

Occurrence, Distribution and Behaviour of Beluga (*Delphinapterus leucas*) and Bowhead (*Balaena mysticetus*) Whales at the Franklin Bay Ice Edge in June 2008

NATALIE C. ASSELIN,^{1,2} DAVID G. BARBER,¹ PIERRE R. RICHARD³ and STEVEN H. FERGUSON³

(Received 10 May 2011; accepted in revised form 2 November 2011)

ABSTRACT. Ice edges and polynyas have long been noted for their high biological productivity within the Arctic environment. In June 2008, an aggregation of belugas and bowheads was identified at the Franklin Bay ice edge in the eastern Beaufort Sea, adjacent to the Cape Bathurst polynya. We conducted five ice-edge surveys by helicopter to study the distribution and behaviour of the whales. Bowheads were sighted in significantly shallower water than belugas. In addition, we used the helicopter platform to observe behaviour. Belugas and bowheads were engaged in directed travel and diving near and under the ice. Five beluga dives were timed and found to have an average duration of 106 ± 61 s (\pm SD) and a range of 30–197 s. One bowhead under-ice dive was timed and had a duration of 417 s. The under-ice dives are consistent with feeding behaviour observed for belugas and bowheads in other ice-edge locations. We hypothesize that higher prey densities along the Franklin Bay ice edge than in the adjacent open water may attract belugas and bowheads to the ice edge in June. Further research is needed to identify the abundance and type of prey species consumed and to assess the relative energetic importance of spring ice-edge feeding to the eastern Beaufort Sea beluga and bowhead populations.

Key words: aerial survey, polynyas, floe edge, *Delphinapterus leucas*, *Balaena mysticetus*, diving behaviour, habitat selection, fast ice

RÉSUMÉ. Depuis longtemps, les lisières de glace et les polynies sont connues pour leur grande productivité biologique au sein de l'environnement arctique. En juin 2008, un groupement de bélugas et de baleines boréales a été repéré à la lisière de glace de la baie Franklin, dans l'est de la mer de Beaufort, lisière adjacente à la polynie du cap Bathurst. Au moyen d'hélicoptères, nous avons effectué cinq études de lisières de glace afin d'examiner la répartition des baleines de même que leur comportement. Les baleines boréales évoluaient dans des eaux beaucoup moins profondes que les bélugas. De plus, nous avons étudié le comportement des baleines à partir de la plateforme destinée aux hélicoptères. Les bélugas et les baleines boréales se déplaçaient de manière dirigée et plongeaient près de la glace et sous celle-ci. Les plongeurs de bélugas ont été chronométrés, et leur durée moyenne s'établissait à 106 ± 61 s (\pm SD), avec une étendue de 30–197 s. Le plongeur sous glace d'une baleine boréale a duré 417 s. Les plongeurs sous glace vont de pair avec le comportement alimentaire observé chez les bélugas et les baleines boréales d'autres emplacements en lisières de glace. Nous avançons l'hypothèse que la plus grande densité de proies le long de la lisière de glace de la baie Franklin comparativement aux eaux libres adjacentes peut attirer les bélugas et les baleines boréales à la lisière de glace en juin. Il faut pousser les recherches plus loin pour déterminer l'abondance et le type d'espèces-proies consommées et pour évaluer l'importance énergétique relative de l'alimentation à la lisière de glace au printemps pour les populations de bélugas et de baleines boréales de l'est de la mer de Beaufort.

Mots clés : étude aérienne, polynies, glace de banc, *Delphinapterus leucas*, *Balaena mysticetus*, comportement de plongée, sélection de l'habitat, glace rapide

Traduit pour la revue *Arctic* par Nicole Giguère.

INTRODUCTION

Arctic animals have evolved and adapted to survive large seasonal variations in temperature, light, and sea-ice extent by feeding opportunistically within ephemeral areas offering a high density of food items. As in other zones with extreme climates, such as deserts and alpine zones, certain

areas have relatively low faunal and floral densities, while others serve as oases with much higher species abundance. Within the Arctic marine environment, polynyas and ice edges have long been recognized as habitats with higher species abundance than the surrounding ice-covered regions (Stirling, 1980, 1997; Dunbar, 1981). Ice edges also contribute to primary productivity in the Arctic and may be

¹ Centre for Earth Observation Science, Department of Environment and Geography, University of Manitoba, Winnipeg, Manitoba R3T 2N2, Canada

² Corresponding author; present address: Wapusk National Park and Manitoba North National Historic Sites, Parks Canada, Box 127, Churchill, Manitoba R0B 0E0, Canada; natalie.asselin@pc.gc.ca

³ Fisheries and Oceans Canada, 501 University Crescent, Winnipeg, Manitoba R3T 2N6, Canada

more productive than the open-water environment at high latitudes (Perrette et al., 2011). From marine mammals to birds and plankton, these areas of open water adjacent to ice-covered waters support a large variety of life, especially in spring, when migrating animals return to high latitudes (Stirling, 1997).

Beluga (*Delphinapterus leucas*) and bowhead (*Balaena mysticetus*) whales are two of the Arctic marine mammals that are often reported along ice edges and in polynyas (Fay, 1974; Carroll and Smithhisler, 1980; Stirling, 1980; Reeves et al., 1983; Carroll et al., 1987; Crawford and Jorgenson, 1990; Cosens and Dueck, 1991; Richard et al., 1998; Stewart, 2001; Harwood and Smith, 2002). Beluga behaviour at fast-ice edges is affected by the location of the edge in relation to the migration route (i.e., whether or not the ice is blocking the whales' travel) and includes directed movement (Bradstreet, 1982; Cosens and Dueck, 1991; Huntington et al., 1999), back-and-forth movement (Bradstreet, 1982), circling (Cosens and Dueck, 1991), diving under the ice (Bradstreet, 1982), and under-ice feeding (Huntington et al., 1999). Bowhead whales also engage in under-ice feeding, at least during spring migration (Carroll et al., 1987).

Within the Arctic, belugas and bowheads follow yearly migration patterns that largely coincide with sea-ice conditions (DFO, 2002; Ainley et al., 2003). They migrate into seasonally ice-covered regions in spring, following breakup, and migrate out in fall, prior to freeze-up. The Eastern Beaufort Sea (EBS) populations of bowheads and belugas overwinter in the Bering Sea (Fraker, 1979). The timing and direction of the spring migration of both whales are influenced by ice conditions (Fraker, 1979; Carroll and Smithhisler, 1980; Moore and Reeves, 1993; Huntington et al., 1999; Mymrin et al., 1999; Quakenbush and Huntington, 2010). In the past, bowheads and belugas traveled through the waters of northwestern Alaska in late April and early May (Fraker, 1979; Quakenbush and Huntington, 2010), but more recently, bowheads have been seen as early as late March and early April (Quakenbush and Huntington, 2010). Traveling through leads far offshore, bowheads reach the EBS in early to mid May (Braham et al., 1980), while belugas arrive in mid to late May (Fraker, 1979). The first destination for both groups is the Cape Bathurst polynya and flaw lead system in Amundsen Gulf (Fraker, 1979). This region is also used throughout the summer (Stirling, 1980). Belugas are believed to feed for four to six weeks in Amundsen Gulf (Fraker, 1979; Stirling, 1980) before part of the population migrates west to the Mackenzie estuary (Fraker, 1979; Richard et al., 2001). Similarly, bowheads also occupy the area near Cape Bathurst earlier in the year than they occupy the Mackenzie Delta region (Fraker and Bockstoce, 1980). The Cape Bathurst polynya is believed to be an important feeding ground for both belugas and bowheads in the spring (Stirling, 1980).

In 2007 and 2008, the EBS was the target of extensive scientific research during the International Polar Year (IPY) Circumpolar Flaw Lead (CFL) System Study (Barber et al., 2010). As part of the CFL study, ice-edge use by belugas

and bowheads was investigated from the CCGS *Amundsen* research icebreaker and by aerial surveys. Focusing our investigation on Franklin Bay, we documented the occurrence, diving behaviour, and habitat use of an aggregation of belugas and bowheads at the Franklin Bay fast-ice edge in June 2008.

MATERIALS AND METHODS

Study Area

The study area is in Franklin Bay, Northwest Territories, Canada. This bay is situated in the southeastern Beaufort Sea, on the east side of Cape Bathurst (Fig. 1). Oceanic water masses in the Beaufort Sea include a surface layer of Pacific origin (Polar-Mixed Layer) (McLaughlin et al., 1996) that circulates anticyclonically (Coachman and Aagaard, 1974) and a region below the top 40 to 60 m, known as the Beaufort undercurrent (Pacific Halocline), where circulation is cyclonic, or reversed (Aagaard et al., 1989). Waters of Atlantic origin are found between 200 and 600 m (Atlantic Layer) (McLaughlin et al., 1996). In Amundsen Gulf in 2008, the depth ranges of these three water masses were measured by Geoffroy et al. (2011), who report the presence of the Polar-Mixed Layer from 0 to 60 m, the Pacific Halocline from 60 to 200 m, and the Atlantic layer from ~200 m to the bottom. Franklin Bay reaches maximum depths of 220 m, and a major river, the Horton River, drains into its west side (Fig. 1). On average in Franklin Bay, freeze-up begins in September, while breakup starts in late June or early July (Galley et al., 2008), but in the spring of 2008, sea-ice concentrations and extent were relatively low throughout the eastern Beaufort Sea (Fig. 2). A fast-ice edge was present in the bay until 21 June 2008, extending to the mouth of the Horton River. On 21 June, large fractures formed in the ice, and by 22 June, those fractures widened to the point where there was considerable open water in the bay (Fig. 3).

Aerial Surveys

A helicopter (Messerschmidt BO 105) was used to conduct aerial surveys and to record beluga and bowhead behaviour at the Franklin Bay fast-ice edge. Ice-edge surveys were conducted on 11, 15, 16, 18, and 21 June 2008 (Fig. 3). On 24 June, a final survey was flown through the area after the fast ice had broken up (Fig. 3). In all cases, the helicopter flew along the fast-ice edge from west to east at an altitude of 305 m (1000 ft) and a speed of 185 km/hr. The position of the helicopter was logged every 2 s on a Global Positioning System (GPS) unit. An experienced whale observer (NA) sat in the front left seat and counted all groups of belugas and bowheads and the number of individuals in each group. For the purpose of our research, a group was defined as individuals in relatively close proximity (within 1 body length for belugas and 5 body lengths for

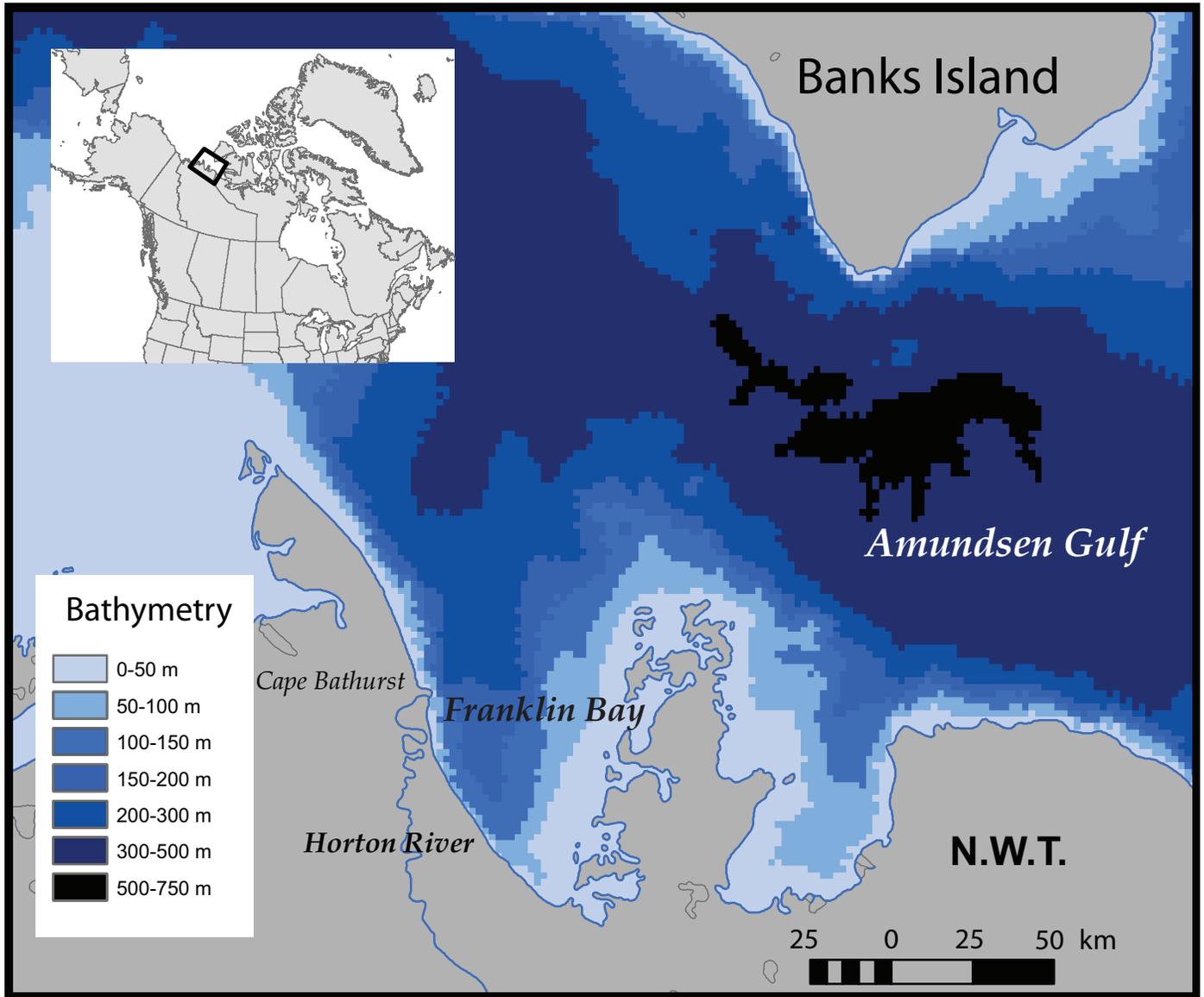


FIG. 1. Study area (bathymetry from Jakobsson et al., 2008).

bowheads) and behaving cohesively. Direction of travel of the groups was also noted when possible. When sightings were numerous, the helicopter slowed down to allow for complete counts of visible animals before continuing along the ice edge.

Two additional flights were conducted on 15 and 21 June to study behaviour at the floe edge. During these flights, the helicopter flew at an altitude of 305 m along the fast-ice edge until a group of animals was encountered. The aircraft then slowed or hovered, and a Sony HDR-HC3 handheld video camera was used to film activity. Whales were monitored for responses to the presence of the helicopter. Following Patenaude et al. (2002), a disturbance response was defined as unusual behaviour, such as vigorous swimming, abrupt dives, tail slapping, or animals orienting away from the aircraft.

Data Processing

From the GPS log track, we geo-referenced sightings by using the location of the helicopter as an approximation of the location of the sightings. The videos from the behavioural flights were viewed to time complete dives and surface intervals (i.e., time spent at the surface between dives). Complete dives were timed when we could be reasonably certain from the group size and location that the same animals were being observed before and after a dive. The start and end of a dive were determined by the first animal of a group diving or surfacing. Surfacing times for groups were calculated in the same way. When possible, dives were classified as shallow or deep on the basis of the angle of descent of the animals (Fig. 4). For shallow dives, whales dove beneath the ice edge while almost parallel with the surface.

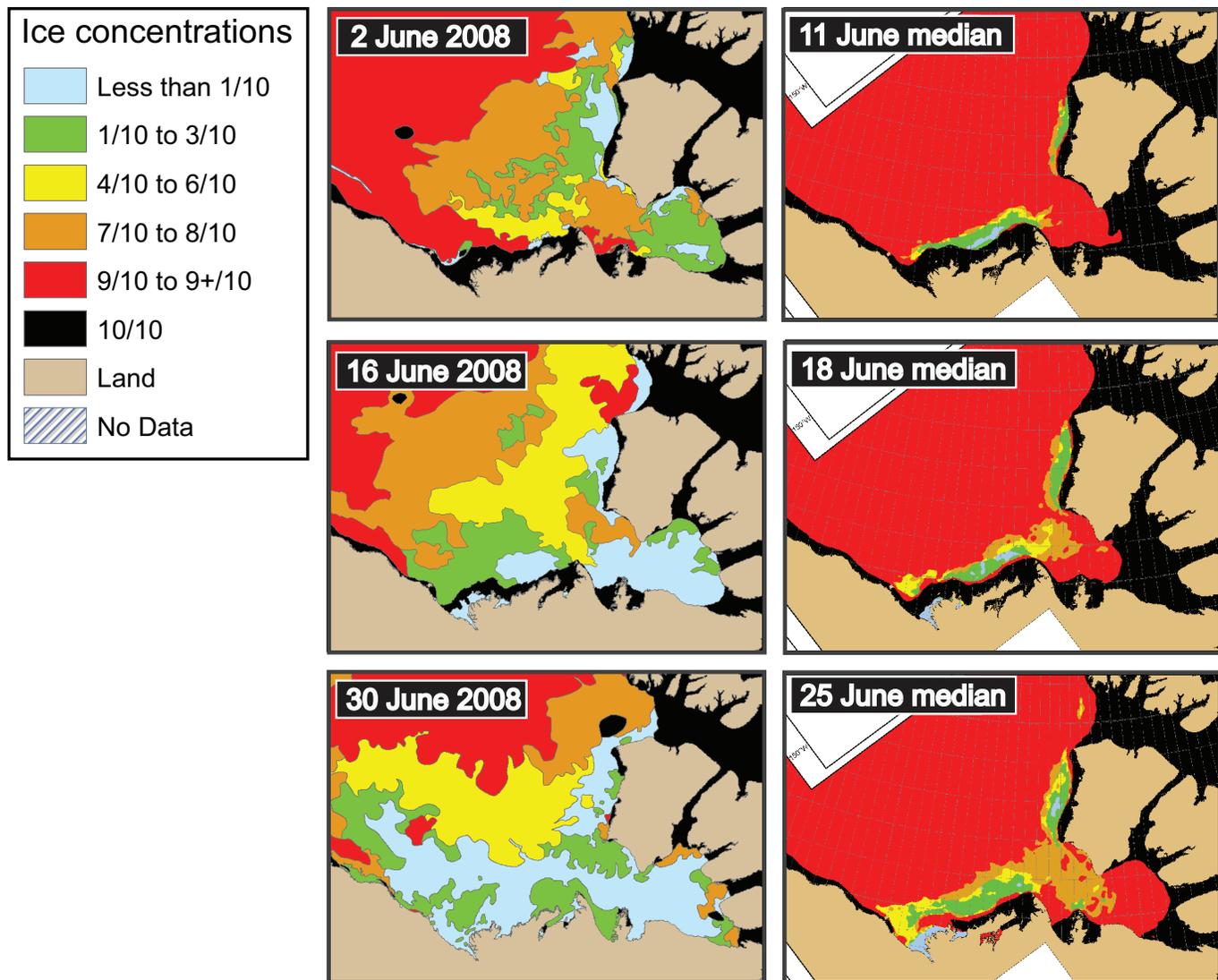


FIG. 2. Ice concentrations in the Beaufort Sea and adjacent channels. Left: Concentrations for 2, 16, and 30 June 2008 (created in ArcGIS 9.2 with .e00 files from CIS, 2008). Right: 30-year median ice concentrations from 1971 to 2000 for 11, 18, and 25 June (CIS, 2008).

During deep dives, whales descended at a steep angle (approaching 90°) from the surface to depth.

GIS Methods and Analytical Methods

Using ArcGIS 9.2, locations of beluga and bowhead sightings were overlaid on a bathymetric raster layer of the region and a vector layer of the Northwest Territories (Geogratis <http://geogratis.cgdi.gc.ca/>). The bathymetric layer was generated from the International Bathymetric Chart of the Arctic Ocean (Jakobsson et al., 2008). We calculated the seafloor slope in ArcGIS 9.2 from the IBCAO dataset, using a pixel size of $2 \text{ km} \times 2 \text{ km}$.

Kruskal-Wallis one-way analysis of variance was run in Systat 11 to test whether beluga and bowhead locations differed with respect to depth, seafloor slope, and distance to the mouth of the Horton River. We used ArcGIS 9.2 to

determine the values of these three environmental descriptors at each sighting location. Water depth and seafloor slope were used as explanatory variables because these two factors have been found to correlate with the distribution of belugas in the eastern Beaufort Sea in June (Asselin et al., 2011). The choice of distance to the mouth of the Horton River as a third explanatory variable was based on knowledge that belugas enter estuaries in large numbers after breakup in late-spring/early-summer (Norton and Harwood, 1985; Frost and Lowry, 1990; Harwood et al., 1996; Martin et al., 2001; Hobbs et al., 2005). In order to provide measurements of the “available habitat” within our ice-edge study area, the fast-ice edge on 16 June was used as the general location of the edge during whale observations (11–21 June). In ArcGIS 9.2, the depth, seafloor slope, and distance to the mouth of the Horton River were determined for 799 points at 100 m intervals along this fast-ice edge.

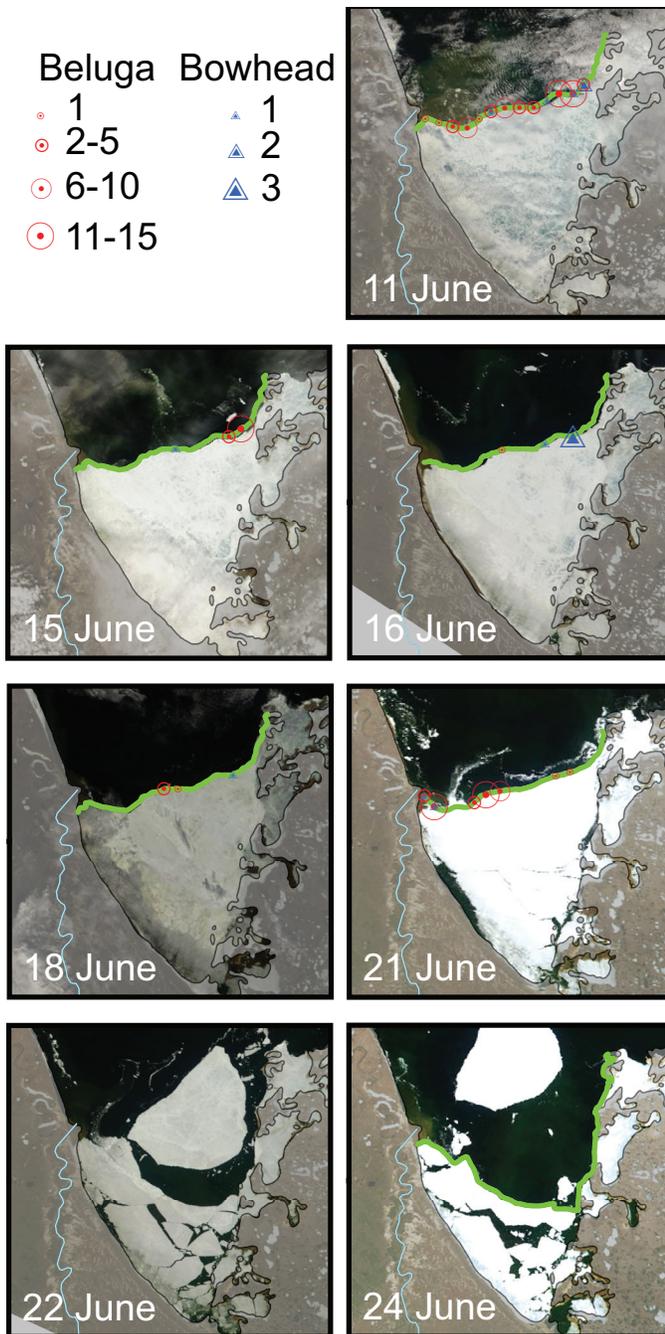


FIG. 3. Beluga and bowhead sightings with survey tracks (in green) from the five surveys conducted along the Franklin Bay ice edge (11–21 June), 22 June ice conditions, and 24 June survey track (in green). The Horton River is shown in blue, and MODIS Terra images coinciding with the survey dates are used in all of the maps to show ice conditions (NASA Earth Data, 2012). Beluga and bowhead sightings are grouped at 5 km intervals for map clarity.

RESULTS AND DISCUSSION

During the five surveys along the Franklin Bay fast-ice edge, we sighted a total of 192 belugas and 15 bowheads (Table 1). Juveniles of both species were also present, including at least one neonate beluga sighted on 15 June. The number of groups sighted in a single survey ranged from 1 (on 16 June) to 58 (11 June) for belugas, and from

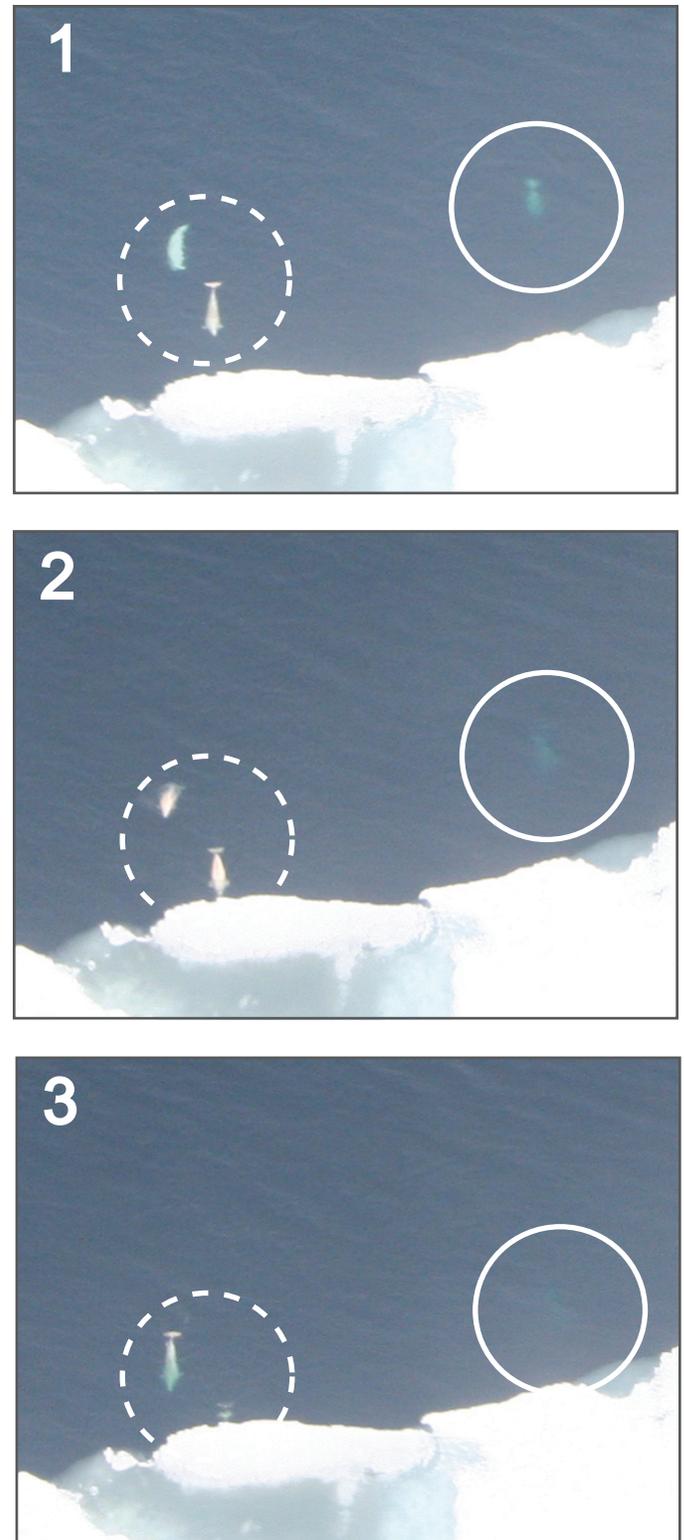


FIG. 4. Examples of shallow dives (dashed circle) and a deep dive (solid circle).

1 (15 and 18 June) to 5 (11 June) for bowheads (Table 1, Fig. 3). On 24 June, after breakup of the fast ice, no belugas or bowheads were observed along the survey route across the bay (Fig. 3).

TABLE 1. Summary of survey observations from helicopter surveys along the Franklin Bay ice edge, 11 June to 24 June 2008.

Date	Survey length (km)	Beluga		Bowhead	
		Number of groups	Total individuals	Number of groups	Total individuals
11 June	85	58	100	5	5
15 June	88	16	24	1	1
16 June	80	1	1	4	6
18 June	87	4	4	1	1
21 June	75	44	63	2	2
24 June	133	0	0	0	0
Totals	548	123	192	13	15

Behaviour at the Fast-Ice Edge

Generally, belugas and bowheads were engaged in traveling or diving behaviour. Not many animals were observed resting at the surface. Much of the traveling was parallel to the ice edge, in a westerly or easterly direction, although some individuals were observed swimming towards or away from the ice edge. A response to the helicopter was noted once, when a beluga immediately dove as the shadow of the helicopter passed over it. Both shallow and deep dives (as determined by body angle) were observed for belugas traveling and for belugas diving near or under the ice. On 15 June, of 18 beluga dives that were classified for depth, 10 were shallow and 8 were deep. Bowheads were observed resting at the surface, traveling, and diving. The orientation of the whales was noted for 66 groups of belugas and 8 groups of bowheads. During these sightings, belugas were oriented west ($n = 40$, 60.6%), east ($n = 13$, 19.7%), towards the ice ($n = 9$, 13.6%) and away from the ice ($n = 4$, 6.1%). Bowheads were oriented west ($n = 3$, 37.5%), towards the ice ($n = 4$, 50.0%) and away from the ice ($n = 1$, 12.5%).

On 15 June, 25 belugas were observed and videotaped during a 20-minute period. The results presented are for dive durations and surface intervals of groups. Group size was found to be dynamic, ranging from one to five individuals as animals joined and left groups. While some belugas swam along the edge in an easterly or westerly heading, others were observed first swimming along the ice edge and then turning suddenly and diving under the ice. We were able to time five under-ice dives, and they had an average duration of 106 ± 61 s (SD) and a range of 30–197 s. Four surface intervals were also timed and found to have an average duration of 52 ± 24 s (SD) and a range of 23–77 s. On 21 June, one bowhead under-ice dive was timed and had a duration of 417 s (0:06:31).

While average dive and surface-interval duration can provide information on general beluga activity, the detailed activities of individuals or beluga groups can help elucidate the potential role of the ice edge. Two examples of behaviour observed on 15 June follow.

Example 1: One beluga, observed for 130 s, came out from under the ice as it surfaced from depth. After a 23 s surface interval, it executed a 30 s deep dive in the same region as its initial surfacing. The beluga then spent 77 s at the surface and swam back and forth along the ice edge prior to diving once again at the same location.

Example 2: A group of three belugas, observed for 452 s, was first seen swimming along the ice edge heading east. They then turned and dove under the ice edge in succession. They emerged from the ice 121 s later with a fourth individual. The group of four belugas then spent 43 s at the surface swimming along the ice edge and doing small dives before diving under the edge, at a shallow angle and once again in succession. After 197 s, the group of four belugas re-emerged (Fig. 5.1) with a fifth whale close behind (Fig. 5.2). The group of four then appeared to chase the fifth beluga (Fig. 5.3). After 64 s at the surface, the group of four dove under the ice edge once again at a shallow angle while the fifth whale dove deeper (Fig. 5.4, 5.5, and 5.6).

Belugas diving under fast ice have also been reported in the spring in Norton Bay, Alaska, where belugas feed first on herring and later on tomcod under the ice (Huntington et al., 1999). Mymrin et al. (1999) indicate that when belugas are feeding at the ice edge in the northern Bering Sea, they dive under the ice as a group and re-surface to breathe in the same place, but when migrating, in contrast, they swim in one direction and move rapidly out of sight (Mymrin et al., 1999). The similarity of the behaviours described by Huntington et al. (1999) and Mymrin et al. (1999) to those we observed in Franklin Bay in June 2008 suggest that the belugas we observed were feeding under the ice.

Belugas forage on a large variety of fish species and invertebrates (Kleinenberg et al., 1964; Seaman et al., 1982), but arctic cod (*Boreogadus saida*) has been identified as their main prey throughout the Arctic (Kleinenberg et al., 1964; Heide-Jørgensen and Teilmann, 1994; Dahl et al., 2000; Loseto et al., 2009). Arctic cod are considered ice-associated and have been observed beneath sea ice, as well as within its cracks and crevices (Bradstreet, 1982; Percy et al., 1985; Lønne and Gulliksen, 1989; Crawford and Jorgenson, 1990, 1993; Gradinger and Bluhm, 2004). They have also been found at depth in Admiralty Inlet (Crawford and Jorgenson, 1990)—and, notably, in Franklin Bay—in March and April (Benoit et al., 2008). In the winter of 2008, Geoffroy et al. (2011) identified large aggregations of arctic cod in Amundsen Gulf. These were found until breakup in the last week of April and solely in ice-covered waters at depths greater than 221 m (Geoffroy et al., 2011), which exceeds the depth of Franklin Bay. Craig et al. (1982) indicate that arctic cod are not numerous in nearshore habitats during the start of the open-water season, and scuba divers (H. Hop, pers. comm. 2010) and fish researchers involved

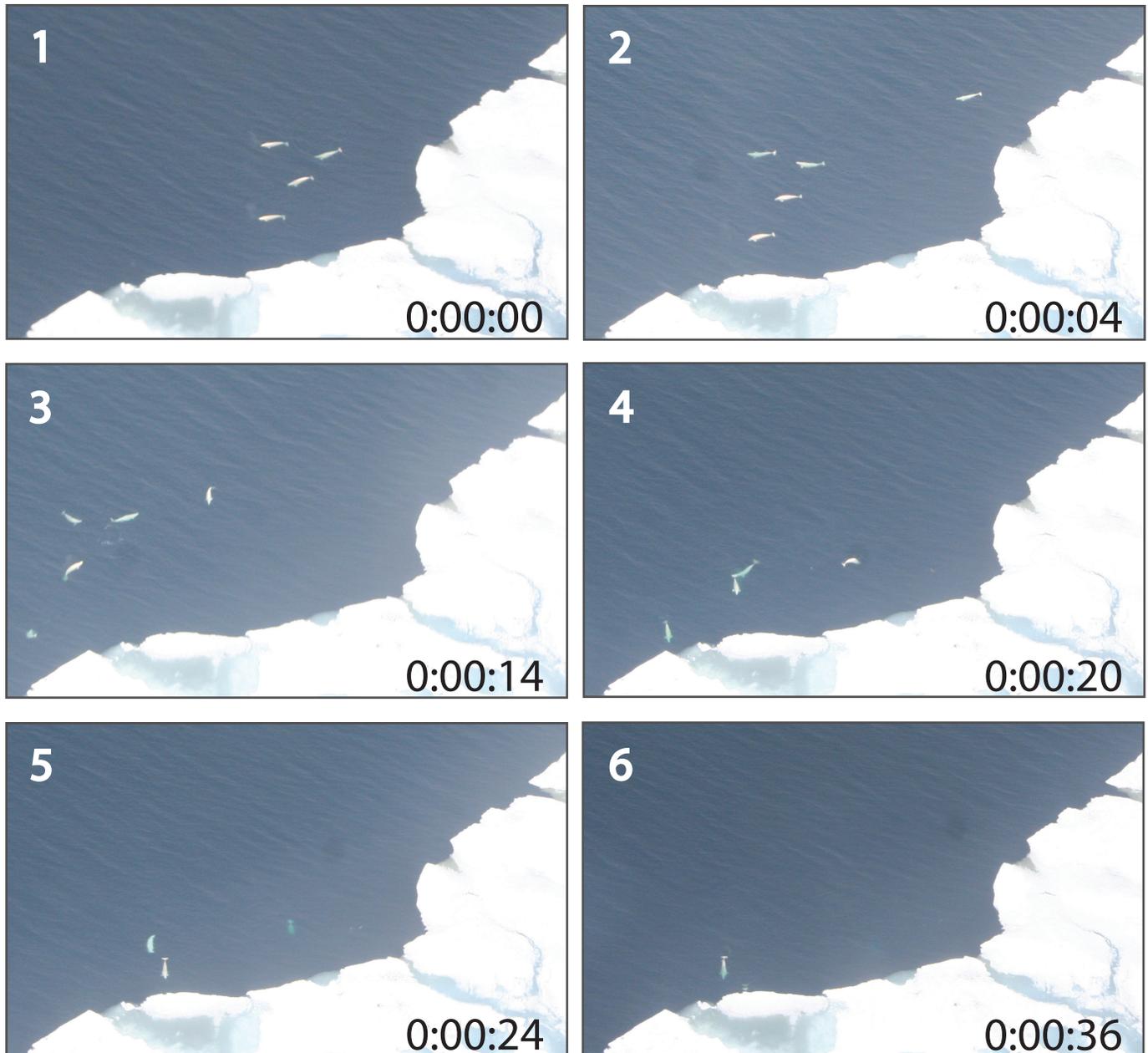


FIG. 5. Sequence of movements of a group of four belugas interacting with a lone beluga. Time stamps indicate elapsed time from image 1 (0:00:00).

in the CFL system study did not identify any significant aggregations of adult arctic cod in Franklin Bay in June 2008. It is possible that belugas at the Franklin Bay ice edge were under-ice feeding (for shallow dives) and benthic foraging (for deep dives) on arctic cod, but we hypothesize that other prey items may explain the attraction of the floe edge at that time.

In coastal waters of western Alaska in summer, belugas consume saffron cod (*Eleginus gracilis*), sculpins (Family Cottidae), and various salmon species (Seaman et al., 1982), while in the Mackenzie River estuary, they consume arctic cisco (*Coregonus autumnalis*), burbot (*Lota lota*), and whitefish (*Coregonus* spp.) (Harwood and Smith, 2002). In Norton Bay, Alaska, in spring, belugas feed under the ice

on Pacific herring (*Clupea pallasii*) and tomcod (*Eleginus gracilis*) (Huntington et al., 1999). The Horton River does have a small population of arctic char (*Salvelinus alpinus*) (MacDonell, 1989) that moves seaward in spring (McCart, 1980) and may have been targeted by belugas. However, Pacific herring is the main fish caught in Franklin Bay (Percy et al., 1985), and these fish are known to aggregate for spawning in subtidal waters in spring (Hay, 1985). We consequently hypothesize that Pacific herring may have been one of the prey items targeted by belugas in Franklin Bay in June 2008.

The behaviour of the group of four belugas in example 2 (above and Fig. 5) first resembled feeding behaviour, as described by Mymrin et al. (1999). These four whales

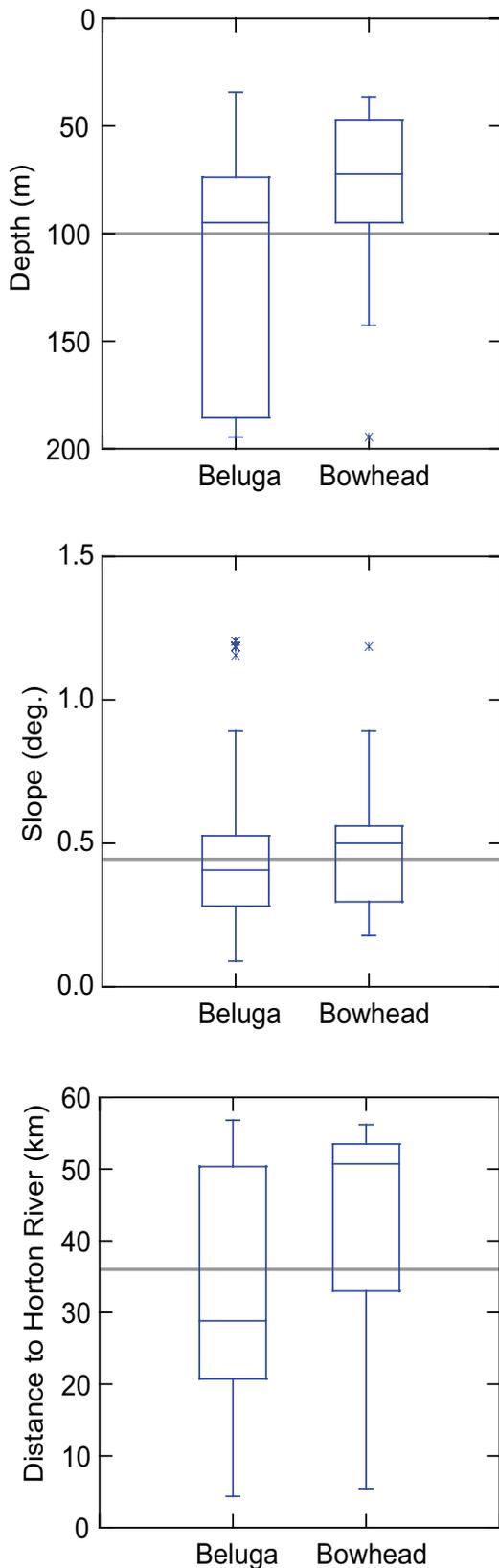


FIG. 6. Box plots of the depth (top), the seafloor slope (middle), and the distance to the Horton River (bottom) for beluga and bowhead sightings. The box encompasses the middle 50% of values, and the line within it indicates the median. The whiskers extend to $1.5 \times$ the interquartile range and x's indicate near outliers. The grey horizontal line across each plot indicates the average value along the fast-ice edge.

also displayed aggressive behaviour towards the fifth whale, which matches the description of a chase and possibly a charge given in the beluga ethogram (developed with belugas in captivity) in DiPaola et al. (2007). In other odontocetes, instances of aggression are often related to male-male competition (Norris, 1967; MacLeod, 1998; Scott et al., 2005). Loseto et al. (2006) hypothesized that smaller male belugas in the EBS in summer may be segregating from large males partly to avoid aggression. Without knowing the sex of the animals, we cannot interpret whether the interaction we observed was intra-sexual competition.

Bowheads were also observed diving repeatedly under the ice and swimming along and very close to the fast-ice edge. In Alaska, bowheads have been observed diving below the fast ice to feed (Carroll et al., 1987; Quakenbush and Huntington, 2010) and also skim-feeding by swimming along fast-ice edges with their mouths open (Quakenbush and Huntington, 2010). An examination of prey items from bowheads feeding under the ice near Point Barrow, Alaska, determined that the whales were mainly feeding pelagically, on copepods and euphausiids, but some near-bottom feeding was also identified (Carroll et al., 1987). Similarly, euphausiids and copepods are the main prey of bowheads in the Alaskan Beaufort Sea in spring (Lowry et al., 2004). In summer, bowheads in the Beaufort Sea engage in three types of feeding: skim-feeding at or near the surface, in the water column, and at or near the bottom (Würsig et al., 1989), and stomach contents from one whale taken in August in the Mackenzie Delta contained mainly pelagic prey (Pomerleau et al., 2010). Notably, copepods make up 90% of bowhead prey biomass in the Canadian Beaufort Sea (Schell and Saupe, 1993), and two copepods, *Calanus hyperboreus* and *C. glacialis*, are present in Franklin Bay in winter (Benoit et al., 2008). In Franklin Bay in May and June 2008, the three copepods *C. glacialis*, *Metridia longa*, and *C. hyperboreus* dominated the large class of zooplankton ($> 1000 \mu\text{m}$), with *C. hyperboreus* contributing the most to biomass (G. Darnis, unpubl. data). Furthermore, from 8 to 21 June 2008 in Franklin Bay, at sampling depths of 0 to 5 m, the highest concentrations of copepods were found within 1 m of the ice undersurface, and *C. glacialis* was the most abundant (Hop et al., 2011). From these findings, we conclude that bowheads observed diving under the ice in Franklin Bay were likely engaged in pelagic feeding on copepods. Those observed swimming along the ice edge were either skim-feeding, also on copepods, or traveling.

Differences in the Distribution of Beluga and Bowhead

The distribution of water depths of beluga sightings differed significantly from that of bowhead sightings ($KW = 5.034$, $df = 1$, $p = 0.025$), with belugas on average in deeper water (Fig. 6). On average, belugas were closer than bowheads to the mouth of the Horton River but this difference was not significant ($KW = 2.835$, $df = 1$, $p = 0.092$) (Fig. 6). Also, beluga and bowhead sighting locations did not differ

significantly with respect to seafloor slope ($KW = 1.181$, $df = 1$, $p = 0.277$) (Fig. 6).

In the Alaskan Arctic, in summer and fall, belugas were also found to use deeper waters than bowheads, reflecting the differences in their feeding modes and prey items (Moore and DeMaster, 1998). Differences in the feeding ecology of belugas and bowheads, while on a much smaller scale, may also explain the difference in distributions with respect to water depth along the Franklin Bay ice edge in June 2008. While bowheads consume fairly specific prey types, eating mainly copepods and euphausiids (Lowry et al., 2004), belugas are able to exploit a variety of prey species (Kleinenberg et al., 1964; Seaman et al., 1982). Consequently, while the range of depth distributions is similar for belugas and bowheads, the 50th percentile of those values is narrower for bowheads than it is for belugas (Fig. 6). Although consideration must be given to the possible influence of the smaller sample size for bowheads, the distribution may indicate that belugas are foraging on a variety of prey distributed at various depths, while bowheads are restricted to a few species associated with a narrower depth range. Similarly, while not statistically significant, the relative proximity of belugas to the Horton River may indicate they are also exploiting nearshore or riverine resources. The lack of difference in the seafloor slope distribution between bowhead and beluga sightings may indicate that this variable does not vary sufficiently in Franklin Bay to measure a significant difference, that belugas and bowhead relate to seafloor slope similarly, or that we did not have a sufficiently large sample size to identify a difference.

The importance of these observations must be assessed cautiously, as the data were not collected through systematic surveys as required to compare ice-edge regions to offshore regions. Also, our survey design did not provide information on both habitat available and habitat used, and therefore conclusions on selection must be considered cautiously. Thus, further research is needed to understand foraging behaviour of belugas and bowheads at the Franklin Bay ice edge. A larger sample size, especially for bowhead whales, would help us to understand the differences in habitat selection for these two species. While a response to the helicopter was noted only once, it is possible that the helicopter affected the behaviour of belugas and bowheads in ways too subtle for us to notice. Large-scale, systematic surveys could help us to understand the importance of fast-ice edges to belugas and bowheads and to determine the overall spring distributions of both species within the EBS.

The present study is the first description of beluga and bowhead activity at a fast-ice edge in the EBS. Belugas are known to aggregate at ice edges to await breakup (Cosens and Dueck, 1991; Stewart, 2001); however, as the Franklin Bay ice edge does not block their migration path, which is generally east-west (DFO, 2000), we hypothesize that this floe-edge habitat might have been a preferred habitat compared to the surrounding open-water areas. The presence of both belugas and bowheads at the Franklin Bay ice edge, along with the probable feeding behaviour identified,

underlines the importance of ice edges and polynyas to Arctic marine mammals noted by others (Stirling, 1980, 1997; Dunbar, 1981). Dunbar (1981) emphasized that it was the ice edge, as opposed to the open water, that appeared to be key to the biological importance of polynyas. In spring in the Arctic, ice-edge phytoplankton blooms can be observed within 20 days of ice retreat (Perrette et al., 2011), and upwelling along ice edges can further increase primary productivity (Mundy et al., 2009). These increases in primary productivity can lead to increases in productivity at higher trophic levels that benefit foraging cetaceans (Croll et al., 2005). For cetaceans in the Arctic, which rely on dense aggregations of prey (Moore and DeMaster, 1998), habitat selection is likely linked to foraging success. We consequently hypothesize that the Franklin Bay fast-ice edge may provide bowheads with the higher-than-average concentrations of zooplankton required to meet their energetic needs (Lowry, 1993) and belugas with one or many of the fish prey species on which they forage.

Laidre et al. (2008) considered Arctic cetaceans to be more resilient to climate change than other Arctic marine mammals, partly because they are less sensitive to sea-ice changes. While Asselin et al. (2011) found that EBS belugas preferred heavy ice cover and water depths of 200–500 m in spring, the present results confirm that belugas can also exploit fast-ice edges. These 2008 observations lend evidence to the hypothesis proposed by Asselin et al. (2011) that EBS belugas may shift their distribution shoreward and to fast-ice edges in spring during years with low ice concentrations. Belugas in West Greenland shift their distribution in response to changes in sea-ice extent (Heide-Jørgensen et al., 2010), while bowheads have been found to have improved body condition during low-ice years, which may be due to increased primary productivity (George et al., 2009). Belugas in the EBS may adapt to a loss of sea ice by concentrating their foraging effort in areas with dependable concentrations of prey, such as ice edges, while bowheads may thrive in an environment with less sea-ice extent. However, because of the springtime coupling of sea-ice extent and phytoplankton (Heide-Jørgensen et al., 2007), it is likely that the spring feeding habitat of bowheads will be altered by climate change.

The identification of an aggregation of belugas and bowheads at the Franklin Bay ice edge indicates that this habitat is important to whales in the EBS in the spring. The respective distributions of belugas and bowheads differed significantly in terms of water depth, with belugas being on average in deeper water. While belugas and bowheads were observed traveling along the ice edge, both species also engaged in repeated dives under the ice. These dives are consistent with feeding behaviour observed in other locations and provide further evidence of the biological importance of ice edges and polynyas to marine mammals. While we could not conclusively identify prey species with the data available, we hypothesize that belugas and bowheads may find higher-than-average concentrations of prey at the Franklin Bay ice edge in the form of a variety of fish

species (for belugas) and abundant zooplankton (for bowheads). Further research is needed to fully examine the distribution of belugas and bowheads in spring in the EBS and to investigate the prey species being targeted by foraging dives.

ACKNOWLEDGEMENTS

We gratefully acknowledge the assistance in the field of the officers and crew of the CCGS *Amundsen* and particularly of the helicopter pilots, Guillaume Carpentier and Serge Arsenault. Klaus Hochheim also provided field support and the photos used in Figures 4 and 5. This work was supported by the Natural Sciences and Engineering Research Council of Canada, the Canada Research Chairs program, the Department of Fisheries and Oceans, and ArcticNet. This is a contribution arising from the International Polar Year Circumpolar Flaw Lead System Study project.

REFERENCES

- Aagaard, K., Pease, C.H., Roach, A.T., and Salo, S.A. 1989. Beaufort Sea mesoscale circulation study—Final report. NOAA Technical Memorandum ERL PMEL-90. 114 p. http://www.pmel.noaa.gov/publications/search_abstract.php?fmContributionNum=1155.
- Ainley, D.G., Tynan, C.T., and Stirling, I. 2003. Sea ice: A critical habitat for polar marine mammals and birds. In: Thomas, D.N., and Dieckmann, G.S., eds. *Sea ice: An introduction to its physics, chemistry, biology and geology*. Oxford: Blackwell Science Limited. 240–266.
- Asselin, N.C., Barber, D.G., Stirling, I., Ferguson, S.H., and Richard, P.R. 2011. Beluga (*Delphinapterus leucas*) habitat selection in the eastern Beaufort Sea in spring, 1975–1979. *Polar Biology* 34(12):1973–1988, doi:10.1007/s00300-011-0990-5.
- Barber, D.G., Asplin, M.G., Gratton, Y., Lukovich, J.V., Galley, R.J., Raddatz, R.L., and Leitch, D. 2010. The International Polar Year (IPY) Circumpolar Flaw Lead (CFL) system study: Overview and the physical system. *Atmosphere Ocean* 48(4):225–243.
- Benoit, D., Simard, Y., and Fortier, L. 2008. Hydroacoustic detection of large winter aggregations of arctic cod (*Boreogadus saida*) at depth in ice-covered Franklin Bay (Beaufort Sea). *Journal of Geophysical Research-Oceans* 113(C6), doi:10.1029/2007jc004276.
- Bradstreet, M.S.W. 1982. Occurrence, habitat use, and behavior of seabirds, marine mammals, and arctic cod at the Pond Inlet ice edge. *Arctic* 35(1):28–40.
- Braham, H.W., Fraker, M.A., and Krogman, B.D. 1980. Spring migration of the western Arctic population of bowhead whales. *Marine Fisheries Review* 42(9-10):36–46.
- Carroll, G.M., and Smithhisler, J.R. 1980. Observations of bowhead whales during spring migration. *Marine Fisheries Review* 42(9-10):80–85.
- Carroll, G.M., George, J.C., Lowry, L.F., and Coyle, K.O. 1987. Bowhead whale (*Balaena mysticetus*) feeding near Point Barrow, Alaska, during the 1985 spring migration. *Arctic* 40(2):105–110.
- CIS (Canadian Ice Service). 2008. Latest ice conditions. <http://www.ec.gc.ca/glaces-ice/default.asp?lang=En&n=E4B3AD2B->
- Coachman, L.K., and Aagaard, K. 1974. Physical oceanography of Arctic and Subarctic seas. In: Herman, Y., ed. *Marine geology and oceanography of the Arctic seas*. New York: Springer-Verlag. 1–72.
- Cosens, S.E., and Dueck, L.P. 1991. Group size and activity patterns of belugas (*Delphinapterus leucas*) and narwhals (*Monodon monoceros*) during spring migration in Lancaster Sound. *Canadian Journal of Zoology* 69(6):1630–1635.
- Craig, P.C., Griffiths, W.B., Haldorson, L., and McElderry, H. 1982. Ecological studies of arctic cod (*Boreogadus saida*) in Beaufort Sea coastal waters, Alaska. *Canadian Journal of Fisheries and Aquatic Sciences* 39(3):395–406.
- Crawford, R., and Jorgenson, J. 1990. Density distribution of fish in the presence of whales at the Admiralty Inlet landfast ice edge. *Arctic* 43(3):215–222.
- . 1993. Schooling behavior of arctic cod, *Boreogadus saida*, in relation to drifting pack ice. *Environmental Biology of Fishes* 36(4):345–357.
- Croll, D.A., Marinovic, B., Benson, S., Chavez, F.P., Black, N., Ternullo, R., and Tershy, B.R. 2005. From wind to whales: Trophic links in a coastal upwelling system. *Marine Ecology Progress Series* 289:117–130.
- Dahl, T.M., Lydersen, C., Kovacs, K.M., Falk-Petersen, S., Sargent, J., Gjertz, I., and Gulliksen, B. 2000. Fatty acid composition of the blubber in white whales (*Delphinapterus leucas*). *Polar Biology* 23(6):401–409.
- DFO (Department of Fisheries and Oceans). 2000. Eastern Beaufort Sea beluga whales. Department of Fisheries and Oceans Science. Stock Status Report E5-38. 14 p. www.dfo-mpo.gc.ca/csas/Csas/status/2000/E5-38e.pdf.
- . 2002. Beluga. UnderwaterWorld 6. Ottawa: Communications Directorate, Fisheries and Oceans Canada. 8 p. <http://www.dfo-mpo.gc.ca/science/publications/uww-msm/articles/beluga-eng.htm>.
- DiPaola, S., Akai, C., and Kraus, B. 2007. Experiencing belugas: Action selection for an interactive aquarium exhibit. *Adaptive Behavior* 15(1):99–113, doi:10.1177/1059712306076251.
- Dunbar, M.J. 1981. Physical causes and biological significance of polynyas and other open water in sea ice. In: Stirling, I., and Cleator, H.J., eds. *Polynyas in the Canadian Arctic*. Canadian Wildlife Service Occasional Paper 45. 29–43.
- Fay, F.H. 1974. The role of ice in the ecology of marine mammals of the Bering Sea. In: Hood, D.W., and Kelley, E.J., eds. *Oceanography of the Bering Sea with emphasis on renewable resources*. Fairbanks: Institute of Marine Science. 383–399.
- Fraker, M.A. 1979. Spring migration of bowhead (*Balaena mysticetus*) and white whales (*Delphinapterus leucas*) in the Beaufort Sea. Canadian Fisheries and Marine Services Technical Report 859. 36 p.

- Fraker, M.A., and Bockstoce, J.R. 1980. Summer distribution of bowhead whales in the eastern Beaufort Sea. *Marine Fisheries Review* 42(9-10):57–64.
- Frost, K.J., and Lowry, L.F. 1990. Distribution, abundance, and movements of beluga whales, *Delphinapterus leucas*, in coastal waters of western Alaska. In: Smith, T.G., St. Aubin, D.J., and Geraci, J.R., eds. *Advances in research on the beluga whale, Delphinapterus leucas*. Canadian Bulletin of Fisheries and Aquatic Sciences 224. 39–57.
- Galley, R.J., Key, E., Barber, D.G., Hwang, B.J., and Ehn, J.K. 2008. Spatial and temporal variability of sea ice in the southern Beaufort Sea and Amundsen Gulf: 1980–2004. *Journal of Geophysical Research-Oceans* 113, C05S95, doi:10.1029/2007jc004553.
- Geoffroy, M., Robert, D., Darnis, G., and Fortier, L. 2011. The aggregation of polar cod (*Boreogadus saida*) in the deep Atlantic layer of ice-covered Amundsen Gulf (Beaufort Sea) in winter. *Polar Biology* 34(12):1959–1971, doi:10.1007/s00300-011-1019-9.
- George, J.C., Nicolson, C., Drobot, S., Maslanik, J., and Rosa, C. 2009. Update on SC/57/E13: Progress Report: Sea ice density and bowhead whale body condition. International Whaling Commission. 9 p. http://iwcoffice.org/_documents/sci_com/workshops/climate%20change/SC-F09-CC1.pdf.
- Gradinger, R.R., and Bluhm, B.A. 2004. In-situ observations on the distribution and behavior of amphipods and arctic cod (*Boreogadus saida*) under the sea ice of the High Arctic Canada Basin. *Polar Biology* 27(10):595–603, doi:10.1007/s00300-004-0630-4.
- Harwood, L.A., and Smith, T.G. 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., Innes, S., Norton, P., and Kingsley, M.C.S. 1996. Distribution and abundance of beluga whales in the Mackenzie estuary, southeast Beaufort Sea, and west Amundsen Gulf during late July 1992. *Canadian Journal of Fisheries and Aquatic Sciences* 53(10):2262–2273.
- Hay, D.E. 1985. Reproductive biology of Pacific herring (*Clupea harengus pallasi*). *Canadian Journal of Fisheries and Aquatic Sciences* 42:111–126.
- Heide-Jørgensen, M.P., and Teilmann, J. 1994. Growth, reproduction, age structure and feeding habits of white whales (*Delphinapterus leucas*) in West Greenland waters. *Meddelelser om Grønland Bioscience* 39:195–212.
- Heide-Jørgensen, M.P., Laidre, K.L., Logsdon, M.L., and Nielsen, T.G. 2007. Springtime coupling between chlorophyll *a*, sea ice and sea surface temperature in Disko Bay, West Greenland. *Progress in Oceanography* 73(1):79–95, doi:10.1016/j.pocan.2007.01.006.
- Heide-Jørgensen, M.P., Laidre, K.L., Borchers, D., Marques, T.A., Stern, H., and Simon, M. 2010. The effect of sea-ice loss on beluga whales (*Delphinapterus leucas*) in West Greenland. *Polar Research* 29(2):198–208, doi:10.1111/j.1751-8369.2009.00142.x.
- Hobbs, R.C., Laidre, K.L., Vos, D.J., Mahoney, B.A., and Eagleton, M. 2005. Movements and area use of belugas, *Delphinapterus leucas*, in a subarctic Alaskan estuary. *Arctic* 58(4):331–340.
- Hop, H., Mundy, C.J., Gosselin, M., Rossnagel, A.L., and Barber, D.G. 2011. Zooplankton boom and ice amphipod bust below melting sea ice in the Amundsen Gulf, Arctic Canada. *Polar Biology* 34(12):1947–1958, doi:10.1007/s00300-011-0991-4.
- Huntington, H.P., and the Communities of Buckland, Elim, Koyuk, Point Lay, and Shaktoolik. 1999. Traditional knowledge of the ecology of beluga whales (*Delphinapterus leucas*) in the eastern Chukchi and northern Bering Seas, Alaska. *Arctic* 52(1):49–61.
- Jakobsson, M., Macnab, R., Mayer, L., Anderson, R., Edwards, M., Hatzky, J., Schenke, H.-W., and Johnson, P. 2008. An improved bathymetric portrayal of the Arctic Ocean: Implications for ocean modeling and geological, geophysical and oceanographic analyses. *Geophysical Research Letters* 35, L07602, doi:10.1029/2008GL033520. <http://www.ngdc.noaa.gov/mgg/bathymetry/arctic/>.
- Kleinenberg, S.E., Yablokov, A.V., Bel'kovich, B.M., and Tarasevich, M.N. 1964. Beluga (*Delphinapterus leucas*): Investigation of the species. Jerusalem: Israel Program for Scientific Translations. 376 p.
- Laidre, K.L., Stirling, I., Lowry, L.F., Wiig, Ø., Heide-Jørgensen, M.P., and Ferguson, S.H. 2008. Quantifying the sensitivity of Arctic marine mammals to climate-induced habitat change. *Ecological Applications* 18(2):S97–S125.
- Lønne, O.J., and Gulliksen, B. 1989. Size, age and diet of polar cod, *Boreogadus saida* (Lepechin 1773), in ice covered waters. *Polar Biology* 9(3):187–191.
- Loseto, L.L., Richard, P., Stern, G.A., Orr, J., and Ferguson, S.H. 2006. Segregation of Beaufort Sea beluga whales during the open-water season. *Canadian Journal of Zoology* 84(12):1743–1751, doi:10.1139/z06-160.
- Loseto, L.L., Stern, G.A., Connelly, T.L., Deibel, D., Gemmill, B., Prokopowicz, A., Fortier, L., and Ferguson, S.H. 2009. Summer diet of beluga whales inferred by fatty acid analysis of the eastern Beaufort Sea food web. *Journal of Experimental Marine Biology and Ecology* 374(1):12–18, doi:10.1016/j.jembe.2009.03.015.
- Lowry, L.F. 1993. Foods and feeding ecology. In: Burns, J.J., Montague, J.J., and Cowles, C.J., eds. *The bowhead whale*. Society for Marine Mammalogy, Special Publication 2. Lawrence, Kansas: Allen Press. 201–238.
- Lowry, L.F., Sheffield, G., and George, J.C. 2004. Bowhead whale feeding in the Alaskan Beaufort Sea, based on stomach contents analyses. *Journal of Cetacean Research and Management* 6(3):215–223.
- MacDonell, D. 1989. Report on the test fisheries conducted at the Hornaday, Brock and Horton Rivers and at Tom Cod Bay from 1987 to 1989; and an evaluation of the arctic char fishery at Paulatuk, N.W.T. Fisheries Joint Management Committee Report 89-003. 107 p.
- MacLeod, C.D. 1998. Intraspecific scarring in odontocete cetaceans: An indicator of male 'quality' in aggressive social interactions? *Journal of Zoology* 244:71–77.
- Martin, A.R., Hall, P., and Richard, P.R. 2001. Dive behaviour of belugas (*Delphinapterus leucas*) in the shallow waters of western Hudson Bay. *Arctic* 54(3):276–283.

- McCart, P.J. 1980. A review of the systematics and ecology of arctic char, *Salvelinus alpinus*, in the western Arctic. Canadian Technical Report of Fisheries and Aquatic Sciences 935. 89 p.
- McLaughlin, F.A., Carmack, E.C., Macdonald, R.W., and Bishop, J.K.B. 1996. Physical and geochemical properties across the Atlantic Pacific water mass front in the southern Canadian Basin. *Journal of Geophysical Research-Oceans* 101(C1):1183–1197.
- Moore, S.E., and DeMaster, D.P. 1998. Cetacean habitats in the Alaskan Arctic. *Journal of Northwest Atlantic Fishery Science* 22:55–69.
- Moore, S.E., and Reeves, R.R. 1993. Distribution and movement. In: Burns, J.J., Montague, J.J., and Cowles, C.J., eds. *The bowhead whale*. Society for Marine Mammalogy, Special Publication 2. Lawrence, Kansas: Allen Press. 313–386.
- Mundy, C.J., Gosselin, M., Ehn, J., Gratton, Y., Rossnagel, A., Barber, D.G., Martin, J., et al. 2009. Contribution of under-ice primary production to an ice-edge upwelling phytoplankton bloom in the Canadian Beaufort Sea. *Geophysical Research Letters* 36, L17601, doi:10.1029/2009gl038837.
- Mymrin, N.I., the Communities of Novoe Chaplino, Sireniki, Uelen, and Yanrakinnot, and Huntington, H.P. 1999. Traditional knowledge of the ecology of beluga whales (*Delphinapterus leucas*) in the northern Bering Sea, Chukotka, Russia. *Arctic* 52(1):62–70.
- NASA Earth Data. 2012. Near real time (orbit swath) images: Terra/MODIS. <http://rapidfire.sci.gsfc.nasa.gov/realtime>.
- Norris, K.S. 1967. Aggressive behavior in cetacea. In: Clemente, C.D., and Lindsley, D.B., eds. *Aggression and defense*. Berkeley: University of California Press. 225–241.
- Norton, P., and Harwood, L.A. 1985. White whale use of the southeastern Beaufort Sea, July–September 1984. Canadian Technical Report of Fisheries and Aquatic Sciences 1401. 46 p.
- Patenaude, N.J., Richardson, W.J., Smultea, M.A., Koski, W.R., Miller, G.W., Würsig, B., and Greene, C.R. 2002. Aircraft sound and disturbance to bowhead and beluga whales during spring migration in the Alaskan Beaufort Sea. *Marine Mammal Science* 18(2):309–335.
- Percy, R., Smiley, B., and Mullen, T. 1985. *Fishes, invertebrates and marine plants: The Beaufort Sea and the search for oil*. Ottawa: Department of Fisheries and Oceans. 167 p.
- Perrette, M., Yool, A., Quartly, G.D., and Popova, E.E. 2011. Near-ubiquity of ice-edge blooms in the Arctic. *Biogeosciences* 8(2):515–524, doi:10.5194/bg-8-515-2011.
- Pomerleau, C., Ferguson, S.H., and Walkusz, W. 2010. Stomach contents of bowhead whales (*Balaena mysticetus*) from four locations in the Canadian Arctic. *Polar Biology* 34(4):615–620, doi:10.1007/s00300-010-0914-9.
- Quakenbush, L.T., and Huntington, H.P. 2010. Traditional knowledge regarding bowhead whales in the Chukchi Sea near Wainwright, Alaska. OCS Study MMS 2009-063. Fairbanks: University of Alaska, Coastal Marine Institute.
- Reeves, R., Mitchell, E., Mansfield, A., and McLaughlin, M. 1983. Distribution and migration of the bowhead whale, *Balaena mysticetus*, in the eastern North American Arctic. *Arctic* 36(1):5–64.
- Richard, P.R., Orr, J.R., Dietz, R., and Dueck, L. 1998. Sightings of belugas and other marine mammals in the North Water, late March 1993. *Arctic* 51(1):1–4.
- Richard, P.R., Martin, A.R., and Orr, J.R. 2001. Summer and autumn movements of belugas of the Eastern Beaufort Sea stock. *Arctic* 54(3):223–236.
- Schell, D.M., and Saupe, S.M. 1993. Feeding and growth as indicated by stable isotopes. In: Burns, J.J., Montague, J.J., and Cowles, C.J., eds. *The bowhead whale*. Society for Marine Mammalogy, Special Publication 2. Lawrence, Kansas: Allen Press. 491–509.
- Scott, E.M., Mann, J., Watson-Capps, J.J., Sargeant, B.L., and Connor, R.C. 2005. Aggression in bottlenose dolphins: Evidence for sexual coercion, male-male competition, and female tolerance through analysis of tooth-rake marks and behaviour. *Behaviour* 142:21–44.
- Seaman, G.A., Lowry, L.F., and Frost, K.J. 1982. Foods of belukha whales, *Delphinapterus leucas*, in western Alaska. *Cetology* 44:1–19.
- Stewart, D.B. 2001. Inuit knowledge of belugas and narwhals in the Canadian eastern Arctic. Report prepared for Department of Fisheries and Oceans, Iqaluit, Nunavut. Winnipeg, Manitoba: Arctic Biological Consultants. 32 p.
- Stirling, I. 1980. The biological importance of polynyas in the Canadian Arctic. *Arctic* 33(2):303–315.
- . 1997. The importance of polynyas, ice edges, and leads to marine mammals and birds. *Journal of Marine Systems* 10(1-4):9–21.
- Würsig, B., Dorsey, E.M., Richardson, W.J., and Wells, R.S. 1989. Feeding, aerial and play behaviour of the bowhead whale, *Balaena mysticetus*, summering in the Beaufort Sea. *Aquatic Mammals* 15(1):27–37.