EFFECTS OF CONSTRUCTION NOISE ON THE COOK INLET BELUGA WHALE (*DELPHINAPTERUS LEUCAS*) VOCAL BEHAVIOR

Lindsey Saxon Kendall[1], Ana Širović[1, 2], Ethan H Roth[3]

1-Alaska Pacific University, 4101 University Drive, Anchorage, AK 99508, USA
2-current address: Scripps Institution of Oceanography, University of California San Diego, 9500 Gilman Drive MC 0205, La Jolla, CA 92093-0205, USA
3-School of Ocean and Earth Science and Technology, University of Hawai'i at Manoa, 1000 Pope Road, Honolulu, HI 96822, USA

ABSTRACT

Cook Inlet beluga whales (*Delphinapterus leucas*) are listed as endangered under the US Endangered Species Act. Potential threats to this population include anthropogenic noise and coastal zone development. The Port of Anchorage Marine Terminal Redevelopment (MTR) Project, taking place in the Knik Arm of Cook Inlet, Alaska, involves multiple construction activities including dredging, gravel fill and pile driving. The impacts of construction noise on beluga vocalizations were investigated in this study. Passive sonobuoys were deployed in a four mooring array during 20 d in August and September 2009 near the MTR Project. Data were recorded in real-time at a shore-based observation station. No beluga whistles or noisy vocalizations were recorded during this period; however, beluga echolocation clicks were frequently detected. An energy summation method was used to automatically detect echolocation clicks. Times with and without construction noise (*i.e.*, dredging and pile driving) were determined from long-term spectral averages. The detected hourly click rate was higher during times without (429 detected clicks/h) than with (291 detected clicks/h) construction activity; however, the difference was not statistically significant ($t_{(24)} = -0.56$, $P = 0.58$). Lower frequency beluga whale vocalizations (*e.g.*, whistles) were potentially masked, there may be have been an overall reduction in beluga vocalizations, or it is possible belugas were avoiding the area during construction activity.

RÉSUMÉ

Le béluga (*Delphinapterus leucas*) de Cook Inlet est en voie de disparition selon le Loi sur les Espèces en Voie de Disparition des EE.UU. Ses animaux ont le potentiel d'être menacé par des bruits d'origine anthropique et le développement du secteur côtier. Le projet de Réaménagement de Terminal Marine (RTM) du Port de Anchorage, qui aura lieu à Knik Arm de Cook Inlet, Alaska, consiste de plusieurs travaux, comme le dragage, remplissage du gravier et de battage des pieux. Dans cette étude, on a investigué les effets du bruit des travaux sur les vocalises des bélugas. Bouées acoustiques ont été déployées dans un réseau de quatre mouillages pendant 20 jours en Août et Septembre 2009, près du projet RTM. Les données ont été recueillies en temps réel à une station d'observation côtière. Les sifflets ou vocalisations bruyantes des bélugas n'ont pas été enregistrées pendant cette période, mais les clics d'écholocation ont été détectés fréquemment. La somme de l'énergie a été utilisée pour détecter d'une manière automatique des clics d'écholocation. Les temps avec et sans bruit des travaux (c'est-à le dragage et battage) ont été déterminés par l'examen des spectrogrammes comprimé. Le taux de clic détecté était plus élevé pendant les périodes sans travaux (429 clics détectés / h) qu'avec (291 détecté clics / h), mais la différence n'était pas statistiquement significatif (t (24) = 0,56, P = 0,58). Le vocalises des bélugas de la fréquence basse (par exemple, sifflets) ont été potentiellement masqués, il peut y avoir eu une générale réduction des vocalisations des bélugas, ou il est possible que les bélugas évitaient la domaine pendant l'activité de construction.

1. INTRODUCTION

Cook Inlet beluga whales (*Delphinapterus leucas*) are geographically isolated and genetically distinct from other US beluga whale stocks (O'Corry-Crowe *et al.* 1997, Laidre *et al.* 2000, O'Corry-Crowe *et al.* 2002). In 2008, the population was listed as endangered under the US Endangered Species Act (NMFS 2008*a*). The population, currently estimated at 312 individuals (Hobbs *et al.* 2012), was expected to increase 2-6% per year following increased restrictions on the subsistence harvest of beluga in 1999 (Hobbs *et al.* 2008). However, population trends since harvest restrictions indicate a continued decline of 1.3% per year (Hobbs *et al.* 2012). Many factors are identified as potential threats to the Cook Inlet beluga whale, including coastal zone development and anthropogenic noise (NMFS 2008*b*). Known effects of noise on cetaceans include behavioral changes, avoidance or displacement from important habitat, masking of important sounds and changes to acoustic behavior (Richardson *et al.* 1995, Lesage *et al.* 1999, McDonald *et al.* 2006).

Beluga whales have highly developed hearing and vocal abilities. Their hearing is most sensitive from 10-100 kHz (Awbrey *et al.* 1988, Johnson *et al.* 1989, Richardson *et al.* 1995) which is related to their use of high frequencies for echolocation and communication (Richardson *et al.* 1995). Beluga whales were one of the first cetaceans to be recorded underwater and they were found to produce a variety of sounds (Schevill and Lawrence 1949). Beluga whale whistles range between 0.26-20 kHz, pulsed tones between 0.4-12 kHz, noisy vocalizations between 0.5-16 kHz (Schevill and Lawrence 1949, Sjare and Smith 1986*a*, *b*, Richardson *et al.* 1995) and their echolocation clicks have been recorded up to 120 kHz (Au *et al.* 1985). Whistles, noisy vocalization and pulsed sounds at lower frequencies are generally associated with social behaviors (Sjare and Smith 1986*b*, Faucher 1988, Karlsen *et al.* 2002, Belikov and Bel'kovich 2006, 2007, 2008), while high frequency 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).

Beluga whale vocalizations have been studied in stocks found in Cunningham Inlet (Sjare and Smith 1986*a*, *b*), Churchill River (Chmelnitsky and Ferguson 2012) and St. Lawrence Estuary, Canada (Faucher 1988), Bristol Bay, Alaska (Angiel 1997), Svalbard, Norway (Karlsen *et al.* 2002) and the White Sea in Russia (Belikov and Bel'kovich 2006, 2007, 2008), as well as in captive animals (Au *et al.* 1985, Au *et al.* 1987, Turl and Penner 1989, Lammers and Castellote 2009). Similarities in whistles, pulsed sounds and noisy vocalizations among these stocks include frequency band, contour types, duration of contour types and the production of multicomponent whistles (Sjare and Smith 1986*a*, Karlsen *et al.* 2002, Belikov and Bel'kovich 2006, 2007, 2008). Echolocation clicks have been examined in captive belugas (Au *et al.* 1985, Au *et al.* 1987, Turl and Penner 1989, Lammers and Castellote 2009), but have not been compared between wild stocks. Belugas emit two distinct pulses in a single echolocation click (Lammers and Castellote 2009) and their click trains can be separated into three categories based on their distinctly different interclick interval patterns (Au *et al.* 1987). Additionally, beluga clicks may vary in frequency and bandwidth depending on the ambient noise levels (Au *et al.* 1985). Currently, there are no peer-reviewed studies on the vocal repertoire of the Cook Inlet beluga whale.

The presence of anthropogenic noise can affect marine mammals behaviorally, acoustically and physiologically (Nowacek *et al.* 2007). Beluga whale behavioral responses in the presence of anthropogenic noise (*e.g.*, watercraft, aircraft and pile driving) include changes in swimming speed, diving patterns, direction, behavioral states (Patenaude *et al.* 2002), avoidance (Blane and Jaakson 1994, Erbe and Farmer 2000) and vocalizations (Lesage *et al.* 1999, Scheifele *et al.* 2005). Changes in beluga vocalizations include a reduction in call rate, increase in the production of tonal and pulsed calls, shift in frequency band (Lesage *et al*. 199) and the Lombard vocal response (Scheifele *et al.* 2005). In addition, documented beluga responses in the presence of pile driving activity include changes in sighting duration, behavior (*e.g.*, traveling and diving), group composition and group formation (*e.g.*, densely packed or dispersed; Kendall 2010).

A way to increase our understanding of the effects of anthropogenic noise on marine mammals is to use passive acoustic monitoring studies. Passive acoustic monitoring is an innovative technique that is increasingly used for cetacean surveys (Mellinger *et al.* 2007). Traditional visual surveys require daylight and good weather conditions, often resulting in low detection rates (Mellinger *et al.* 2007), while passive acoustic monitoring can continue throughout the night and in poor weather conditions (Barlow and Taylor 2005; Mellinger *et al.* 2007). Sonobuoy hydrophones are relatively inexpensive and have been used successfully for a variety of passive acoustic studies, including documenting the presence and locations of calling animals at high latitudes in challenging environmental conditions (Clark and Ellison 1988, McDonald and Moore 2002, Laurinolli *et al.* 2003, Širović *et al.* 2006).

The Port of Anchorage (POA) Marine Terminal Redevelopment (MTR) Project in the Knik Arm of Cook Inlet, Alaska, takes place in an area frequented by beluga whales (Rugh *et al.* 2000, Hobbs *et al.* 2005). The MTR Project involves several types of construction activities including dredging, gravel fill and pile driving. The combination of these construction activities increases underwater noise levels that could interfere with beluga whale communication and echolocation (Richardson *et al.* 1995, NMFS 2008*c*). We investigated the presence of different beluga whale vocalizations in these recordings and evaluated the impact of construction noise adjacent to the MTR Project on beluga whale echolocation using a fixed array of sonobuoys. Data were manually examined for beluga vocalizations in real-time during data collection and then again by examining long-term spectral averages (LTSA).We used an automatic detector to determine the presence of echolocation clicks in 20 d of recorded data. We determined time periods with and without construction noise and then calculated the detected hourly click rate to determine if there are differences in the rate of detected beluga whale clicks with and without construction activity near the MTR Project.

2. METHODS

2.1 Study Design

The study was conducted in the Knik Arm of Upper Cook Inlet, adjacent to the MTR Project near Anchorage, Alaska, close to in-water construction activities (Figure 1). Four moored lines were deployed in a rhomboid formation on 1 August and were left in the water until 7 October, 2009 (Figure 1). Each mooring was anchored with approximately 270 kg of railroad rail sections and attached to a 45-55 m line with a surface float. These moorings allowed quick re-deployment of multiple sonobuoys in the array throughout the survey. After each sonobuoy deployment, observers at the Cairn Point Station (CPS) on Joint Base Elmendorf-Richardson monitored and recorded signals received from the sonobuoys in real-time. The location of the moorings was chosen based on proximity to the construction activity at the MTR Project, favorable bathymetric conditions, and relative safety from dredging and shipping operations. The time period of this study (late summer and early fall) was chosen to correspond with times when beluga whales are most frequently observed in the area (Rugh *et al.* 2000, Hobbs *et al.* 2005). The days and times of sonobuoy deployments and acoustic data collection were driven by tides and weather conditions, limiting the ability to launch the deployment boat, which could not be done during low tide.

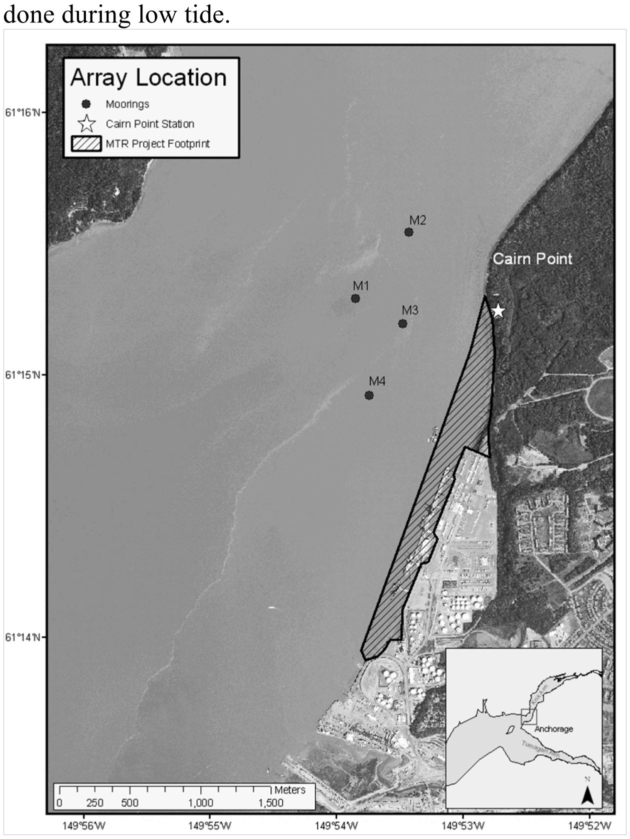

Figure 1. The location of the fixed array of 4 moored lines (black dots), placed between 400 and 700 m apart and approximately 600 m off Cairn Point. Passive sonobuoys were attached to the moorings during each day of acoustic monitoring. The Marine Terminal Redevelopment (MTR) Project footprint is outlined and crosshatched and Cairn Point Station is denoted by the star.

Passive sonobuoys are relatively inexpensive, expendable electronic devices that consist of a hydrophone, surface float, radio transmitter, antenna and salt-water battery. Omnidirectional sonobuoys, AN/SSQ-57B, used in this study have a calibrated broadband frequency response from 10-20,000 Hz, but can effectively detect signals up to 30 kHz (Horsley 1989). Signals received by the omnidirectional hydrophone are amplified and conducted up a cable to the radio transmitter and antenna, which are housed in the surface float.

Prior to each deployment, the sonobuoys were modified to withstand the high tidal current conditions of Knik Arm. Each sonobuoy was stripped from its original housing and placed in a plastic canister attached to a life ring. The life ring provided additional structural support and buoyancy against the fast moving currents, allowing the sonobuoy surface float to remain in a vertical position on the surface for sufficient signal transmission to the CPS. Twenty-seven m (90 ft) of cable and the clumped weight, preamplifier and hydrophone were passed through an opening on the bottom of the canister, which allowed the hydrophone and cable to suspend in the water column. A life ring with one sonobuoy was attached to each mooring float at the beginning of each day of acoustic observations. Previously deployed sonobuoys were collected each time before the deployment of new sonobuoys. The deployment location was recorded on each day of acoustic observations using a handheld Garmin GPS to verify the location of the moorings. The daily position of each mooring was compared to its deployment location to verify the moorings did not move during the study. Once deployed, the sonobuoys continuously transmitted their radio signal to the observers at the CPS until scuttling 8-10 h later. In the case of a non-operational sonobuoy, the deployment team immediately recovered the failed sonobuoy and deployed another one. Due to restrictions in the ability to launch a boat for sonobuoy deployment, most data collection started on the slack high tide and proceeded during the ebb flow.

Two omnidirectional Diamond D130J Super Discone antennae were mounted on the observational platform at the CPS to receive radio signals from the sonobuoys. A set of custom electronics and software was used to record and analyze the acoustic data. The antennae passed the signals to four software-controlled ICOM scanner radio receivers (IC-PCR 100 or IC-PCR1500 models), each tuned to receive individual FM signals transmitted by the sonobuoy array. Each radio was connected to a computer, which was connected to a MOTU Traveler mk2 that acquired the analog signal and provided a digitized output to another computer running the software program *Ishmael* (Mellinger 2001). Sample rates were initially adjusted to test electronics' capability and maximize recording capacity. On 3 August, data were sampled at 44 kHz, from 4-18 August the sampling rate was 48 kHz and from 20 August-30 September the sampling rate was 88.2 kHz. Data were saved as .WAV files.

During the daily acoustic observation period at CPS following sonobuoy deployments, construction and environmental data were collected and preliminary acoustic analysis was manually conducted. Data collected during the observation period included: deployment date, time, latitude, longitude and transmission channel for each sonobuoy as reported by the deployment team;

beginning and end of the acoustic observation period; start and end time of vocalizations (if detected), the species detected, and the channel(s) with vocalizations; environmental conditions; type of construction activity (*e.g.*, impact pile driving [IPD] or vibratory pile driving [VPD]); and duration of construction activity. Construction activities were defined as any anthropogenic activities associated with the construction of the MTR Project. All anthropogenic activities within the study area were also documented during daily observation efforts. Events were categorized as: no activity, IPD, VPD, dredging, in-water gravel fill placement, and aircraft and vessel activities. The duration of each activity was recorded. Data were entered into *Microsoft Excel* for *Windows*.

2.3 Data Analysis

Sonobuoy recordings were manually examined for beluga whale social vocalizations in real-time during data collection by listening to incoming recordings and visually scrutinizing scrolling spectrograms using the software program *Ishmael* (Mellinger 2001). In post-processing, an energy summation algorithm was used for the automatic detection of echolocation clicks. An energy detector was selected as an automatic detection method due to the short duration and broadband frequency of beluga whale clicks. To reduce the number of false detections, the ratio between the energy in the frequency band of interest (*i.e.* echolocation click) and that in an adjacent band of noise not containing the sound of interest was used. The frequency band used for the calculation of signal energy was 23-25 kHz, which was compared to the energy in the adjacent "noise" frequency band from 18-20 kHz. Due to the initial variation in sampling rate from 3-18 August, the energy summation parameters were adjusted to account for the difference in sampling rate (44 kHz and 48 kHz). Files from 3 August were manually scanned for echolocation clicks. Detections for 4-18 August were based on the energy ratio between the energy in the signal band from 23-23.9 kHz and the noise band from 15-18 kHz. When *Ishmael* signaled a detection, 2 s of the signal before and after the detection were saved into an individual .WAV file. Each file was visually verified for the presence of beluga whale echolocation clicks and false detections were removed from subsequent analysis.

Long-term spectral averages (LTSAs; Wiggins and Hildebrand 2007, Wiggins *et al.* 2010), were used to manually review the data for beluga social vocalizations and to determine times with and without construction activity (Figure 2). LTSAs were calculated with 10 s time bins and 500 Hz frequency resolution from the original .WAV files using *Triton*, a *MatLab* (MathWorks, Natick, MA) based customized sound analysis program developed by Wiggins *et al.* (2010). Only data where clicks were detected were used in the analysis on the effect of noise on echolocations. Each LTSA was manually scanned for the start and end of construction activity. Manual classification, rather than a more objective, automated classification was necessary because of the constantly varying effects of tides and currents on the overall sonobuoy signal strength, which was difficult to quantify and implement in an automatic framework. All construction activities (IPD, VPD, dredging) were pooled because they frequently overlapped and were not easily distinguishable in the LTSA. Gravel fill did not take place during the study, and therefore, was not included in the analysis. Times when pile driving (IPD or VPD) or dredging took place were considered time periods "with" construction activity. All other time periods were considered "without" construction activity. Although time periods without construction activity may have included other sources of anthropogenic noises such as air- or watercraft, they were considered control conditions because they were unaffiliated with construction activities. Construction activity had to continue for > 5 min in order to classify the time period as "with" construction activity. The total time with and without construction activity was calculated for each day of observation.

The detected hourly click rate during time periods with and without construction was calculated for each day of observations. To avoid counting the same click twice, only clicks from the sonobuoy with the longest recording were counted if more than one sonobuoy detected clicks on a particular day. An independent samples t-test was used to determine if there was a statistical difference in the rate of detected beluga whale clicks during periods with and without construction activity. The alpha level was set at $P < 0.05$.

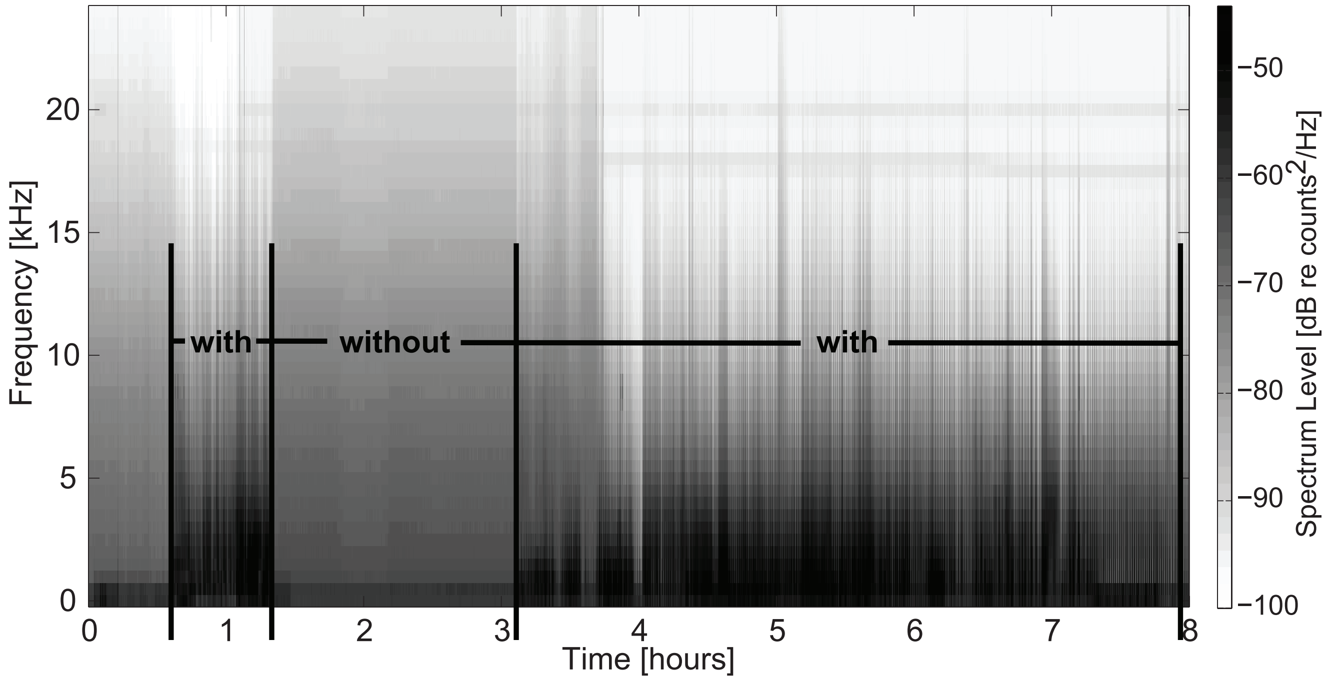

Figure 2. A long-term spectral average (LTSA) for 20 August 2009. The LTSA provides an overall picture of acoustic activity at the Marine Terminal Redevelopment Project on a daily basis. Example times "with" and "without" construction activity are marked.

3. RESULTS

Acoustic observations were conducted for more than 148 h over 20 d (mean of 7:25 ± 0:29 h of observation/d) in August and September 2009. Eighty-six sonobuoys were deployed during the study, 8 of which failed (failure rate 9.3 %). A total of 373 h of recordings were collected from all moorings. The VHF signal reception from sonobuoys varied with tidal stage. Occasionally, a signal from a sonobuoy was lost during high flood or ebb tides because the sonobuoy transmitter was submerged. The signal resumed once the sonobuoy resurfaced after approximately 20-60 min. During the recovery of sonobuoys in subsequent days, the hydrophone was often detached from the sonobuoy cable, likely due to the fast moving currents. Occasionally, this resulted in abbreviated daily sampling effort; however, more often the hydrophone detached after the daily sampling period ended.

Echolocation clicks were frequently produced by beluga whales in the vicinity of the MTR Project, but no other types of vocalizations (*e.g.*, whistles or other social signals) were detected with the sonobuoy array. A total of 63,392 clicks were detected during 14 d (out of 20) of the passive acoustic study, although some of those clicks were likely the same clicks detected on multiple sonobuoys in the array. The false detection rate of the automated detector was 35.5 %. Most of the acoustic energy received from beluga whale clicks recorded near the MTR Project construction site was above 15 kHz. Due to the sample rate, the full frequency range and the frequency of peak energy of clicks could not be observed. Beluga whale clicks were detected most commonly on mooring M1, the westernmost mooring.

Construction activity took place approximately 76 % of the time during the 14 d beluga whale clicks were detected, resulting in a total of approximately 71 h of recordings with and approximately 22 h without construction activity (Table 1). The detected click rate was higher without (429 detected clicks/h) than with (291 detected clicks/h) construction activity; however, the difference was not significant ($t_{(24)} = -0.56$, $P = 0.58$; Figure 3).

4. DISCUSSION

4.1 Effects of Construction Noise on Beluga Vocalizations

Construction activity took place during the majority of the acoustic survey (3/4 of the time). While no beluga whistles and noisy vocalizations were detected during the survey, it is possible that persistent noise associated with construction activity at the MTR Project masked beluga vocalizations. The frequency band of noise associated with activity near the MTR Project was generally below 10 kHz; however, the frequency band recorded from IPD extended to 20 kHz. Majority of the beluga whale whistles and noisy vocalizations are within the frequency band taken up by the construction activity noise (Richardson *et al.* 1995). VPD or dredging, in particular, could potentially mask beluga whale vocalizations because in addition to frequency overlap, they are also longer in duration.

Alternatively, to avoid interference from continuous construction noise, beluga whales may not use whistles or noisy vocalizations when they are near the MTR Project. Beluga whales may change their behavior to avoid masking from the construction noise or the construction noise may deter them from engaging in social activities when they are in the vicinity of the MTR Project. Therefore, behavioral changes or the lack of social activity in general could also explain the absence of whistles or noisy vocalizations in the study area.

Table 1. Sonobuoy sampling effort, total time, total number of detected echolocation clicks and detected hourly click rate with and without construction activity during the 14 d beluga whale clicks were detected.

Date	Sonobuoy Sampling Effort (hh:mm)	Total Time WITH (hh:mm)	Total Time WITHOUT (hh:mm)	No. of Clicks WITH[a]	No. of Clicks WITHOUT[b]	Detected Click Rate WITH (clicks/h)	Detected Click Rate WITHOUT (clicks/h)
4-Aug-09	3:46	3:46	0:00	29	−	8	−
13-Aug-09	8:17	8:17	0:00	1,283	−	155	−
18-Aug-09	7:25	4:07	3:18	31	0	8	0
20-Aug-09	7:36	5:56	1:40	10	0	2	0
22-Aug-09	6:48	3:49	2:59	4,380	4,239	1,147	1,422
25-Aug-09	5:11	3:12	1:59	14	7	4	4
1-Sep-09	6:36	3:54	2:42	185	1,182	47	438
4-Sep-09	6:58	5:20	1:38	134	43	25	26
8-Sep-09	3:41	2:20	1:21	61	36	26	27
10-Sep-09	6:10	5:46	0:24	1,094	0	190	0
20-Sep-09	4:58	3:12	1:46	400	177	125	100
23-Sep-09	7:52	6:59	0:53	5,775	481	827	547
25-Sep-09	8:47	7:28	1:19	630	155	84	117
27-Sep-09	9:10	7:05	2:05	10,109	5,122	1,428	2,463
Total	93:15:00	71:11:00	22:04:00	24,135	11,442	291[c]	429[c]

[a] The number of clicks used in the analysis for each day corresponds to the total number of clicks detected on the sonobuoy that had the longest recording during the respective day.
[b] On 4 and 13 August, there were no recorded periods without construction activity; therefore, "−" represents that no clicks could be detected "without" construction activity on those days.
[c] These values are the mean detected click rates.

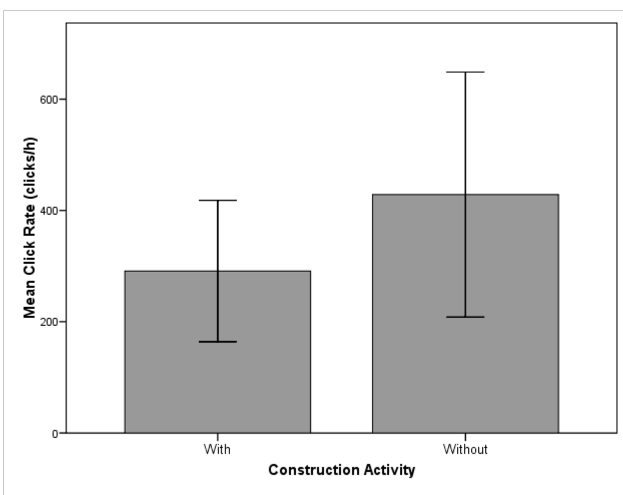

Figure 3. Detected hourly beluga whale echolocation click rates with and without construction activity near the Marine Terminal Redevelopment (MTR) Project during the 14 d beluga whale clicks were detected between 1 August and 30 September, 2009.

Conversely, because the type of vocalizations used by beluga whales is likely determined by the behavioral state of the whale (Sjare and Smith 1986b, Au *et al.* 1985, Panova *et al.* 2012), they may be engaged primarily in echolocation (Richardson *et al.* 1995) as they travel through the study area (Cornick and Kendall 2008*a*, *b*, Cornick *et al.* 2010). Echolocation could be particularly important to beluga whales for navigating in the turbid waters of Cook Inlet where whales cannot rely on eyesight for navigation. As a result, echolocation could be the primary type of vocalization utilized by beluga whales when traveling through the study area. This final explanation is consistent with the fact that we recorded no whistles even during periods without construction; however, a more detailed study of the association of behavioral states and call production would be needed to test that hypothesis.

In addition to the absence of whistles and noisy vocalizations used by beluga whales in the study area, click rate was higher without construction activity. Although the difference was not significant, we had a relatively small sample size and a large variance in the number of detected clicks between days. The lower detected click rate with construction activity could be another possible indication of a reduction in vocal activity by the beluga whales in the study area during construction. Masking is not likely a concern when producing echolocation clicks because most of the acoustic energy in the beluga whale click extended above the frequency band recorded for the construction activity at the MTR Project. However, it is possible beluga whales may shift the frequency in echolocation clicks in response to construction (Au *et al.* 1985), producing clicks we did not detect, thus the observed reduced click rate could result from our relatively low sample rate. Alternatively, the reduction in click rate with construction activity could indicate a reduction in the number of beluga whales in the area. Similar responses have been observed for harbor porpoises (*Phocoena phocoena*) during the installation of offshore wind turbines, suggesting that the reduction in echolocation clicks was a result of the reduction in the number of harbor porpoises present in the area (Carstensen *et al.* 2006, Brant *et al.* 2011). A reduction of beluga whales in the study area could suggest avoidance of the area near the construction site.

Beluga whales were not equally detected across our array, but there was a spatial pattern to their detections. The echolocation clicks were more commonly detected offshore near the deep channel in Knik Arm (moorings M1 and M2) rather than adjacent to the shoreline (M3 and M4). This may indicate beluga whales use areas offshore more frequently than originally believed (Moore *et al.* 2000). Over the past several years, the visual observers for the MTR project (Scientific Marine Mammal Observers [MMO]), observed beluga whales more often along the shoreline and adjacent to the MTR Project footprint than offshore (Markowitz and McGuire 2007, Cornick and Kendall 2008*a*, *b*, Cornick *et al.* 2010). However, sightings are directly related to the location and elevation of the observation station from the beluga whales, therefore, beluga whales at greater distances from the observation station are more likely missed (Buckland *et al.* 2001, Markowitz and McGuire 2007). If acoustic detections were primarily west of the moorings, belugas may be using a more energetically efficient method of travel by taking advantage of the fast-moving current in the deep channel located in the center of Knik Arm (Smith *et al.* 2005). Alternatively, the location of acoustically detected beluga whales near the central channel of Knik Arm may indicate disturbance or avoidance from the nearshore construction activity.

Though the noise from the construction activity may cause behavioral disturbance to the beluga whales, they may choose to travel through the area despite the consequences because the habitat beyond the construction area is extremely important to their existence (Goetz *et al.* 2012, NMFS 2011). Knik Arm is designated critical habitat for the Cook Inlet beluga whale (NMFS 2011). The construction area, located at the entrance of Knik Arm has been exempt from the critical habitat designation (NMFS 2011). Beluga whales must either travel through or adjacent to the construction area to get to the upper reaches of the Arm. Critical habitat provides areas for summer foraging, calving, molting, and predator avoidance as well as known fall and wintering areas (NMFS 2011). Beluga whales have been documented year round in Knik Arm (Hobbs *et al.* 2005), using it as a known summer foraging area (NMFS 2011), as well as potential nursery and predator avoidance area (Huntington 2000, NMFS 2011). The MTR Project Scientific MMOs documented a decrease in the total time beluga whales were in view of visual observers within the study area since the MTR Project began (Cornick and Kendall 2008*a*, *b*, Cornick *et al.* 2010, Kendall 2010). However, if disturbance from the construction activity outweighed the benefits of traveling through the construction area to important habitat, avoidance or displacement from the area could occur (Goetz *et al.* 2012). The use of the central channel observed during the acoustic survey and the increased use of the western shoreline near Port MacKenzie documented by the Scientific MMOs (Cornick and Kendall 2008*a*, *b*, Cornick *et al.* 2010, Kendall 2010) imply possible avoidance of the construction area by beluga whales.

Carstensen *et al.* (2006) observed harbor porpoises returned to a construction area between pile driving events; however, the return time often took several days. Brandt *et al.* (2011) observed the reduction of harbor porpoise activity and density at a construction area over the entire 5 mo period pile driving took place. They also documented increased use of areas 20 km away from the construction site. Considering that the Cook Inlet beluga whale's range has been contracting over the past three decades (NMFS 2008*b*, Rugh *et al.* 2010), avoidance or displacement of the Cook Inlet beluga whale from the upper reaches of Knik Arm could be detrimental to the population's recovery.

4.2. Study Limitations and Challenges

In general, passive acoustic monitoring offers numerous advantages over visual surveys of cetaceans (Mellinger *et al.* 2007), but there are numerous challenges associated with studying beluga whales in Cook Inlet using passive acoustics due to environmental and technological constraints. First of all, the Knik Arm of Cook Inlet is a difficult environment to conduct any type of passive acoustic monitoring. Bottom-mounted autonomous recorders, more typically used for passive acoustic monitoring, were not chosen for this study because of the concerns that the heavy sediment load carried in the water would cover the instrument and make it impossible to retrieve. Also, there was a high potential for damage to the instruments due to the strong tides and currents carrying debris. The tides and currents, with speeds over 7 knots (Smith *et al.* 2005), occasionally inhibited signal transmission or damaged the equipment used during this study; however, the relative inexpensiveness of sonobuoys, enabling repeated deployment after any fouling event, made them the most practical choice for this study.

Sonobuoy deployments were conducted in an array formation to enable sound source localization of beluga whale social vocalizations. However, since we did not record any social vocalizations, and echolocation clicks propagated over much shorter distance (approximately 400 m) and thus were never detected on three sonobuoys at the same time, localization was not possible. The use of sonobuoys, also limited our recording bandwidth. Beluga whale clicks extend well above the frequency response of the sonobuoys (Au *et al.* 1985) and we were not able to detect echolocation clicks above 30 kHz, which limited the number and types of clicks we detected.

Extreme tides were another environmentally constraining condition, as they limited the ability to launch the boat to deploy sonobuoys. The tidal constraints may have created a bias in the data because beluga whales are highly dependent on the tidal stages for traveling throughout Cook Inlet (Moore *et al.* 2000) and our data were mostly collected around high tides.

Surprisingly, flow noise was not an issue during our study considering the strong currents in the area; construction noise, on the other hand, was the most prevalent source of underwater sound. Background noise levels measured in the area range from 113-133 dB re 1 μPa (Blackwell and Greene 2002, Blackwell 2005, Širović and Kendall. 2009). Sound levels measured during pile driving activity (IPD or VPD) ranged from 162-196.9 dB re 1 μPa with varying distance from the source and pile size (Blackwell 2005, Širović and Kendall 2009). Dredging sound levels measured in the area at 156.9 dB re 1 μPa at 30 m (SFS 2009). Noise associated with construction was nearly continuous at times. If pile driving was not taking place, dredging occurred or vice versa. Because of frequent overlaps, the construction data were pooled. Periods without construction activity mostly consisted of only brief moments (~5 min) when construction ceased, therefore, most of the times considered "without" construction activity were simply prolonged breaks in construction activity.

While our recordings indicate beluga whales may not be using whistles and noisy vocalizations when traveling near the MTR Project, they may decrease click rates or otherwise modify their echolocation clicks in the presence of construction noise, or there may be a decrease in the number of beluga whales traveling through the area. Of course, it does not necessarily mean beluga whales were not present during times when we did not detect beluga vocalizations; they may just be silent as they move through the area. To fully understand the impacts of noise associated with construction activity on the Cook Inlet beluga whale, we need to understand Cook Inlet beluga whale vocalizations under different behavioral states. Since cetacean detection rates vary between acoustic and visual survey methods (Clark *et al.* 1985, McDonald and Moore 2002, Širović *et al.* 2006, O'Boisseau *et al.* 2007, Kimura *et al.* 2009), it is important to integrate both survey methods in order to effectively monitor belugas in harsh environments such as Knik Arm. By improving our understanding of the behavioral context of calling, we may also increase our ability to evaluate the impact of noise on belugas and perhaps improve our understanding of factors causing the population decline.

4.3 Conclusions

There were four major findings and issues of importance in this study. 1) No beluga whale whistles or noisy vocalizations were detected in the vicinity of the MTR Project during the study, which is unusual behavior for highly vocal beluga whales (Schevill and Lawrence 1949). 2) We observed a decreasing trend in the hourly click rate between times without and with construction activity which may be an indication of disturbance. 3) There is limited information on construction impacts on beluga whales in particular and marine mammals in general. This study adds to the body of knowledge regarding construction impacts on this endangered population. 4) Upper Cook Inlet is a major urban area that contains half of Alaska's population, yet it provides a very challenging environment for conducting research. There are many ongoing and upcoming coastal zone development projects in Upper Cook Inlet, especially in Knik Arm, where beluga whales are frequently observed. For successful management of this population as well as continuing urban development, it is imperative to use all available sources of information to increase our understanding of the impacts from coastal zone development and the associated noise on this population.

ACKNOWLEDGEMENTS

We would like to thank the US Department of Transportation Maritime Administration, the POA, ICRC and the At-Sea Processors Association for funding this project. A special thanks to Lyn Dokoozian, Laurie Butler and Sam Cunard at ICRC for logistical support. Thanks to John Hildebrand at the Scripps Institution of Oceanography for providing the sonobuoys. Thanks to all the acoustic observers at APU for field support throughout the project. Thanks to Marie Roch for helping translate the abstract to French. Leslie Cornick (APU)

and Mike Williams (NMFS) provided valuable input on this manuscript which was part of LSK's Master's thesis.

REFERENCES

Angiel, N. M. 1997. The vocal repertoire of the beluga whale in Bristol Bay, Alaska. MS Thesis, University of Washington, Seattle, WA.

Au, W. W. L., D. A. Carder, R. H. Penner and B. L. Scronce. 1985. Demonstration of adaptation in beluga whale echolocation signals. Journal of Acoustic Society of America 77: 726-730.

Au, W. W. L, R. H. Penner and C. W. Turl. 1987. Propagation of beluga echolocation signals. Journal of Acoustic Society of America 82: 807-813.

Awbrey, F. T., J. A. Thomas, R.A. Kastelein. 1988. Low-frequency underwater hearing sensitivity in belugas, *Delphinapterus leucas*. Journal of Acoustic Society of America 84: 2273-2275.

Barlow, J. and B. Taylor. 2005. Estimates of sperm whale abundance in the northeastern temperate pacific from a combined acoustic and visual survey. Marine Mammal Science 21:429-445.

Belikov, R. A., and V. M. Bel'kovich. 2006. High-pitched tonal signals of beluga whales (*Delphinapterus leucas*) in a summering assemblage off Solovetskii Island in the White Sea. Acoustical Physics 52:125-131.

Belikov, R. A., and V. M. Bel'kovich. 2007. Whistles of beluga whales in the reproductive gathering off Solovetskii Island in the White Sea. Acoustical Physics 53:528-534.

Belikov, R. A., and V. M. Bel'kovich. 2008. Communicative pulsed signals of beluga whales in the reproductive gathering off Solovetskii Island in the White Sea. Acoustical Physics 54:115-123.

Blackwell, S.B. and C.R. Greene Jr. 2002. Acoustic measurements in Cook Inlet, Alaska during August 2001. Greeneridge Report 271-2. Report from Greeneridge Sciences, Inc., Santa Barbara for National Marine Fisheries Service, Anchorage, Alaska. 41 p.

Blackwell, S.B. 2005. Underwater measurements of pile driving sounds during Port MacKenzie Dock Modifications 13-16 August 2004. Report 328-1. Report from Greeneridge Science, Inc., Goleta, CA, and LGL Alaska Research Associates, Inc. Anchorage AK, in association with HDR Alaska, Inc., for Knik Arm Bridge and Toll Authority, Anchorage, AK, Department of Transportation and Public Facilities, Anchorage, AK, and Federal Highway Administration, Juneau, AK. 33p.

Blane, J. M. and R. Jaakson. 1994. The impact of ecotourism boats on the St. Lawrence beluga whales. Environmental Conservation 21(3): 267-269.

Brandt, M. J., A. Diederichs, K. Betke and G. Nehls. 2011. Responses of harbor porpoise to pile driving at Horn Rev II offshore wind farm in the Danish North Sea. Marine Ecology Progress Series. 421:205-216.

Buckland, S. T., D. R. Anderson, K. P. Burnham, J. L. Laake, D. L. Borchers and L. Thomas. 2001. Introduction to distance sampling-Estimating abundance of biological populations: Oxford University Press.

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). Marine Ecology Progress Series 321:295-308.

Chalmnitsky, E. G. and S. H. Ferguson. 2012. Beluga whale, *Delphinapterus leucas*, vocalizations from the Churchill River, Manitoba, Canada. Journal of the Acoustical Society of America 131: 4821-4835.

Clark, C. W., W. T. Ellison and K. Beeman. 1985. Acoustic tracking of migrating bowhead whales. Oceans '86 Conference Record: Science-Engineering-Adventure: Conference 86:341-346.

Clark, C. W. and W. T. Ellison. 1988. Numbers and distributions of bowhead whales, *Balaena mysticetus*, based on the 1985 acoustic study off Pt. Barrow, Alaska. Report for International Whaling Commission 38: 365-370.

Cornick, L. A. and L. S. Kendall. 2008*a*. Distribution, habitat use, and behavior of Cook Inlet beluga whales in Knik Arm, Fall 2007. Prepared for Integrated Concepts and Research Corporation. Prepared by Alaska Pacific University. Anchorage, Alaska. 29 pp.

Cornick, L. A. and L. S. Kendall. 2008*b*. 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. Prepared for U.S. Department of Transportation Maritime Administration, Port of Anchorage and Integrated Concepts and Research Corporation. Prepared by Alaska Pacific University. Anchorage, Alaska. 29 pp.

Cornick, L. A., L. S. Kendall and L. 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. Scientific Marine Mammal Monitoring Program 2009 Annual Report. Prepared for U.S. Department of Transportation Maritime Administration, the Port of Anchorage and Integrated Concepts and Research Corporation. Prepared by Alaska Pacific University. Anchorage, Alaska. 40 pp.

Croll, D. A., C. W. Clark, J. Calambokidis, W. T. Ellison and B.R. Tershy. 2001. Effects of anthropogenic low-freuency noise on foraging ecology *Balaenoptera* whales. Animal Conservation 4:13-27.

Erbe, C. and D. M. Farmer. 2000. Zones of impact around icebreakers affecting beluga whales in the Beaufort Sea. Journal of Acoustic Society of America 108:1332-1340.

Faucher, A. 1998. The vocal repertoire of the St. Lawrence Estuary population of beluga whale (*Delphinapterus leucas*) and it behavior, social and environmental contexts. MS Thesis, Dalhousie University, Halifax, Nova Scotia.

Frantzis, A. (1998) Does acoustic testing strand whale? Nature 392: 29.

Goetz, K. T., R. A. Montgomery, J. M. Ver Hoef, R. C. Hobbs and D. S. Johnson. 2012. Identifying essential summer habitat of the endangered beluga whales *Delphinapterus leucas* in Cook Inlet, Alaska. Endangered Species Research 16: 135-147.

Greene Jr., C. R., M W. McLennan, R. G. Norman, T. L. McDonald, R. S. Jakubaczak and W. J. Richardson. 2004. Directional frequency and recording (DIFAR) sensors in seafloor recorders to locate calling bowhead whales during their fall migration. Journal of Acoustic Society of America 116: 799-813.

Hobbs, R. C., K. L. Laidre, D. J. Vos, B. A. Mahoney and M. Eagleton. 2005. Movement and area use of belugas, *Delphinapterus leucas*, in subarctic Alaskan estuary. Arctic. 58: 331-340.

Hobbs, R. C., K. E. W. Shelden, D. J. Rugh and S. Norman. 2008. 2008 status review and extinction risk assessment of Cook Inlet belugas (*Delphinapterus leucas*). AFSC Processed Rep. 2008-002, 116 p. Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA, Seattle, WA.

Hobbs, R.C., C.L. Sims, and K.E.W. Shelden. 2012. Estimated abundance of belugas whales in Cook Inlet, Alaska, from aerial surveys conducted in June 2012. NMFS, NMML Unpublished Report. 7pp.

Horsley, L. E. 1989. Modification and deployment techniques for hand-deployed arctic long-life sonobuoys. IEEE Journal of Oceanic Engineering 14: 211-220.

Huntington, H. P. 2000. Traditional knowledge of the ecology of the belugas*,* *Delphinapterus leucas*, in Cook Inlet, Alaska. Marine Fisheries Review 62(3): 134-140.

Jepson, P. D., M. Arbelo, R. Deaville, *et al.* 2003. Gas-bubble lesions in stranded ceataceans – was sonar responsible for a spate of whale deaths after an Atlantic military exercise? Nature 425: 575-576.

Johnson, C. S., M. W. McManus and D. Skaar. 1989. Masked tonal hearing thresholds in beluga whale. Journal of Acoustic Society of America 85:2651-2654.

Karlsen, J. D., A. Bisther, C. Lydersen, T. Haug and K. M. Kovacs. 2002. Summer vocalizations of adult male white whales (*Delphinapterus leucas*) in Svalbard, Norway. Polar Biology 25:808-817.

Kendall, L. S. 2010. Behavior and distribution of the Cook Inlet beluga whales (*Delphinapterus leucas*) pre- and during pile driving activity at the Port of Anchorage Marine Terminal Redevelopment Project, 2005-2009. MS Thesis. Alaska Pacific University. Anchorage, Alaska. 88 pp.

Kimura, S., T. Akamatsu, K. Wang, D. Wang, S. Li, S. Dong and N. Arai. 2009. Comparison of stationary acoustic monitoring and visual observation of finless porpoises. Journal of Acoustic Society of America 125: 547-553.

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. Marine Fisheries Review 6 (3):27-36.

Lammers, M. O. and M. Castellote. 2009. The beluga whale produces two pulses to form its sonar signal. Biology Letters 5: 297-301.

Laurinolli, M. H., A. E. Hay, F. Desharnais and C. T. Taggart. 2003. Localization of North Atlantic right whale sounds in the Bay of Fundy using a sonobuoy array. Marine Mammal Science 19: 708-723.

Lesage, V., C. Barrette, M. C. S. Kingsley and B. L. Sjare. 1999. The effect of vessel noise on the vocal behavior of belugas in the St. Lawrence River estuary, Canada. Marine Mammal Science 15: 65-84.

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.

Markowitz, T. M. and T. L. McGuire. 2007. Temporal-spatial distribution, movements and behavior of beluga whales at the Port of Anchorage, Alaska. Report prepared by LGL Alaska Research, Inc., Anchorage, AK, for Integrated Concepts and Research Corporation and the U.S. Department of Transportation Maritime Administration. 93 pp.

McDonald, M. A. and S. E. Moore. 2002. Calls recorded from North Pacific right whales (*Eubalaena japonica*). Journal of Cetacean Research and Management 4: 261-266.

McDonald, M. A., J. A. Hildebrand and S. Wiggins. 2006. Increases in deep ocean ambient noise in the Northeast Pacific west of San Nicolas Island, California. Journal of Acoustic Society of America 120: 711-718.

Mellinger, D. K. 2001. Ishmael 1.0 User's Guide. NOAA Tech. Memo. OAR-PMEL-120, NOAA Pacific Marine Environmental Laboratory, Seattle, WA 26 pp.

Mellinger, D. K., K. M. Stafford, S. E. Moore, R. P. Dziak and H. Matsumoto. 2007. An overview of fixed passive acoustic observation methods for cetaceans. Oceanography 20: 36-45.

Moore, S. E., K. E. W. Shelden, L. K. Litzky, B. A. Mahoney and D. J. Rugh. 2000. Beluga, *Delphinapterus leucas*, Habitat Associations in Cook Inlet, Alaska. Marine Fisheries Review 62(3): 60-80.

National Marine Fisheries Service (NMFS). 2008*a*. Endangered and Threatened Species; Endangered Status for the Cook Inlet Beluga Whale. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service. 50 CFR Part 224. 73(205): 62919-62930 (73 FR 62919).

National Marine Fisheries Service (NMFS). 2008*b*. Conservation Plan for the Cook Inlet beluga whale (*Delphinapterus leucas*). National Marine Fisheries Service, Juneau, Alaska. 122 pp.

National Marine Fisheries Service (NMFS) (2008c) Small Takes of Marine Mammals Incidental to Specified Activities; Port of Anchorage Marine Terminal Redevelopment Project, Anchorage, Alaska. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service. 73(53): 14443-14453 (73 FR 14443).

National Marine Fisheries Service (NMFS). 2011. Endangered and Threatened Species: Designation of Critical Habitat for Cook Inlet Beluga Whale. 50 CFR Part 226. 76(69): 20180-20214 (76 FR 20180).

National Oceanic and Atmospheric Administration (NOAA) Fisheries Service. 2011. NOAA Fisheries News Release. Alaska Regional Office. National Marine Fisheries Service. Juneau, AK. Available from: < <http://www.fakr.noaa.gov/newsreleases/2012/cibelugas010912.htm> (accessed March 27, 2012).

National Research Council (NRC). 2003. Ocean Noise and Marine Mammals: National Academies Press, Washington, D.C.

Nowacek, D. P., L. H. Thorne, D. W. Johnson and P. L. Tyack. 2007. Responses of cetaceans to anthropogenic noise. Marine Mammal Review 37 (2): 81-115.

O'Boisseau, J. M., D. Gillespie, C. Lacey, A. Moscrop and N. El Ouamari. 2007. A visual and acoustic survey for harbor porpoise off North-West Africa: further evidence of a discrete population. African Journal of Marine Science 29(3): 403-410.

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. In: Molecular Ecology 6: 955-970.

O'Corry-Crowe, G. M., 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, p.53-64. In C. J. Pfieffer (editor), Molecular and cell biology of marine mammals. Malabar, Florida: Krieger Publishing Company.

Panova, E. M., R. A. Belikov, A. V. Agafonov and V. M. Bel'kovich. 2012. The relationship between the behavioral activity and the underwater vocalization of the beluga whale (*Delphinapterus leucas*). Oceanology 52: 79-87.

Patenaude, N., 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. Marine Mammal Science 18: 309-335.

Richardson, W. J., C. R. Greene Jr., C. I. Malme and D. H. Thomson. 1995. Marine Mammals and Noise: Academic Press.

Rugh, D. J., K. E. W. Shelden and B. A. Mahoney. 2000. Distribution of belugas, *Delphinapterus leucas*, in Cook Inlet, Alaska, during June/July 1993-2000. Marine Fisheries Review 62(3): 6-21.

Rugh, D. J., K. E. W. Shelden and R. C. Hobbs. 2010. Range contraction in a beluga whale population. Endangered Species Research 12: 69-75.

Scheifele, P. M., S. Andrew, R. A. Cooper, M. Darre, F. E. Musiek and L. Max. 2005. Indication of a Lombard vocal response in the St. Lawrence River beluga. Journal of Acoustic Society of America 117: 1486-1492.

Schevill, W. E. and B. Lawrence. 1949. Listening to the white whale porpoise, *Delphinapterus leucas*. Science 109: 143-144.

Scientific Fishery Systems, Inc. (SFS). 2009. 2008 Underwater Nose Survey during Construction Pile Driving at the Port of Anchorage Marine Terminal Redevelopment Project. Prepared by Scientific Fishery Systems, Inc. in support of Alaska Native Technologies, LLC., Anchorage, Alaska, prepared for the US Department of Transportation Maritime Administration, the Port of Anchorage and Integrated Concepts and Research Corporation, Anchorage, Alaska.

Širović, A., J. A. Hildebrand and D. Thiele. 2006. Baleen whales in the Scotia Sea during January and February 2003. Journal of Cetacean Research and Management 8: 161–171.

Širović, A. and L.S. Kendall. 2009. Passive acoustic monitoring of beluga whales. Analysis Report. Prepared by Alaska Pacific University, Anchorage, Alaska, prepared for the US Department of Transportation Maritime Administration, Port of Anchorage and Integrated Concepts and Research Corporation, Anchorage, Alaska.

Smith, O. P., A. Khokholov and M. Zieserl. 2005. Water property, sediment, tide, and current measurement analyses in the vicinity of the proposed Knik Arm Bridge. Contract report for URS Corporation and HDR Alaska, Inc., Anchorage, AK. Prepared for Knik Arm Bridge and Toll Authority, the Alaska Department of Transportation and Public Facilities and the Federal Highway Administration, Anchorage, Alaska.

Sjare, B. L. and T. G. Smith. 1986*a*. The vocal repertoire of white whales, *Delphinapterus leucas*, summering in Cunningham Inlet, Northwest Territories. Canadian Journal of Zoology 64: 407-415

Sjare, B. L. and T. G. Smith. 1986*b*. The relationship between behavioral activity and underwater vocalizations of the white whale, *Delphinapterus leucas*. Canadian Journal of Zoology 64: 2824-2831.

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 and Carribean Research 20: 75-80.

Turl, C. W. and R. H. Penner. 1989. Differences in echolocation click patterns of the beluga whale (*Delphinapterus leucas*) and the bottlenose dolphin (Tursiops trucatus). Journal of Acoustic Society of America 86: 497-502.

Turl, C. W. 1990. Echolocation abilities of the beluga whale, *Delphinapterus leucas*: a review and comparison with the bottlenose dolphin, Tursiops trucantus. In: T Smith, D St. Aubin, and J Gerci [ed.] Advances in research on the beluga whale *Delphinapterus leucas*. Canadian Bulletin of Fisheries and Aquatic Science 224:119-128.

Wiggins, S. and J. A. Hildebrand. 2007. High-Frequency Acoustic Recording Package (HARP) for broad-band, long-term marine mammal monitoring. UT07+SSC07, Tokyo, Japan, 17-20 April 2007. 551-557.

Wiggins, S., M. Roch, J. A. Hildebrand. 2010. TRITON software package: analyzing large passive acoustic monitoring data sets using MATLAB. Journal of Acoustic Society of America 128: 2299.

Würsig, B., C. R. Greene Jr. and T. A. Jefferson. 2000. Development of an air bubble curtain to reduce underwater noise of percussive piling. Marine Environmental Research 49:79-93.


SVS
SOUND & VIBRATION SOLUTIONS CANADA Inc.
Dynamic Products from Industry Leaders
p. 519-853-4495
w. svscanada.ca
e. andy@svscanada.ca
The most complete Sound Level Meter on the market today!
Specialists in Acoustic Measurement Instrumentation
Integrated Solutions from World Leaders
Precision Measurement Microphones
Intensity Probes
Outdoor Microphones
Sound Level Meters Type 1
Ear Simulation Devices
Speech Simulation Devices
Calibrators
Array Microphones
Sound Quality
Sound Intensity
Sound Power
Room Acoustics
Noise Monitoring
Dynamic Signal Analyzers
Electro Dynamic Shaker Systems
Doppler Laser Optical Transducers
Laser Vibrometers
Multi-Channel Dynamic Analyzer/Recorder
Soundbook™
Designed for You:
2-4-8 Channel √
IEC conform √
PTB Aproved √
User friendly √
General purpose √
Tough (MIL) √
Reliable √
G.R.A.S.
SOUND & VIBRATION
CRYSTAL
instruments
Norsonic
SINUS
Messtechnik GmbH