Behavior and Distribution of Cook Inlet Beluga Whales, *Delphinapterus leucas*, Before and During Pile Driving Activity

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Introduction

Beluga whales, *Delphinapterus leucas*, are found throughout the Arctic and subarctic regions of the Northern Hemisphere, summering in coastal waters and estuaries and wintering in polynyas or in areas of shifting ice (Reeves et al., 2008). Worldwide, there are 29 stocks of beluga whales, but some stock boundaries overlap spatially and seasonally (IWC, 2000). Five stocks of beluga whales exist in U.S. waters (Beaufort Sea, eastern Chukchi Sea, eastern Bering Sea, Bristol Bay, Cook Inlet). Cook Inlet beluga whales are genetically distinct and geographically isolated from the other stocks (O'Corry-Crowe et al., 1997; Laidre et al., 2000; O'Corry-Crowe et al., 2002).

In 2008, the National Oceanic and Atmospheric Administration's (NOAA) National Marine Fisheries Service (NMFS) listed the Cook Inlet population as endangered under the U.S. Endangered Species Act (ESA; NOAA, 2008a). The Cook Inlet population was estimated at 312 individuals in 2012 (Hobbs et al., 2015a). The population was expected to increase each year following increased restrictions on subsistence hunting (Hobbs et al., 2015a); however, the population has continued to decline at a rate of approximately 1.6 % per year from 1999–2012 (Hobbs et al., 2015a). According to population modeling studies, an optimal sustainable population should contain no fewer than 780 individuals (NMFS[1]). Extinction risk models show a 42–71% probability of decline and up to a 14% probability of extinction within the next 100 years (Hobbs et al., 2015b).

The "Draft Recovery Plan for the Cook Inlet Beluga Whale (*Delphinapterus leucas*)" (NMFS[1]) includes a review and assessment of the known and possible threats to Cook Inlet belugas. Natural threats include stranding events, predation, parasitism, disease, and environmental changes. Potential anthropogenic threats include subsistence hunting, poaching, fishing, pollution, vessel traffic, tourism and whale watching, coastal zone development, noise, oil and gas development, and scientific research (Norman et al., 2015).

Anthropogenic noise is of particular concern as coastal zone development increases in upper Cook Inlet (Castellote et al., 2011; Norman et al., 2015). Current and proposed development projects include the Knik Arm ferry, the Knik Arm crossing, Chuitna coal mine, ORPC Alaska tidal energy projects, Port MacKenzie expansion, dredging off the Port of Anchorage (POA) to support deep-draft vessels, and the POA Marine Terminal Redevelopment (MTR) Project (NMFS[1,2]).

In-water construction activities at the MTR Project include dredging,

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[1]NMFS. 2015. Draft recovery plan for the Cook Inlet beluga whales (*Delphinapterus leucas*). NOAA, Natl. Mar. Fish. Serv., Alaska Regional Office, Protected Species Division, Juneau. (Avail. online at www.fisheries.noaa.gov/pr/recovery/plans/draft_cib_recovery_plan_15may2015.pdf).

[2]NMFS. 2015. Development projects in Cook Inlet beluga habitat. Cook Inlet beluga whales. (Avail. online at alaskafisheries.noaa.gov/protectedresources/whales/beluga/development.htm, accessed 18 June 2015).

ABSTRACT–Five stocks of beluga whales, Delphinapterus leucas, *exist in U.S. waters. Cook Inlet beluga whales are genetically distinct and geographically isolated from the other stocks and are listed as endangered under the U.S. Endangered Species Act. Many factors are identified as potential threats to Cook Inlet beluga whales, including coastal zone development and anthropogenic noise. The Port of Anchorage Marine Terminal Redevelopment (MTR) Project in Anchorage, Alaska, involves several types of in-water construction including dredging, gravel fill, and pile driving. Pile driving is a major concern because of potential harassment from in-water noise produced by this activity. We investigated beluga whale behavior before (2005–06) and during (2008–09) pile driving activity at the MTR Project. Shore-based visual observations were conducted to document beluga behavior in the presence and absence of pile driving activities. A Pearson's correlation coefficient (2-tailed) was used to examine the relationship between monthly sighting and pile driving rates. Sighting rates, sighting duration, behavior, group size, group composition, and group formation were compared using chi-square goodness-of-fit tests or a Mann-Whitney U test. There was no significant correlation between monthly sighting and pile driving rates; nor was there a significant difference in sighting rates or mean group size. Mean sighting duration was shorter during pile driving (18 ± 3 min vs. 39 ± 6 min). There was also an increase in traveling through the study area relative to other behaviors during pile driving, and an increase in diving with reduced observed feeding. There were significant changes in group composition and increased group dispersion during pile driving. These results suggest that pile driving has potential negative impacts on beluga whales, but whether the impact is long- or short-term is unknown.*

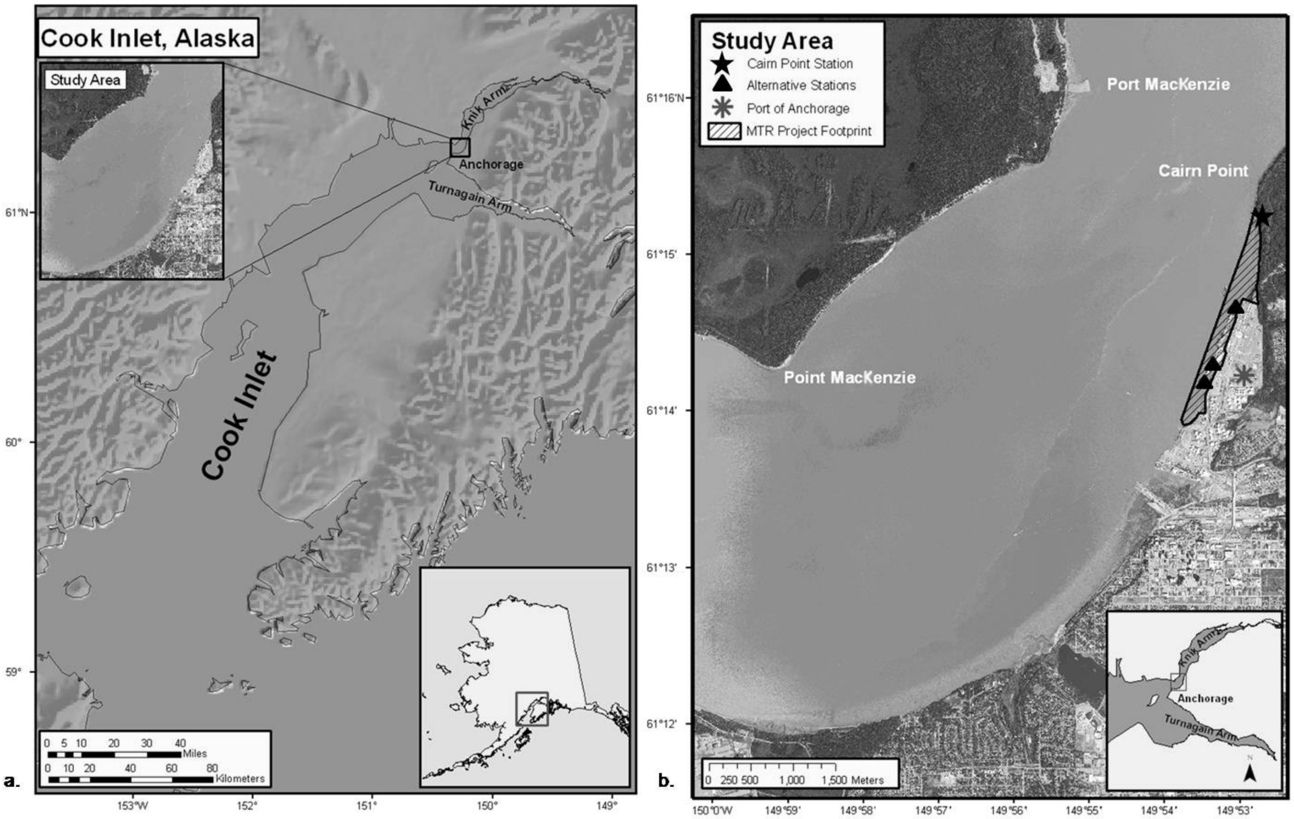

Figure 1.—Cook Inlet, Alaska (a), with an inset of the study area near Anchorage, Alaska. The study area (b) in Knik Arm, upper Cook Inlet adjacent to Anchorage, Alaska. Cairn Point Station (star) is north of Anchorage. The three alternative observation stations, two at the Petroleum, Oil, and Lubricants Towers and one at the northeast corner of the POA dock (triangles) were located at the Port of Anchorage (asterisk) during the 2005—06 seasons. The MTR Project footprint is outlined and crosshatched.

gravel fill, and pile driving (NOAA, 2008b). The combination of these activities could affect beluga whales through an increase in underwater noise, which could interfere with beluga whale communication and echolocation, cause behavioral changes (e.g., increased travel speed, change in dive patterns), mask important sounds, cause avoidance or displacement from important habitat or have a physiological impacts such as impaired auditory senses (Richardson et al. 1995; IWC, 2012).

Studies evaluating impacts of construction activities, such as pile driving, on cetaceans are few (Richardson et al., 1995; Würsig et al., 2000; NRC, 2003; Carstensen et al., 2006; Tougaard et al., 2009; Bailey et al., 2010; Brandt et al., 2011; Dähne et al., 2013; Kendall et al., 2013; Wang et al., 2014), but they demonstrate changes in cetacean behavior. Bailey et al. (2010) showed that pile driving noise can be detected up to 70 km from the source. Responses from Indo-Pacific hump-backed dolphins, *Sousa chinensis* (Würsig et al., 2000; Wang et al., 2014), and harbor porpoises, *Phocoena phocoena*, (Carstensen et al., 2006; Tougaard et al., 2009; Brandt et al., 2011; Dähne et al., 2013), in the presence of pile driving activity include reduced vocal activity and avoidance of the area.

Cook Inlet beluga whale vocal activity also changed in the presence of construction activity (Kendall et al., 2013). Since Cook Inlet beluga whales frequent areas with high levels of construction, it is important to understand how pile driving impacts these whales. We investigated beluga whale behavior before (2005–06) and during (2008–09) pile driving activity at the MTR Project. Sighting rates, mean sighting duration, behavior, mean group size, group composition, and group formation were compared between the two periods. The relationship between beluga whale sighting rates and the rate of pile driving was also examined.

Methods

Study Area

The study area included all visible water from shore-based observation stations located in Knik Arm, upper Cook Inlet near Anchorage, Alaska (Fig. 1a). The POA and Port MacKenzie are both located at the entrance to Knik Arm (Fig. 1b). All observation stations were located on the east side of Knik Arm in the vicinity of the

Table 1.—Summary of sampling effort from 2005–2009.

Year	Observer	Days (d/wk)	Duration (h/d)	Shifts/ day	Seasonal duration	Theodolite	500 x 500 m grid	Effort (h)	Pile driving
2005	Single	2	6	1	2 Aug–28 Nov	Yes	Yes	374.40	No
2006	Single	4	6	1	26 Apr–03 Nov	Yes	Yes	563.80	No
2008	Double	4	4	2	24 Jun–14 Nov	Yes	Yes	611.50	Yes
2009	Double	4	4	2	4 May–18 Nov	Yes	Yes	779.40	Yes

POA (Fig. 1b). The main station was located at Cairn Point on Joint Base Elmendorf Richardson facing south and overlooking the study area.

During 2005–06, three alternative sites were used in addition to the Cairn Point Station (CPS; Fig. 1b). In 2005, two stations at the Petroleum, Oil, and Lubricants Towers (Towers) were used to determine the best vantage point for marine mammal monitoring for the MTR Project (Prevel-Ramos et al.[3]). After the 2005 season, the Towers were no longer used because CPS was determined to be the best location for the study (Prevel-Ramos et al.[3]; Markowitz and McGuire[4]). In 2006, access to CPS was variable; therefore, an alternative station located at the northeast corner of the dock at the POA was occasionally used for observations (Markowitz and McGuire[4]). CPS was the only station used during 2008–09 seasons.

Data Collection

Data for 2005–06 were collected and provided by LGL Alaska Research Associates, Inc. (Prevel-Ramos et al.[3]; Markowitz and McGuire[4]). In 2005, observations were conducted 2 d/wk, 6 h/d, from 2 Aug. to 28 Nov. (Table 1; Prevel-Ramos et al.[3]). Two observers were located at separate stations during daily observational periods; one at CPS and one at the Towers. In 2006, a single observer conducted observations 4 d/wk, 6 h/d from 26 Apr. to 3 Nov. at CPS (Table 1; Markowitz and McGuire[4]). If access to CPS was unavailable, the observer was located at the northeast corner of the dock at the POA.

Twenty minute scan samples were conducted using the naked eye for the first 10 min followed by 10 min of scanning with binoculars (Bushnell[5] 7 x 50 with internal magnetic compass; Funk et al.[6]). Observers used a surveyor's theodolite (tripod mounted Topcon DT-102) to track the location of beluga whale groups. If the theodolite was unavailable, observers used a 500 x 500 m grid overlaying a map of the study area to document the location of whale groups (Prevel-Ramos et al.[3]; Markowitz and McGuire[4]).

During 2008–09, observation effort increased to 4 d/wk, 8 h/d in two shifts of 4 h from 24 Jun. to 14 Nov. 2008 and from 4 May to 18 Nov. 2009 (Table 1). Two observers were located at CPS during all observational periods (Cornick and Kendall[7]; Cornick et al.[8]). During the 2008–09 seasons, protocols were modified to 10-min scan sampling intervals using binoculars (Bushnell 7x50 with internal compass; Nikon Monarch ATB 10x42; Cornick and Kendall[7]; Cornick et al.[8]). One observer tracked whale groups using a surveyor's theodolite (tripod mounted Topcon DT-200) and the other used the 500 x 500 m grid. Observers continued to use the 500 x 500 m grid to maintain consistency in data collection and as a backup if the theodolite was unavailable or not working. For all seasons, daily observation hours were dependent on the available daylight hours.

During all seasons, once a whale group was observed, it was focal-followed until no longer in view (either dove and did not resurface or moved out of the study area) (Altmann, 1974). One focal group was defined as one sighting. Observers documented the location, direction, color class, number of whales, and behavior and movement patterns and noted the time and location of each pattern. Any construction activity was also documented (Funk et al.[6]; Cornick et al.[8]). Descriptive statistics were calculated for sampling effort to determine monthly and annual totals. Numbers of sightings were calculated by month and year (Table 2).

Theodolite tracking was used to triangulate the location of whale groups by measuring the horizontal angles from a selected reference point and vertical angles relative to the axis of gravity (Würsig et al., 1991; Gailey and Ortega-Ortiz, 2000). The height of the eyepiece (measured daily), the vertical height of the station (surveyed at 62 m above mean lower low water [MLLW]) and tide levels (height from MLLW) were also used to calculate the position of the whale group. Once the horizontal and vertical angles, the height of the station, and the tide height were known, each group's

[3]Prevel-Ramos, A., T. M. Markowitz, D. W. Funk, and M. R. Link. 2006. Monitoring beluga whales at the Port of Anchorage: pre-expansion observations, August–November, 2005. Rep. LGL Alaska Res. Assoc., Anchorage, for Integrated Concepts Res. Corp. Port of Anchorage, and U.S. Dep. Transp. Marit. Admin., 30 p.

[4]Markowitz, T. M., and T. J. McGuire. 2007. Temporal-spatial distribution, movements and behavior of beluga whales at the Port of Anchorage, Alaska. Rep. LGL Alaska Res. Assoc., Inc., Anchorage, for Integrated Concepts Res. Corp. and the U.S. Dep. Transportation Marit. Admin., 93 p.

[5]Mention of trade names or commercial firms does not imply endorsement by the National Marine Fisheries Service, NOAA.

[6]Funk, D. W., T. M. Markowitz, and R. Rodrigues. 2005. Baseline studies of beluga whale habitat use in Knik Arm, Upper Cook Inlet, Alaska: July 2004–July 2005. Rep. from LGL Alaska Res. Assoc. Inc., Anchorage, in assoc. with HDR Alaska, Inc., Anchorage, for the Knik Arm Bridge and Toll Authority, Anchorage, Dep.Transportation Public Facil., Anchorage, and Fed. Highway Admin., Juneau, 217 p.

[7]Cornick, L. A, and L. S. Kendall. 2008. Distribution, habitat use and behavior of Cook Inlet beluga whales and other marine mammals at the Port of Anchorage Marine Terminal Redevelopment Project June–November, 2008. Rep. prep. for U.S. Dep. Trans. Marit. Admin., Port of Anchorage, and Integrated Concepts and Res. Corp. by Alaska Pac. Univ., Anchorage, p. 27.

[8]Cornick, L. A., L. S. Kendall, and L. C. Pinney. 2010. Distribution, habitat use and behavior of the Cook Inlet beluga whales and other marine mammals at the Port of Anchorage Marine Terminal Redevelopment Project, May–November 2009. Sci. Mar. Mammal Monitoring Program, 2009 Ann. Rep. prep. for U.S. Dep. Transportation Maritime Admin., Port of Anchorage, and Integrated Concepts and Res. Corp. by Alaska Pac. Univer., Anchorage, p. 38.

Table 2.—Sampling effort and sightings from 2005–2009.

Month	Sampling effort: Days	Sampling effort: Hours	Sightings: No. of days whales sighted	Sightings: No. of whales	Sightings: No. of groups
2005					
August	14	83.10	4	41	4
September	16	96.10	6	51	10
October	12	96.10	2	7	2
November	9	99.10	2	57	7
Total	51	374.40	14	156	23
2006					
April	2	12.00	1	2	2
May	10	60.00	3	7	3
June	18	108.00	3	8	4
July	14	84.00	2	2	2
August	16	92.10	4	35	6
September	16	96.00	6	26	7
October	16	96.00	2	2	2
November	3	15.70	0	0	0
Total	95	563.80	21	82	26
2008					
June	4	27.67	0	0	0
July	19	150.17	0	0	0
August	17	120.50	9	126	32
September	19	133.83	6	57	22
October	22	128.00	2	13	5
November	10	51.33	3	87	15
Total	91	611.50	20	283	74
2009					
May	15	96.00	3	33	15
June	18	144.00	0	0	0
July	18	126.00	0	0	0
August	17	130.40	5	67	22
September	16	121.50	4	35	12
October	18	113.00	0	0	0
November	10	48.50	2	31	5
Total	112	779.40	14	166	54
Overall Total	349	2,329.10	69	687	177

Table 3.—Definitions of focal group behavior and potential acute responses to noise.

Focal group behavior[1]	Description
Traveling	Observation of swimming in one direction without stopping
Diving	Observation of a full back arch or fluke up
Milling	Observation of staying in one location in no particular order
Resting	Observation of motionless on the surface of the water
Observed feeding	Observation of catching prey (e.g., fish) in the mouth
Suspected feeding	Diving must be primary activity, then observation of chasing prey, diving near-shore or in an area known to have prey species (e.g., Ship Creek)
Other	Observation of other behavior worth noting such as spy hopping (i.e., a whale observed in a vertical position with its head extending out of the water), etc.
Acute response[2]	**Description**
Startled effect	A whale group appears to be suddenly disturbed or agitated
Approaches and then leaves the area	A whale group moves toward the area and then change direction and leave the same way they entered
Change in swimming speed	The increase or decrease in the speed of a whale group
Abrupt change in direction	A whale group suddenly changes the direction they are traveling
Abrupt dives	A whale group suddenly alters their diving pattern to more quick dives
Disperse	A whale group suddenly breaks apart and moves in separate directions
Other	A behavior other than the ones described above. Describe the behavior in the comments column.

[1]Mann, 2000.
[2]Ljungblad et al., 1988; Würsig et al., 2000; Patenaude et al., 2002

position was translated into x/y map coordinates.

The theodolite was connected to a Dell laptop computer with an RS-232 cable. Data were collected, organized, and beluga whale locations were calculated using Pythagoras tracking software (http://www.tamug.edu/mmbeg/pythagoras.htm). Station parameters and tide height were entered into Pythagoras prior to observations. Tide heights were generated with JTides 4.7 and 5.2 software (http://www.arachnoid.com/JTides) from the Anchorage (Knik Arm), Alaska station. Tracking data were stored in Microsoft Access for Windows. Only theodolite tracking data from CPS were used in statistical analysis.

Focal group behavior (Mann, 2000) and swimming formation were continuously sampled (Table 3). Milling was not included as a behavioral state during 2005–06; it was added to the list of behavioral states in 2008. Potential indicators of negative responses to noise were documented, if observed.

Group size and composition were recorded continuously until the whales went out of view. As whale groups were tracked through the study area, the number of individuals within each group was recorded multiple times. Once the whale group went out of view, the most accurate count was documented and used for group size statistical analysis. Each group was then classified into size categories (lone, 2–5, 6–10, 11–25, 26–50, >50). Group composition was defined by color class (white, grey, or mixed). Lone individuals of unknown color were excluded only from the group composition analysis ($n = 3$).

In 2009 beluga whales were classified by color because more recent data have suggested that color cannot be used reliably to determine age class in beluga whales (McGuire et al.[9]). Therefore, age classes documented

[9]McGuire, T. L., C. C. Kaplan, M. K. Blees, and M. R. Link. 2008. Photo-identification of beluga whales in Upper Cook Inlet, Alaska. 2007 Annu. Rep. prep. by LGL Alaska Res. Assoc., Inc., Anchorage, for Chevron, Nat. Fish Wild. Found., and ConocoPhillips Alaska, Inc., 52 p.

from 2005 to 2008 were reclassified into color classes as white (previously coded adults), grey (subadults), and dark grey in close proximity of another whale (calf). Animals during this period that were classified as unknown were not reclassified.

Group formation was categorized as densely packed, dispersed, or alone. Group formation was not documented in 2006; therefore, group spread data (defined as body lengths apart) were recoded to match subsequent years' classifications. Group spread included ≤ 3 body lengths apart (densely packed), ≥ 4 body lengths apart (dispersed), and one individual (alone). If spread was not described, no group formation was assigned, and that sighting was not used in group formation analysis.

Data from 2005–06 were classified as before pile driving activity and from 2008–09 were classified as during pile driving activity. In 2005 and 2006, no in-water pile driving took place at the MTR Project. Data from 2007 were excluded from the analysis due to an abbreviated field season (~ 1.5 months).

Regular in-water pile driving began on 24 July 2008 and continued through the end of 2009. Documentation of in-water pile driving began on 1 Aug. 2008. Other in-water construction activities (e.g., dredging and fill placement) also took place from 2005 to 2009.

In 2005–06, general construction activities were noted (Prevel-Ramos et al.[3]; Markowitz and McGuire[4]) and for 2008–09, the specific type and duration of construction activity were recorded. Construction activities often occurred simultaneously; therefore, construction activities were grouped into categories: pile driving (i.e., impact pile driving [IPD], vibratory pile driving [VPD]), and no pile driving (i.e., dredging, fill placement, other).

The MTR Project environmental consulting firm Integrated Concepts and Research Corporation (ICRC) provided data on the total number of hours of pile driving for each year. Because not all months of pile driving activity were broken down into daily events, monthly pile driving activity was used in the statistical analysis. Construction records were normalized to sampling effort. For example, beluga whales were monitored during 17 days in August 2008; therefore, construction activity from those 17 days was used in the statistical analysis.

Statistical Analysis

Monthly in-water pile driving rates at the MTR Project for each year of construction were compared to monthly sighting rates using Pearson's correlation coefficient (2-tailed). Pile driving rates were calculated by dividing the monthly number of hours of pile driving activity that occurred on monitoring days by the monthly sampling effort. Sighting rates were determined by dividing the monthly number of sightings by the monthly sampling effort. Distributions for beluga whale sighting rates, sighting duration, and group size were heavily skewed and were not improved by transformation; therefore, Mann-Whitney U tests were also used to compare these variables before and during pile driving.

Chi-square goodness-of-fit tests were used to compare behavior, group composition, and group formation before and during pile driving. Sampling effort increased from 2005 to 2009, resulting in unequal sample sizes; therefore, expected values for the chi-square tests were proportionally adjusted to correct for the difference in effort. Alpha levels for all analyses were set at $p < 0.05$ and all values are reported as mean ± 1 standard error unless otherwise indicated. SPSS (v. 15.0 for Windows) was used for statistical analyses.

Results

A total of about 2,329 h of sampling effort was completed across 349 d from 2005 to 2009 (Table 2). Overall, 687 whales in 177 groups were documented during the 69 d that whales were sighted (Table 2). A total of about 353 and 1,663 h of pile driving activity took place in 2008 and 2009, respectively. There was no relationship between monthly beluga whale sighting rates and monthly pile driving rates ($r = 0.19$, $p = 0.37$).

Sighting rates before ($n = 12$; 0.06 ± 0.01) and during ($n = 13$; 0.01 ± 0.03) pile driving activity were not significantly different ($U_{std} = .412$, $p = 0.68$). However, sighting duration of beluga whales decreased significantly ($U_{std} = -3.733$, $p < 0.001$) during pile driving (39 ± 6 min before and 18 ± 3 min during; Fig. 2).

There were also significant differences ($\chi^2_{(2)} = 22.80$, $p < 0.01$) in behavior before vs. during pile driving (Fig. 3). Beluga whales primarily traveled through the study area both before and during pile driving; however, traveling increased relative to other behaviors during pile driving activity. Diving ($n = 18$ and $n = 22$, respectively) increased while suspected feeding ($n = 6$ and $n = 4$, respectively) decreased during pile driving. Feeding was observed on two occasions before pile driving and on zero occasions during pile driving. Documentation of milling began in 2008 and was observed on 21 occasions. No acute behavioral responses were documented.

Mean group size decreased during pile driving (5 ± 1 before and 4 ± 0 during); however, this difference was not statistically significant ($U_{std} = -.959$, $p = .34$). There were significant differences in group composition before and during pile driving ($\chi^2_{(6)} = 60.09$, $p < 0.01$; Fig. 4; Table 4). Substantial differences in group composition before and during pile driving occurred among lone grey belugas (11% and 2%, respectively), lone white belugas (19% and 24%, respectively), groups with 2–5 whites (13% and 35%, respectively), mixed groups of 6–10 individuals (15% and 7%, respectively), and mixed groups of 11–25 individuals (15% and 4%, respectively; Table 4). Only one group of 26–50 mixed ($n = 33$, 1%) was observed in the study area during pile driving activity. No groups > 50 were observed.

Differences in group composition were also reflected in significant differences in group formation ($\chi^2_{(2)}$ =

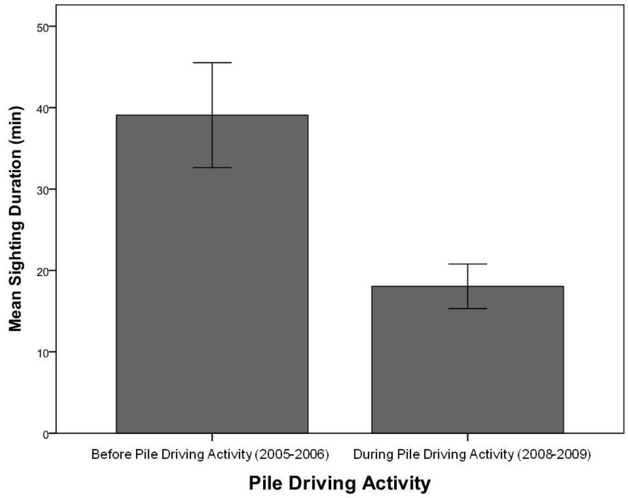

Figure 2.—Mean sighting duration of beluga whales decreased significantly during pile driving (39 ± 6 min before; 18 ± 3 min during; U_{std} = -3.733, $p < 0.001$).

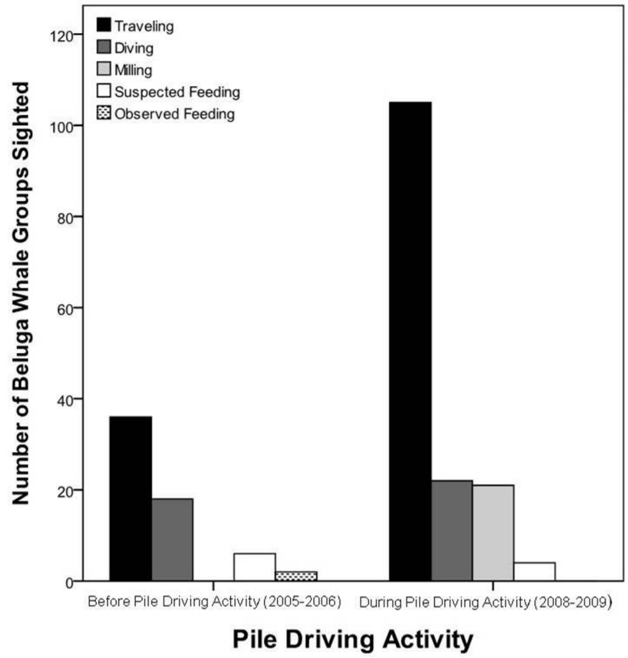

Figure 3.—Beluga whale behavior before and during pile driving. Behavior was significantly different before and during pile driving ($\chi^2_{(2)}$ = 22.80, $p < 0.01$). Beluga whales primarily traveled through the study area both before and during pile driving; however, traveling increased during pile driving. Diving increased while suspected feeding decreased. Observed feeding was only observed before pile driving. Documentation of milling began in 2008 and was observed on 21 occasions. No acute behavioral responses were documented.

7.75, p = 0.02) before and during pile driving (Fig. 5). Beluga whales were primarily observed densely packed before and during pile driving activity (n = 23 and n = 70, respectively); however, the number of dispersed groups increased during pile driving (n = 4 before and n = 21 during), as did observations of lone individuals (n = 13 before and n = 32 during).

Discussion

Although there were no significant differences in beluga whale sighting rates during pile driving, and monthly pile driving rates were not correlated with monthly sighting rates, significant differences in sighting duration, behavior, and group structure were observed during in-water pile driving at the MTR Project. Beluga whales are highly social animals that rely heavily on acoustic signals for communication and socializing, prey detection, and predator avoidance (Richardson et al., 1995). Therefore, even subtle changes in the acoustic profile of the environment may disrupt important activities, and thus impact the population.

Table 4.—Beluga whale group composition (%) before and during pile driving.

Group composition	Before pile driving (%)	During pile driving (%)
Lone white	19	24
Lone grey	11	2
2–5 mixed	26	24
2–5 white	13	35
6–10 mixed	15	7
6–10 white	2	2
11–25 mixed	15	4
11–25 white	0	0
26–50 mixed	0	1
26–50 white	0	0
> 50 mixed	0	0
> 50 white	0	0

The combination of a ~54% reduction in sighting duration (Fig. 2) and a 64% increase in traveling behavior (Fig. 3) suggests that beluga whales altered their movement patterns during pile driving. Temporary avoidance and even abandonment of areas during pile driving has been observed in Indo-Pacific hump-backed dolphins (Würsig et al., 2000; Wang et al., 2014) and harbor porpoise (Carstensen et al., 2006; Brandt et al., 2011, Dähne et al., 2013). In some cases the animals returned to the area once pile driving activity was completed (Wursig et al., 2000; Carstensen et al., 2006); however, the return time occasionally took several days (Carstensen et al., 2006).

Brandt et al. (2011) observed the reduction of harbor porpoise activity and density in construction areas over the entire 5 mo period that pile driving took place. They also documented increased use of areas as far as 22 km away from the construction site. Dähne et al., (2013) documented a similar avoidance response from harbor porpoise at distances 20 km or greater from the source. Würsig et al. (2000) observed a doubling of swim speeds of Indo-Pacific hump-backed dolphins during pile driving. Tougaard et al. (2009) observed changes in harbor porpoise vocal behavior beyond distances of 20 km. Wang et al. (2014) suggested that Indo-Pacific

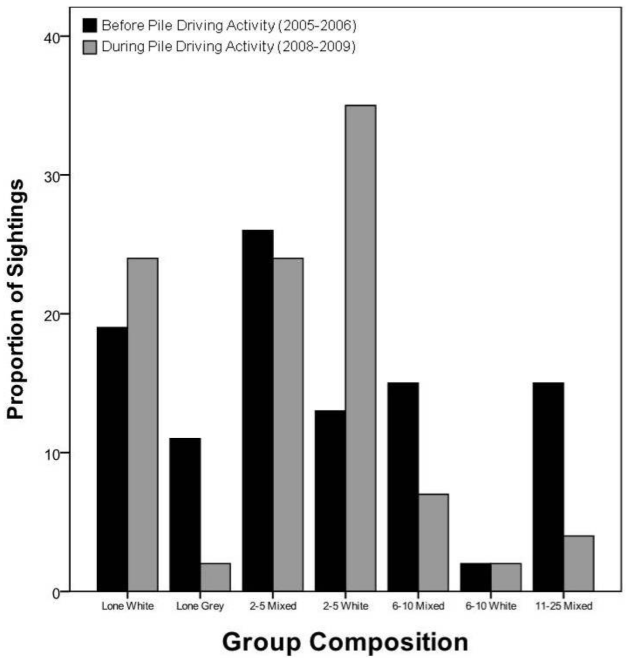

Figure 4.—Beluga whale group composition before and during pile driving activity. Group composition was significantly different before and during pile driving ($\chi^2_{(6)} = 60.09$, $p < 0.01$).

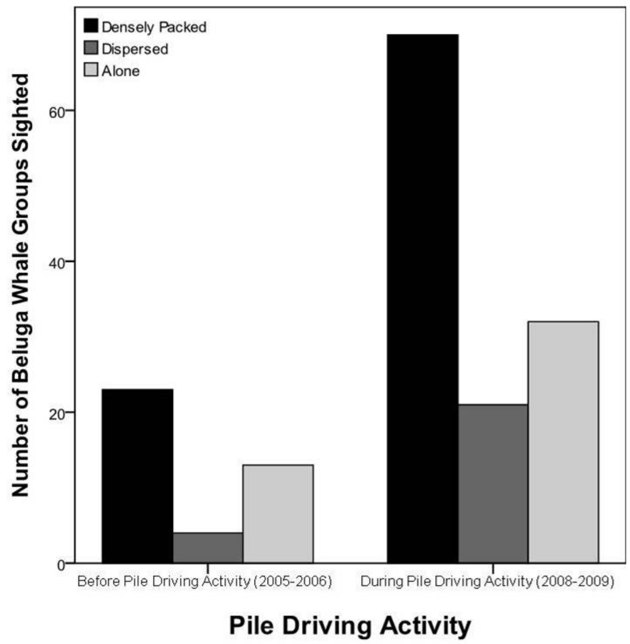

Figure 5.—Beluga whale group formation before and during pile driving. Group formation was significantly different before and during pile driving ($\chi^2_{(2)} = 7.75$, p = 0.02). Beluga whales were primarily observed densely packed both before and during pile driving ($n = 23$ and $n = 70$, respectively). Dispersed groups ($n = 4$ and $n = 21$, respectively) and lone individuals ($n = 13$ and $n = 32$, respectively) increased during pile driving.

hump-backed dolphin's clicks would not be adversely affected during pile driving; however, their whistles would likely be masked. Kendall et al. (2013) only recorded echolocation clicks and no whistles or noisy vocalizations near construction activity during an acoustic study at the MTR Project, which is unusual for this highly vocal species (Reeves et al., 2008). The lack of whistles and noisy vocalizations and the presence of echolocation clicks correspond to the travel behavior observed in this study because echolocation clicks are generally associated with navigation and foraging (Au et al., 1985; Au et al., 1987; Faucher, 1988; Turl and Penner, 1989; Turl, 1990). However, Kendall et al. (2013) observed a higher click rate without construction activity indicating potential disturbance with a possible reduction in vocal activity during construction. Because pile driving can be detected at distances up to 70 km (Bailey et al, 2010) and beluga whales can likely hear pile driving activity over great distances from the source (Erbe and Farmer, 2000), belugas entering Knik Arm may alter their travel patterns through the area and maximize their distance from the source to avoid prolonged exposure to noise associated with pile driving.

Observations of increased diving but reduced suspected/confirmed feeding may suggest disruptions to foraging patterns; however, few observations of suspected and confirmed feeding were documented during this study (10 suspected and 2 confirmed). Beluga whales feed at locations close to the MTR Project (e.g., Ship Creek). With increased noise associated with pile driving, beluga whales may reduce their vocal activity (Kendall et al., 2013), resulting in increased dive frequency but reduced capture success. The change in foraging behavior combined with the increased traveling suggests that during pile driving, beluga whales are choosing to move past these areas to other, potentially richer, feeding areas further into Knik Arm (e.g., Six Mile Creek, Eagle River, Eklutna River). These locations contain predictable salmon runs (ADFG, 2010), an important food source for Cook Inlet beluga whales (NMFS[1]), and the timing of these runs has been correlated with beluga whale movements into the upper reaches of Knik Arm (Ezer et al., 2013).

Mean group size was reduced during pile driving, although this difference was not statistically significant. The trend is supported, however, by the significant increase in the number of lone white whales and the decrease in size of mixed groups from primarily 6 or more animals to groups of 2–5 animals (Fig. 4). Beluga whales in densely packed groups increased by ~67% during pile driving (Fig. 5); however, there were also significant increases in dispersed groups (~81%) and lone white whales (~60%). Given that mixed groups were smaller, it may be that these groups contained calves, and the densely packed formation provided decreased distances for communication in a noisier environment and better protection for calves. This is supported by the significant decrease in the number of lone grey animals (Fig. 4) and previous data that indicate that Knik Arm is potentially a nursery area (Huntington, 2000; Hobbs et al., 2015c).

The shallow waters of Knik Arm may also provide protection from killer whale, *Orcinus orca*, predation on calves (Shelden et al., 2003). Conversely, the increase in dispersed groups is reflective of the increase in the number of lone white whales and the number of small groups (2–5 individuals) of all white whales. Caron and Smith (1990) suggest summer segregation of the sexes; therefore, these dispersed groups of all white animals may be older juvenile and adult males, which likely reduces the need to travel more tightly spaced.

Group living is beneficial because it decreases an animal's susceptibility to predation and decreases their risks from environmental challenges (i.e., decreases their cost of locomotion; Connor, 2000). Bowhead, *Balaena mysticetus*; sperm, *Physter macrocephalus*; and beluga whales have been observed forming densely packed groups in the presence of anthropogenic noise (e.g., seismic airgun blasts, water- and aircraft; Ljungblad et al., 1988, Blane and Jaakson, 1994; Patenaude et al., 2002; Smultea et al., 2007). Smultea et al. (2007) interpreted this response by sperm whales near the main Hawaiian Islands as a predator defense response. The overall reduction in group size and increase in the number of animals in more dispersed groups in the present study may reduce this benefit for Cook Inlet beluga whales during pile driving.

The Cook Inlet beluga whale's range has contracted over the last three decades to the upper reaches of Cook Inlet, and the current population center is just outside the mouth of Knik Arm off the coast of Anchorage (Rugh et al., 2010; Shelden et al., 2015). Knik Arm is designated as Type I Critical Habitat for this population (NOAA, 2011). The area north of the construction site is an important foraging area (Sixmile Creek and Eagle River; Hobbs et al., 2005) and may also serve as a calving and nursery area (Huntington, 2000; Hobbs et al., 2015c).

Any avoidance of Knik Arm could cause permanent displacement from critical habitat, potentially reducing foraging and reproductive success and hindering recovery. Continued monitoring of Cook Inlet beluga whales both during the completion of the MTR Project and well after construction is completed is necessary to determine if there are long-term impacts on Cook Inlet beluga whales, or if the observed changes in movement and association patterns and behavior are a temporary acute stressor on the population during pile driving events. Additionally, other development projects that increase noise levels in Cook Inlet should continue to collect and share data with the scientific community. These data can be compiled and used to determine the cumulative effects of noise and whether noise from development projects is creating long- or short-term impacts on the population, which is currently unknown.

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Literature Cited

ADFG. 2010. Anadromous fish distribution. Interactive map. Anadromous Water Catalog. Div. of Sports Fish. Alaska Dep. Fish Game, Juneau . Online at http://www.sf.adfg.state.ak.us/SARR/awc/index.cfm/FA/maps.interactive (accessed 1 Mar. 2010).

Altmann, J. 1974. Observational study of behavior: sampling methods. Behavior 49:227–265. (doi: 10.1163/156853974X00534).

Au, W. W. L., D. A. Carder, R. H. Penner, and B. L. Scronce. 1985. Demonstration of adaptation in beluga whale echolocation signals. J. Acoust. Soc. Am. 77:726–730. (doi: 10.1121/1.392341).

______, R. H. Penner, and C. W. Turl. 1987. Propagation of beluga echolocation signals. J. Acoust. Soc. Am. 82:807–813. (doi: 10.1007/978-1-4684-7493-0_4).

Baily, H., B. Senior, D. Simmons, J. Rusin, G. Picken, and P. Thompson. 2010. Assessing underwater noise levels during pile-driving at an offshore windfarm and potential effects on marine mammals. Mar. Pol. Bull. 60:888–897. (doi: 10.1016/j.marpolbul.2010.01.003).

Blane, J. M., and R. Jaakson. 1994. The impact of ecotourism boats on the St. Lawrence beluga whales. Environ. Conserv. 21(3):267–269. (doi: 10.1017/S0376892900033282).

Brandt, M. J., A. Diederichs, K. Betke, and G. Nehls. 2011. Responses of harbor porpoises to pile driving at the Horns Rev II offshore wind farm in the Danish North Sea. Mar. Ecol. Prog. Ser. 421:205–216. (doi: 10.3354/meps08888).

Caron, L. M. J., and T. G. Smith. 1990. Philopatry and site tenacity of belugas, *Delphinapterus leucas*, hunted by the Inuit at the Nastapoka estuary, eastern Hudson Bay. *In* T. G. Smith, D. J. St. Aubin, J. R. Geraci (Editors), Advances in research on the beluga whales, *Delphinapterus leucas*, p. 69–79. Can. Bull. Fish. Aquat. Sci. 224.

Carstensen, J., O. D. Henriksen, and J. Teilman. 2006. Impacts of offshore wind farm construction on harbor porpoises: acoustic monitoring of echolocation activity using porpoise detectors (T-PODs). Mar. Ecol. Prog. Ser. 321:295–308. (doi:10.3354/meps321295).

Castellote, M., R. J. Small, S. Atkinson, M. O. Lammers, J. Jenniges, A. Rosinski, C. Garner, S. Moore, and W. W. L. Au. 2011. Acoustic monitoring of beluga whales (*Delphinapterus leucas*) in Cook Inlet, Alaska. J. Acoust. Soc. Am. (130):2459. (doi: 10.1121/1.3654879).

Connor, R. C. 2000. Group living in whales and dolphins. *In* J. Mann, R. C. Connor, P. L. Tyack, and H. Whitehead (Editors), Cetacean societies: field studies of dolphins and whales, p. 199–218. Univ. Chicago Press, Chicago.

Dähne, M. A. Gilles, K. Lucke, V. Peschko, S. Adler. K. Krügel, J. Sundermeyer, and U. Seibert. 2013. Effects of pile-driving on harbor porpoise (*Phocoena phocoena*) at the first offshore wind farm in Germany. Environ. Res. Lett. 8, 025002.

Erbe, C., and D. M. Farmer. 2000. Zones of impact around icebreakers affecting beluga whales in the Beaufort Sea. J. Acoust. Soc. Am. 108:1332–1340. (doi: 10.1121/1.1288938).

Ezer T., J. R. Ashford, C. M. Jones, B. A. Mahoney, and R. C. Hobbs. 2013. Physical-biological interactions in a subarctic estuary: How do environmental and physical fac-

tors impact the movement and survival of beluga whales in Cook Inlet, Alaska? J. Mar. Sys. 111–112:120–129. (doi:10.1016/j.jmarsys.2012.10.007).
Faucher, A. 1988. The vocal repertoire of the St. Lawrence estuary population of beluga whale (*Delphinapterus leucas*) and its behavior, social and environmental contexts. M.S. Thesis, Dalhousie Univ., Halifax, N.S., 102 p.
Gailey, G., and J. Ortega-Ortiz. 2000. Pythagoras Theodolite cetacean tracking: marine mammal research program Tex. A&M Univ., Galveston, 66 p.
Hobbs, R. C., K. L. Laidre, D. J. Vos, B. A. Mahoney, and M. Eagleton. 2005. Movements and area use of belugas, *Delphinapterus leucas*, in a subarctic Alaskan estuary. Arctic 58:331–340.
__________, K. E. W. Shelden, D. J. Rugh, C. L. Sims, and J. M. Waite. 2015a. Estimated abundance and trend in aerial counts for beluga whale, *Delphinapterus leucas,* in Cook Inlet, 1994–2012. Mar. Fish. Rev. 77(1):11–31. (doi: 10.7755/MFR77.1.2).
__________, P. R. Wade, and K. E. W. Shelden. 2015b. Viability of a small, geographically-isolated population of beluga whales, *Delphinapterus leucas*: effects of hunting, predation, and mortality events in Cook Inlet, Alaska. Mar. Fish. Rev. 77(2):59–88. (doi: 10.7755.MFR77.2.4).
__________, C. L. Sims, K. E. W. Shelden, L. Vate Brattström, and D. J. Rugh. 2015c. Annual calf indices for beluga whales (*Delphinapterus leucas*) in Cook Inlet, Alaska, 2006–2012. Mar. Fish. Rev. 77(2):40–58. (doi: 10.7755/MFR.77.2.3).
Huntington H. P. 2000. Traditional knowledge of the ecology of the belugas, *Delphinapterus leucas*, in Cook Inlet, Alaska. Mar. Fish. Rev. 62(3):134–140.
IWC. 2000. Annex I: report of the sub-committee on small cetaceans. Int. Whaling Comm. J. Cetacean Resour. Manage. 2(Suppl.):235–264.
____. 2012. Report of the workshop on interactions between marine renewable projects and cetaceans worldwide, 8–10 June 2012, Panama City, Panama. Rep. SC/64/Rep6, 32 p.
Kendall, L. S., A. Širović, and E. H. Roth. 2013. Effects of construction noise on the Cook Inlet beluga whale (*Delphinapterus leucas*) vocal behavior. Can. Acoust. 41(3):3–13.
Laidre, K. L., K. E. W. Shelden, D. J. Rugh, and B. A. Mahoney. 2000. Beluga, *Delphinapterus leucas*, distribution and survey efforts in the Gulf of Alaska. Mar. Fish. Rev. 62(3):27–36.
Ljungblad, D. K., B. Würsig, S. L. Swartz, and J. M. Keene. 1988. Observations on the behavioral response of bowhead (*Baleena mysticetus*) to active geophysical vessels in the Alaskan Beaufort Sea. Arctic 41:183–194. (doi: 10.14430/arctic1717).
Mann, J. 2000. Unraveling the dynamics of social life: long-term studies and observation methods. *In* J. Mann, R. C. Connor, P. L. Tyack, and H. Whitehead (Editors), Cetacean societies: field studies of dolphins and whales, p. 45–64. Univ Chicago Press, Chicago.
NOAA. 2008a. Endangered and threatened species; endangered status for the Cook Inlet beluga whale. 73 Fed. Regist. 62919 (22 Oct. 2008), p. 62,919–62,930 (avail. online at: https://federalregister.gov/a/E8-25100).
______. 2008b. Small takes of marine mammals incidental to specified activities; Port of Anchorage Marine Terminal Redevelopment Project, Anchorage, Alaska. 73 Fed. Regist. 14443 (08 Mar. 2008), p. 14,443–14453 (avail. online at https://www.federalregister.gov/a/E8-5431).
______. 2011. Endangered and threatened species: Designation of critical habitat for Cook Inlet beluga whale. 76 Fed. Regist. 20179 (05 Mar. 2011), p. 20,179–20,214 (avail. online at https://federalregister.gov/a/2011-8361).
Norman, S. A., R. C. Hobbs, C. C. Goertz, K. A Burek-Huntington, K. E. W. Shelden, W. A. Smith, and L. A. Beckett. 2015. Potential natural and anthropogenic impediments to the conservation and recovery of Cook Inlet beluga whales, *Delphinapterus leucas*. Mar. Fish. Rev. 77(2):89–105. (doi: 10.7755/MFR.77.2.5).
NRC. 2003. Ocean noise and marine mammals. Nat. Res., Counc. Nat. Acad. Press, Wash., D.C., 151 p.
O'Corry-Crowe, G. M., R. S. Suydam, A. Rosenberg, K. J. Frost, and A. E. Dizon. 1997. Phylogeography, population structure and dispersal patterns of the beluga whale *Delphinapterus leucas* in the western Nearctic revealed by mitochondrial DNA. Mol. Ecol. 6:955–970. (doi: 10.1046/j.1365-294X.1997.00267.x).
______, A. E. Dizon, R. S. Suydam, and L. F. Lowry. 2002. Molecular genetic studies of population structure and movement patterns in a migratory species: The beluga whale, *Delphinapterus leucas*, in the western Nearctic. *In* C. J. Pfieffer (Editor), Molecular and cell biology of marine mammals, p. 53–64. Malabar, Florida: Krieger Publ. Co., Malabar, Fla.
Patenaude, N. J., W. J. Richardson, M. A. Smultea, W. R. Koski, G. W. Miller, and B. Würsig. 2002. Aircraft sound and disturbance to bowhead and beluga whales during spring migration in the Alaskan Beaufort Sea. Mar. Mamm. Sci. 18:309–335. (doi: 10.1111/j.1748-7692.2002.tb01040.x).
Reeves, R. R., B. S. Stewart, P. J. Clapham, and J. A. Powell. 2008. National Audubon Society: Guide to marine mammals of the world. Alfred A. Knopf, Inc., N.Y., 517 p.
Richardson, W. J., C.,R. Greene, Jr., C. I. Malme, and D. H. Thomson. 1995. Marine mammals and noise. Acad. Press, San Diego, 532 p.
Rugh, D. J., K. E. W. Shelden, and R. C. Hobbs. 2010. Range contraction in a beluga whale population. Endang. Species Res. 12:69–75. (doi: 10.3354/esr00293).
Shelden, K. E. W., D. J. Rugh, B. A. Mahoney, and M. E. Dahlheim. 2003. Killer whale predation on belugas in Cook Inlet, Alaska: Implications for a depleted population. Mar. Mammal Sci. 19(3):529–544.
____________, K. T. Goetz, D. J. Rugh, D. G. Calkins, B. A. Mahoney, and R. C. Hobbs. 2015. Spatio-temporal changes in beluga whale, *Delphinapterus leucas*, distribution: Results from aerial surveys (1977–2014), opportunistic sightings (1975–2014), and satellite tagging (1999–2003) in Cook Inlet, Alaska. Mar. Fish. Rev. 77(2):1–31. (doi: 10.7755/MFR.77.2.1).
Smultea, M. A., J. R. Mobley, D. Fertl, and G.L. Fulling. 2007. An unusual reaction and other observation of sperm whales near fixed-wing aircraft. Gulf Carrib. Res. 20:75–80. (doi: 10.18785/gcr.2001.10).
Tougaard, J., J. Carstensen, J. Teilmann, H. Skov, and P. Rasmussen. 2009. Pile driving zone of response extends beyond 20 km for harbor porpoises (*Phocoena phocoena* (L.)). J. Acoust. Soc. Am. 126:11–14. (doi: 10.1121/1.3132523).
Turl, C. W., and R. H. Penner. 1989. Differences in echolocation click patterns of the beluga whale (*Delphinapterus leucas*) and the bottlenose dolphin (*Tursiops truncatus*). J. Acoust. Soc. Am. 86:497–502. (doi: 10.1121/1.398229).
______. 1990. Echolocation abilities of the beluga whale, *Delphinapterus leucas*: a review and comparison with the bottlenose dolphin, *Tursiops truncatus*. *In* T. Smith, D. St. Aubin, and J. Gerci (Editors), Advances in research on the beluga whale *Delphinapterus leucas*, p. 119–128. Can. Bull. Fish. Aquat. Sci. 224.
Wang, Z., Y. Wu, G. Duan, H. Cao, J. Liu, K. Wang, and D. Wang. 2014. Assessing the underwater acoustics of the world's largest vibratory hammer (OCTA-KONG) and its potential effects on the Indo-Pacific Humpbacked Dolphin (*Sousa chinensis*). PLoS One. 9(10):e110590. (doi:10.1371/journal.pone.011059).
Würsig B., F. Cipriano, and M. Würsig. 1991. Dolphin movement patterns: Information from radio and theodolite tracking studies. *In* K. Pryor and K. S. Norris (Editors), Dolphin societies: discoveries and puzzles, p. 79–111. Univ. Calif. Press. Berkeley.
__________, C. R. Greene, Jr., and T. A. Jefferson. 2000. Development of an air bubble curtain to reduce underwater noise of percussive piling. Mar. Environ. Res. 49:79–93. (doi:10.1016/S0141-1136(99)00050-1).