differences among them and because a "generic" nomenclature such as "songs I and II" might become confusing if future songs are considerably different. The third song we named the "check mark" song based on spectrographic qualities of the most common unit.

## III. RESULTS

The 59 h of recordings via sonobuoys were made on seven days in from 5 to 14 April 2007 (Fig. 1). Of that sample, only about 6 h did not contain any recognizable bowhead whale calls. Fourteen hours on 5–8 April 2007, contained calls that did not overlap others such that parameters of each call could be measured. Songs and calls were often spectacularly loud. Whales were often seen in the area when sonobuoys were deployed, with the closest animals sighted within 2–3 km of the sonobuoy on 6 April 2007. On 9 and 10 April, there were many whales calling and their overlapping songs and calls could not be distinguished from each other; therefore, no measurements were made but song types were noted (Table I). The only other species recorded by sonobuoys were beluga whales (*Delphinapterus leucas*) which were recorded on 5 and 6 April 2007.

A total of approximately 6 h were recorded via dipping hydrophone on three days from 9 to 15 April. Of that sample, bowhead whales were heard on three stations, bearded seals (*Erignathus barbatus*) on two stations, and narwhals (*Monodon monoceros*) on five stations (Table I). The quality of the recordings from Davis Strait was poor mostly due to the noise from people walking on the ice while taking hydrographic measurements, which transmitted well into the water column, but also because below freezing air temperatures (−25 °C) caused the DAT recorder to seize up. Recordings from Uummannaq (Fig. 1) were much better but contained no bowhead whale calls but many vocalizations of bearded seals and narwhals.

### A. Song types

Bowhead whales in Disko Bay produced three distinctive songs, each containing two to six units. The first two songs were extremely complex, loud, and showed evidence of two different sounds being produced simultaneously, as was suggested by Würsig and Clark (1993) for western Arctic bowhead whales.

The most common song, named "warble song" for its distinctive concluding unit, consisted of an initial FM upsweep followed without a break by a long (22 s) harmonically rich cry (unit one) that was produced at the same time as two lower frequency units (units 2 and 3), terminating in a long low *warble* (unit 4: Fig. 2). The lowest frequency components (units 2 and 3) were produced simultaneously with unit 1 and occurred in groups of three to seven units with unit 2 followed 0.6 s (±0.25) later by unit 3 which was a

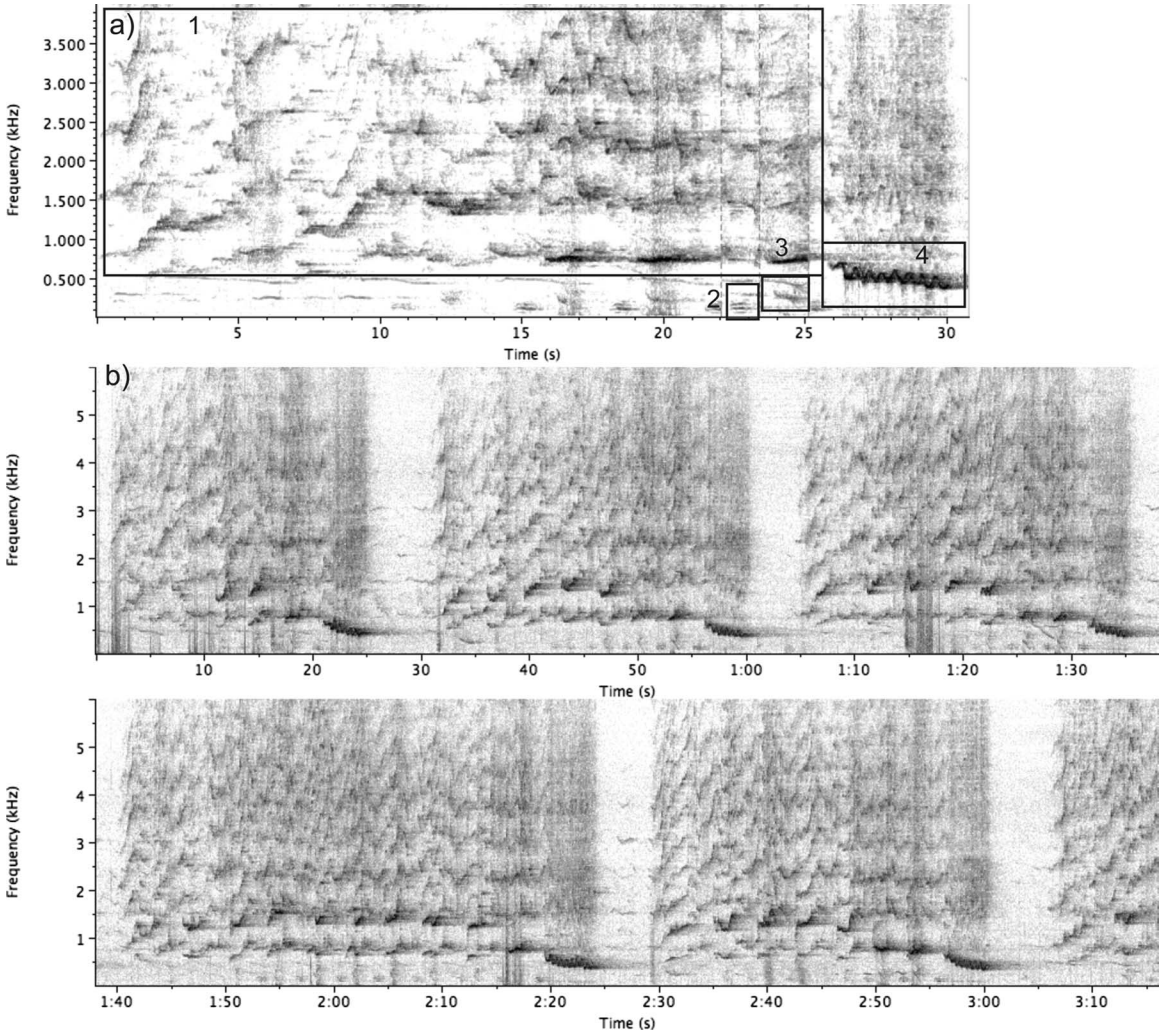


FIG. 2. (a) Warble song units; (b) five warble songs recorded 8 April 2007 (bottom two panels); FFT 4096, 50% overlap, Hanning.

simple 0.7 s (±0.17) down-sweep (Table II). Subsequent unit 2's occurred 1.5 (±0.4) s later. The warble unit lasted almost 5 s with a mean of 7.4 (±1.3) oscillations during each warble. This whole song had a duration of roughly 31 s and was recorded in long repeating bouts during every recording session. The average bout lasted 11.8 ± 9.0 min, with 20 ± 14 songs per bout and the first and last songs in each bout were always shorter than the intervening songs. Although one warble song often dominated the recording due to loudness (likely due to the proximity of the singing whale to the sonobuoy), several other warble songs were often evident in the background, aurally, and on the spectrograms, demonstrating that more than one whale was singing this song at the same time. Our best estimate of the maximum number of animals producing the warble song at any one time was 3, based on overlap of different song parts.

The second most common song, named "screechy song," was also the most complex. The song consisted of six units [Fig. 3(a)], including an aurally distinctive "screeching-squeal" second unit. The song begins with a short low-frequency FM call (unit 1) followed by one to three very *screechy* FM cries (unit 2). This is followed by a loud low-frequency FM down-sweep (unit 3), and then by a series of short, paired, FM cries: first, a high frequency, rich down- or up-down-sweep with tonal elements at ~550 Hz intervals with greatest energy at 1843 Hz that decreased in duration over time (unit 4). The second was a much lower frequency tonal-upsweep (unit 5). Each pair was repeated 3–16 times ($x = 9.2 \pm 2.4$). The song ends with a loud very low-frequency tonal down-sweep (unit 6). The distinctive screechy song starts with a down-sweep (unit 1), which then oscillates one to five times between 1 to 3 kHz before ending in a high pitched *squeal*. The first unit 2 (i.e., screech) was always equal to or longer in duration than subsequent screeches, which never had more than two oscillations.

Screechy songs were recorded on 6, 7, and 9 April, but only songs recorded on 7 April contained distinct units that could be measured. 137 of these songs were audibly distinct on the recordings, 119 contained elements discrete enough to measure, with an additional 8–12 songs visible in spectrograms as background noise. The 137 distinct songs occurred in 19 bouts [Fig. 3(b)]. The mean number of songs/bout was 7.2 (range 1–22). Songs lasted 65.8 ± 11.0 s and bouts lasted 10.3 ± 7.67 min. The intersong interval within bouts was only 8.7 ± 2.4 s. Nearly all (118 of 137) of the songs had two unit 2's (or screeches).

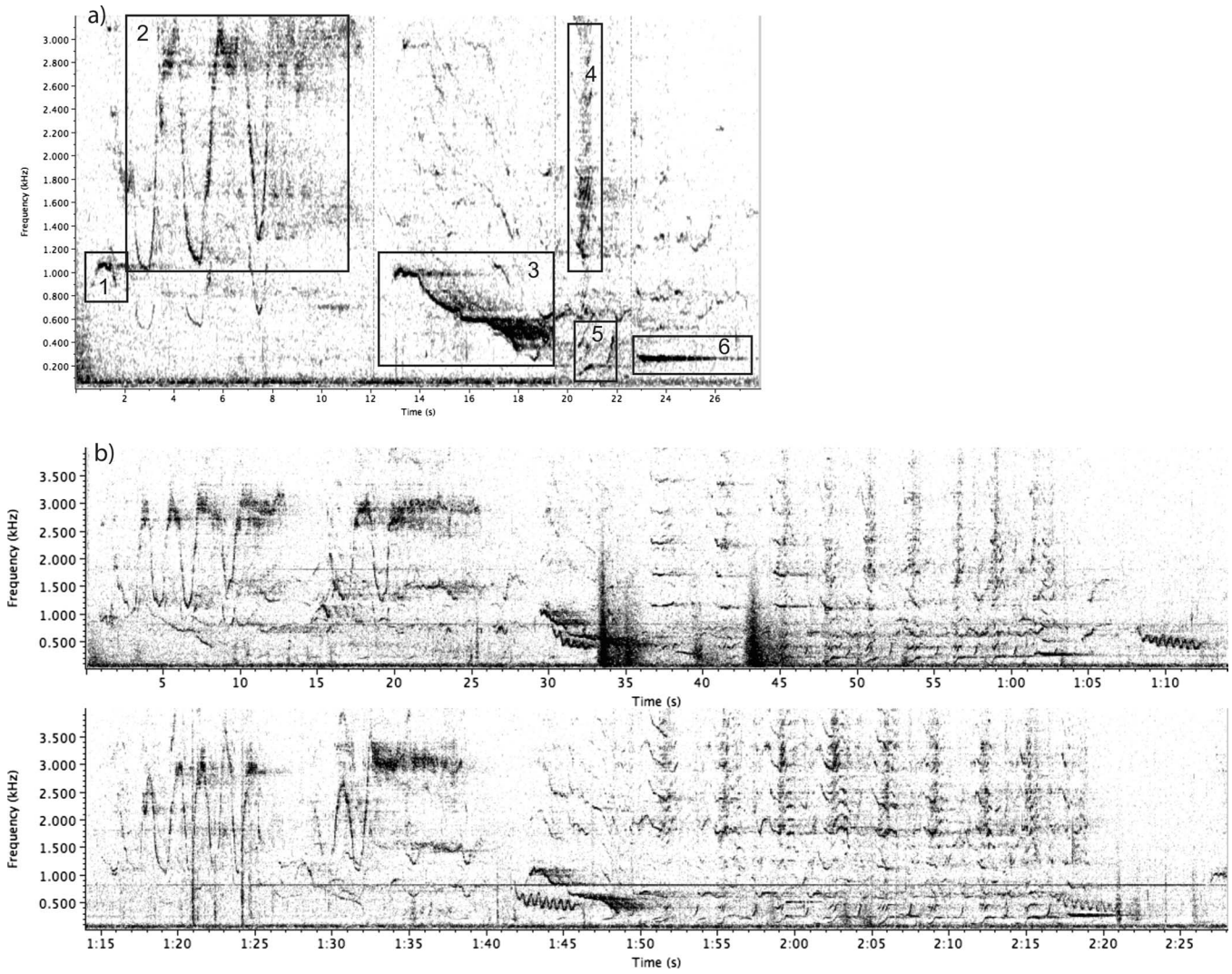


FIG. 3. (a) Screech song units; (b) two screech songs recorded on 7 April 2007 (bottom two panels); FFT 4096, 50% overlap, Hanning window.

The third song (check mark song) was the simplest of the three and was only recorded on 8 April 2007. The check mark song consisted of only two units. The first unit was a down-up swept signal that, on spectrograms, resemble check marks and sounded like "weeoww-whup," which was followed by a single loud tone (Fig. 4). At least 147 of this type

TABLE II. Duration and frequency parameters of song units.

| Song | Duration (±s.d.) (s) | No. of song | Start (s) or low (l) freq. (Hz) | End (e) or high (h) freq. (Hz) | Center (c) or Max (m) freq. (Hz) |
|---|---|---|---|---|---|
| Warble | 30.4 (6.3) | | | | |
| Unit 1 | 22.3 (6.2) | 1 | 574.8 (72.0) (l) | 5678.9 (298.9) (l) | 912.7 (383.9) (m) |
| Unit 2 | 4.7 (0.5) | 2–7 | 124.2 (16.8) (s) | 81.4 (13.7) | |
| Unit 3 | 0.7 (0.2) | 1–5 | 260.9 (39.3) (s) | 113.6 (35.7) | |
| Unit 4 | 4.76 (0.6) | 1–2 | 664 (44.5) (s) | 330 (24.7) | |
| Screech | 65.8 (11.0) | | | | |
| Unit 1 | 0.9 (0.2) | 1–3 | 1134.1 (81.0) (s) | 823.3 (81.9) (e) | |
| Unit 2 | 10.4 (0.9) | 1–3 | 1073.3 (184.5) (l) | 3270.1 (197.5) (h) | 2280.4 (692.3) (m) |
| Unit 3 | 6.4 (0.7) | 1 | 1093.3 (86.0) (s) | 349.1 (68.3) (e) | |
| Unit 4 | 1.8 (0.5) | 3–16 | 1020.9 (254.3) (l) | 4094.9 (585.6) (h) | 1843.5 (618.1) (m) |
| Unit 5 | 1.8 (0.3) | 2–11 | 147.0 (34.9) (s) | 446.3 (34.5) (e) | |
| Unit 6 | 3.9 (1.4) | 1–4 | 318.3 (23.2) (s) | 203.6 (22.5) (e) | |
| Check mark | 12.2–84.4 | | | | |
| Unit 1 | 1.6 (0.2) | 2–12 | 1141.5 (103.2) (s) | 648.4 (51.8) (e) | |
| Unit 2 | 2.1 (0.4) | 1 | | | 378.7 (13.3) (c) |

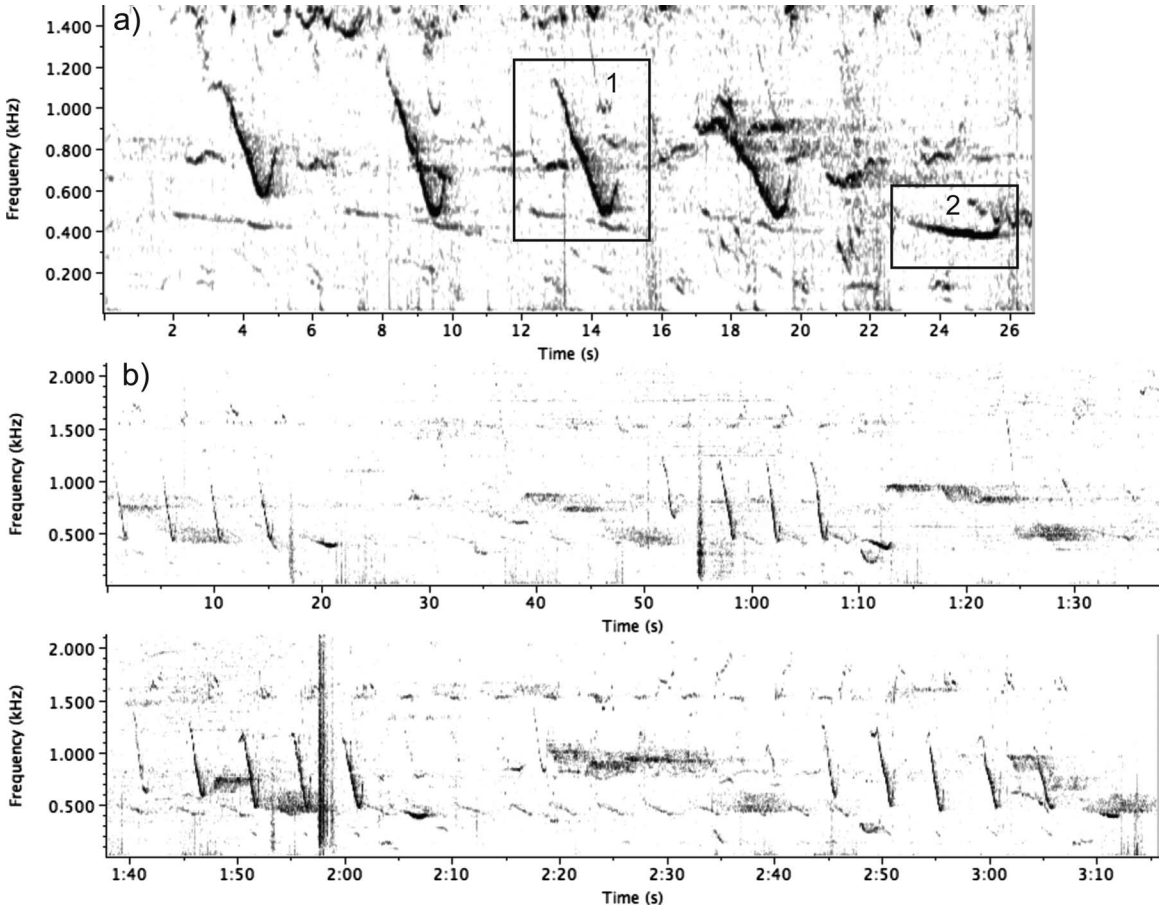


FIG. 4. (a) Check mark song with both units identified; (b) four songs recorded 8 April 2007 (bottom two panels); FFT 4096, 50% overlap, Hanning window.

of song were recorded, although only 107 were distinct enough to measure. The number of check mark units preceding the tone ranged from 2–12 ($x=4.5\pm1.5$). These units lasted $1.6\pm0.2$ s and started, on average, at $1141.5\pm103.2$ Hz ($n=489$). Calls swept down to $433.0\pm80.7$ Hz before the short upsweep to $648.4\pm51.8$ Hz. Not all of these units swept back up, some were simple FM down-sweeps ($n=157$ out of 489). The tone followed all but one of these units and had a center frequency of $378.7\pm13.3$ Hz. Tones lasted $2.1\pm0.4$ s and were the highest amplitude unit. The first unit of each was always highest in frequency and lowest in amplitude. The total duration of a song was a function of the total number of checks and ranged from 12.2 to 84.4 s.

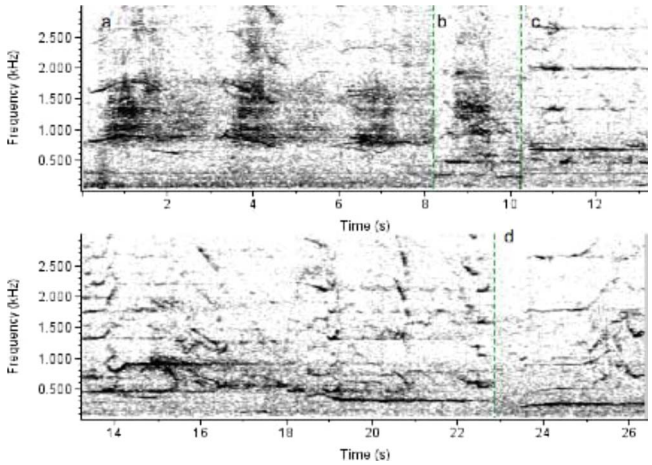


FIG. 5. (Color online) Examples of other nonpatterned bowhead whale calls recorded on sonobuoys in Disko Bay in April 2007. (a) Purr calls; (b) growl call; (c) FM constant and down calls; (d) up call (FFT 2048 points, 50% overlap for all).

### B. Geographic range of song

Bowhead whale song elements and simple calls were recorded in the pack ice using dipping hydrophones on 3 of the 11 stations: T7 (warble songs), and simple "up" calls at T8 and T11. The farthest offshore station where bowhead calls where recorded was T11, approximately 300 km (140 nm) from Disko Bay. The most common sound from these pack ice recordings were the distinctive trills of male bearded seals produced as a breeding display (van Parijs and Clark, 2006); narwhal calls were also recorded.

### C. Other calls

In addition to the three songs, many other calls were recorded from the bowheads in Disko Bay, with a few examples of spectrograms provided in Fig. 5. These calls did not show any pattern in production and seemed typical of bowhead whale calls recorded elsewhere. Calls recorded included low-frequency (<1 kHz) FM calls labeled "up," "down," "constant," "inflect," and "high" depending on their pattern of modulation and frequency content, and the more

labile AM calls categorized as "growls" (<1 kHz) or "trumpets and screams" (0.5–5 kHz) depending on frequency range (Würsig and Clark, 1993). While this lexicon of seven call types, each lasting only 1–2 s, provides a framework for identifying most nonsong sound production, future sampling and measurement of calls are required to determine if bowheads in Disko Bay produce these calls in a context similar to whales in the western Arctic.

## IV. DISCUSSION

This is the first description of bowhead whale song in the eastern Arctic. Previous reports consist only of description of simple calls from a short sampling effort (3 h; 890 calls) in Isabella Bay, Baffin Island, in late summer 1984–1987 (Richardson *et al.*, 1995). Conversely, the calling behavior we describe here consists of patterned sequences of often very loud calls produced by multiple whales. The amplitude and complexity of these songs were so surprising and delightful that we have attempted to describe them in considerable detail that they might be compared with future recordings.

The status of the bowhead whale stock that inhabits the eastern Canadian Arctic, Hudson Bay, and West Greenland is not fully understood, but it seems likely that West Greenland may serve as both a mating and a feeding ground for parts of this population in winter and spring. The animals found in Disko Bay are part of a larger single population that extends into the Canadian high Arctic (Heide-Jørgensen *et al.*, 2007). Disko Bay is one of the most productive regions in West Greenland and offers predictable spring and summer prey resources to a myriad of marine mammals (Heide-Jørgensen and Laidre, 2004). A region such as Disko Bay, where food is seasonally and reliably abundant, allows animals to obtain sufficient nutritional resources and have additional energy to expend on elaborate displays such as those described here.

Singing is a behavioral display usually attributed to males across a broad range of species including insects, amphibians, birds, and whales (Payne and McVay, 1971; Searcy and Andersson, 1986; Romer, 1993). It is unknown if songs are used by cetaceans to advertise a resource (such as food or fitness) or as an intermale spacing mechanism. Humpback whales in a geographic region all sing the same song in the same year with interannual changes in song patterns (Winn *et al.*, 1981). The recording of geographically distinct blue whale (*Balaenoptera musculus*) songs on the same feeding ground has been proposed as a means of segregating different acoustic populations of this species (Stafford, 2003; Mellinger and Clark, 2003) but such population-level acoustic differences are undescribed for bowhead whales despite considerable effort on recordings of bowhead whale acoustics.

The recording of three distinct songs over a brief period in Disko Bay was surprising. Bowhead whales from the Bering Sea stock have been described as changing song between years, but all singers in one year sang the same song (Würsig and Clark, 1993). Overlapping songs recorded simultaneously in Disko Bay show that several whales sang the same song at the same time so the songs were not unique to individuals and different songs were sung at the same time so songs were not unique to certain time periods. Similar to other reports of song, however, songs described here lasted roughly 1 min with song bouts continuing for hours and all ended with loud notes. Although we have no evidence that it is only male bowhead whales that sing, we suggest that this may be the case based on evidence from other species of large whales. Based on DAT recordings in the pack ice, bowhead whales appeared to be singing over a larger area than just Disko Bay; however, song elements and calls were not as loud as those recorded in Disko Bay and no bowhead whales were seen at, nor enroute to, the recording site, suggesting that singing whales were at least 10 s of kilometers from the recording sites. Assuming similar source and ambient noise levels as bowhead whales in the Beaufort Sea, it is unlikely that whales in Disko Bay were those recorded in the pack ice. Bowhead whale song has only been estimated to be detected out to ~11 km (Cummings and Holliday, 1987; Clark *et al.*, 1996).

Several factors may explain why bowhead whale singing is so pronounced in Disko Bay compared to Alaska. First, the recordings were completed somewhat earlier in the season (early April) and prior to migration compared to the typical sampling season during migration in the Beaufort Sea (mid-April to early May; Clark and Johnson, 1984; Cummings and Holliday, 1987). Second, early spring access to bowhead whales offshore West Greenland is logistically less challenging than in the Bering Sea and this aided in obtaining recordings from whales prior to migration. Finally, singing might also be more intense if Disko Bay is an important mating ground. Studies in the Bering Sea suggest that conception occurs between 2 March and 14 April, coinciding well with the period when the whales are in Disko Bay and the period the songs were recorded here (Reese *et al.*, 2001). Genetic studies from biopsy dart samples demonstrate that approximately 85% of the whales in Disko Bay in spring 2007 ($n$ =157) were adult females and observations during spring 2000–2007 have shown that it is primarily mature female whales (lengths over 14 m) that occur offshore West Greenland. Genetic results suggest that the fraction of adult males is low and small (presumably young) whales are rarely seen. There are only a few records of newborns from the whaling period in the 19th century [Eschricht and Reinhardt 1861; Greenland Institute of Natural Resources (unpublished data)].

Seasonally varying hormone levels in males clearly influence singing behavior in male birds (Arnold, 1982) and by extension have been inferred in singing behavior of male whales (Cato *et al.*, 2001). If singing behavior is hormonally driven in bowhead whales singing in early April but seldom in May could reflect decreasing hormone levels. It could also represent the presence of fewer animals as bowhead whales appear to migrate out of Disko Bay in mid-May (Heide-Jørgensen *et al.*, 2006). The fact that almost no records of females with newborns have been detected in Disko Bay supports the hypothesis that this area is a mating ground where intensive singing activity is a part of the mating strategy. The fraction of males, based on biopsy results, that have been detected in Disko Bay is low [<15%, Greenland Institute of Natural Resources (unpublished data)]. This may be a

region where large reproductive males have somehow actively excluded other males, a behavior seen in taxa from frogs to elephants (Wells, 1977; Rasmussen *et al.*, 2008) or simply sexual segregation on a breeding ground, similar to that found in sperm whales (Whitehead *et al.*, 1989). The abundance estimate for bowhead whales in West Greenland has increased recently (Heide-Jørgensen *et al.*, 2007), and this in combination with some cyclical reproductive activity could explain why Disko Bay may have only recently become a mating ground with intensive singing activity.

The three songs we documented over a week were all distinctly different from one another, with both the warble and screech songs dominating the data throughout the entire recording period. We are less convinced that the check mark song is a form of true "song" because it is so simple relative to the other two songs and shows similarities to the repeated series of simple calls described as "call sequences" by Blackwell *et al.* (2007). Nevertheless, it stood out among the general cacophony of the Disko Bay recordings. Clearly the next step in acoustic studies of Disko Bay is to obtain more recordings during the same time frame over multiple years to see if these songs change over time. Longer-term recordings would define the seasonal and diel occurrence of singing behavior in Disko Bay. Finally, intra- and interannual broad scale comparisons of acoustic behavior of bowhead whales from multiple sites (for example, the northern Bering Sea, the Beaufort Sea, and Spitsbergen) would permit broad-scale geographic variations in acoustic repertoires to be studied.

## ACKNOWLEDGMENTS

This study was funded by the NOAA Ocean Exploration grant to K.L.L. and the Greenland Institute of Natural Resources. The Arctic Station of the University of Copenhagen provided the field base and Air Greenland provided helicopter support. We thank the hunters of Qeqertarsuaq and Qaanaaq for help with the field operations.

Arnold, A. P. (**1982**). in *Acoustic Communication in Birds*, edited by D. E. Kroodsma and E. H. Miller (Academic, New York), pp. 75–94.

Blackwell, S. B., Richardson, W. J., Greene, C. R., Jr., and Streever, B. (**2007**). "Bowhead whale (*Balaena mysticetus*) migration and calling behavior in the Alaskan Beaufort Sea, autumn 2001-04: an acoustic localization study," Arctic **60**, 255–270.

Cato, D. H., Paterson, R. A., and Paterson, P. (**2001**). "Vocalization rates of migrating humpback whales over 14 years," Mem. Queensland Mus. **47**, 481–489.

Cerchio, S., Jacobsen, J. K., and Norris, T. F. (**2001**). "Temporal and geographical variation in songs of humpback whales, *Megaptera novaeangliae*: synchronous change in Hawaiian and Mexican breeding assemblages," Anim. Behav. **62**, 313–329.

Charif, R. A., Clark, C. W., and Fristrup, K. M. (**2007**). *Raven Pro 1.3 User's Manual* (Cornell Laboratory of Ornithology, Ithaca, NY).

Clark, C. W., Charif, R. A., Mitchell, S., and Colby, J. (**1996**). "Distribution and behavior of the bowhead whale, *balaena mysticetus*, based on analysis of acoustic data collected during the 1993 spring migration off Point Barrow, Alaska," Rep. Int. Whal. Comm. **46**, 541–552.

Clark, C. W., and Johnson, J. H. (**1984**). "The sounds of the bowhead whales, *Balaena mysticetus*, during the spring migrations of 1979 and 1980," Can. J. Zool. **62**, 1436–1441.

Cosens, S. E., and Blouw, A. (**2003**). "Size- and age-class segregation of bowhead whales summering in northern Foxe Basin: A photogrammetric analysis," Marine Mammal Sci. **19**, 284–296.

Cummings, W. C., and Holliday, D. V. (**1987**). "Sounds and source levels from bowhead whales off Pt. Barrow, Alaska," J. Acoust. Soc. Am. **82**, 814–821.

Eschricht, D. F., and Reinhardt, J. (**1861**). "On the Greenland Right-Whale (*Balaena mysticetus L.*) with special reference to its geographic distribution and migrations in times past and present (in Danish). Om Nordhvalen (*Balaena mysticetus L.*) navnlig med Hensyn til dens Udbredning i Fortiden og Nutiden og til dens ydre og indre Saerkjender," K. Danske Videnskabernes Selskabs Skrifter. Series 5, naturvidenskabelig og mathematisk Afdeling **5**, 433–590.

George, J. C., Zeh, J., Suydam, R., and Clark, C. W. (**2004**). "Abundance and population trend (1978–2001) of western Arctic bowhead whales surveyed near Barrow, Alaska," Marine Mammal Sci. **20**, 755–773.

Heide-Jørgensen, M. P., and Laidre, K. L. (**2004**). "Declining open water refugia for top predators in Baffin Bay and adjacent waters," Ambio **33**(8), 488–495.

Heide-Jørgensen, M. P., Laidre, K. L., Borchers, D., and Samarra, F. I. P. (**2007**). "Increasing abundance of bowhead whales in West Greenland," Biol. Lett. **3**, 577–580.

Heide-Jørgensen, M. P., Laidre, K. L., Jensen, M. V., Dueck, L., and Postma, L. D. (**2006**). "Dissolving stock discreteness with satellite tracking: Bowhead whales in Baffin Bay," Marine Mammal Sci. **22**, 34–45.

Heide-Jørgensen, M. P., Laidre, K. L., Wiig, O., Jensen, M. V., Dueck, L., Maiers, L., Schmidt, H. C., and Hobbs, R. C. (**2003**). "From Greenland to Canada in two weeks: Movements of bowhead whales, *Balaena mysticetus*, in Baffin Bay," Arctic **56**, 21–31.

Laidre, K. L., Heide-Jørgensen, M. P., and Nielsen, T. G. (**2007**). "The role of the bowhead whale as a predator in West Greenland," Mar. Ecol.: Prog. Ser. **346**, 285–297.

Ljungblad, D. K., Leatherwood, S., and Dahlheim, M. E. (**1980**). "Sounds recorded in the presence of an adult and calf bowhead whales," Mar. Fish. Rev. **42**, 86–87.

Ljungblad, D. K., Moore, S. E., and VanSchoik, D. R. (**1986**). "Seasonal patterns of distribution, abundance, migration and behavior of the western Arctic stock of bowhead whales, *Balaena mysticetus*, in Alaskan Seas," Rep. Int. Whal. Comm. **8**, 177–205.

Ljungblad, D. K., Thompson, P. O., and Moore, S. E. (**1982**). "Underwater sounds recorded from migrating bowhead whales, *Balaena mysticetus*, in 1979," J. Acoust. Soc. Am. **71**, 477–482.

Mellinger, D. K., and Clark, C. W. (**2003**). "Blue whale (*Balaenoptera musculus*) sounds from the North Atlantic," J. Acoust. Soc. Am. **114**, 1108–1119.

Payne, R. S., and McVay, S. (**1971**). "Songs of humpback whales," Science **173**, 585–597.

Rasmussen, H. B., Okello, J. B. A., Wittemyer, G., Siegismund, H. R., Arctander, P., Vollrath, F., and Douglas-Hamilton, I. (**2008**). "Age- and tactic-related paternity success in male African elephants," Behav. Ecol. **19**, 9–15.

Reese, C., Calvin, J. A., George, J. C., and Tarpley, R. J. (**2001**). "Estimation of fetal growth and gestation in bowhead whales," J. Am. Stat. Assoc. **96**, 915–938.

Richardson, W. J., Finley, K. J., Miller, G. W., Davis, R. A., and Koski, W. R. (**1995**). "Feeding, social and migration behavior of bowhead whales, *Balaena mysticetus*, in Baffin Bay vs the Beaufort Sea – regions with different amounts of human activity," Marine Mammal Sci. **11**, 1–45.

Romer, H. (**1993**). "Environmental and Biological Constraints for the Evolution of Long-Range Signaling and Hearing in Acoustic Insects," Philos. Trans. R. Soc. London, Ser. B **340**, 179–185.

Searcy, W. A., and Andersson, M. (**1986**). "Sexual selection and the evolution of song," Annu. Rev. Ecol. Syst. **17**, 507–533.

Southwell, T. (**1892**). "The migration of the Right Whale (*Balaena mysticetus*)," Natural Science **12**, 397–414.

Stafford, K. M. (**2003**). "Two types of blue whale calls recorded in the Gulf of Alaska," Marine Mammal Sci. **19**, 682–693.

Thomas, J. A., Fisher, S. R., and Awbrey, F. A. (**1986**). "Acoustic techniques in studying whale behavior," Rep. Int. Whal. Comm. **8**, 121–138.

van Parijs, S. M., and Clark, C. W. (**2006**). "Long-term mating tactics in an aquatic-mating pinniped, the bearded seal, *Erignathus barbatus*," Anim. Behav. **72**, 1269–1277.

Wells, K. D. (**1977**). "Territoriality and male mating success in the green frog (*Rana clamitans*)," Ecology **58**, 750–762.

Whitehead, H., Weilgart, L., and Waters, S. (**1989**). "Seasonality of sperm whales off the Galapagos Islands, Ecuador," Rep. Int. Whal. Comm. **39**, 207–210.

Winn, H. E., Thompson, T. J., Cummings, W. C., Hain, J., Hudnall, J., Hays,

H., and Steiner, W. W. (**1981**). "Song of the humpback whale – population comparisons," Behav. Ecol. **8**, 41–46.
Würsig, B., and Clark, C. (**1993**). *The Bowhead Whale*. edited by J. J. Burns, J. J. Montague, and C. J. Cowles (Society for Marine Mammalogy, Allen, Lawrence, KS), Special Publicatoin No. 2, pp. 157–199.
Würsig, B., Dorsey, E. M., Fraker, M. A., Payne, R. S., and Richardson, W. J. (**1985**). "Behavior of bowhead whales, *balaena mysticetus*, summering in the Beaufort Sea: A description," Fish. Bull. **83**, 357–377.