Construction Impacts on the Cook Inlet Beluga Whale (*Delphinapterus leucas*) at the Port of Anchorage Marine Terminal Redevelopment Project

by

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MS Thesis

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Abstract

Cook Inlet beluga whales (*Delphinapterus leucas*) are geographically isolated and genetically distinct from the other US beluga stocks. They were recently listed as endangered under the US Endangered Species Act. Many factors are identified as potential threats to the Cook Inlet beluga whale population, including coastal zone development and anthropogenic noise. The Port of Anchorage (POA) Marine Terminal Redevelopment (MTR) Project, taking place in Knik Arm, Cook Inlet, involves several types of construction activities including dredging, gravel fill, and pile driving. In this study I investigated the impacts of construction activity on beluga whales using visual and acoustic observations. First, I examined the behavior and distribution of Cook Inlet beluga whales pre- (2005-2007) and during (2008-2009) pile driving activity at the MTR Project by investigating differences in the sighting duration of beluga whales, behavioral states, group size, group composition, group formation and beluga whale distribution within the study area. There were significant differences in sighting duration, behavior, group composition and group formation between pre- and during pile driving periods. There was no significant correlation between monthly sighting rates and pile driving rates. Additionally, beluga whales were most frequently observed along the eastern shoreline of the study area during both periods; however, sightings increased along the western shoreline near Port MacKenzie during pile driving activity. In the second part of the study, I focused on the effects of construction noise at the MTR Project on beluga whale vocal behavior by examining differences in the detected clicks rates during periods with and without construction activity. There was no significant difference in the detected click rate; however, the detected click rate was higher without construction activity. The results from this study indicate changes in beluga whale behavior in the presence of construction activity and possible avoidance of the area.

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Chapter I

Introduction

Beluga whales (*Delphinapterus leucas;* Pallas, 1776) are found throughout the arctic and subarctic regions of the Northern hemisphere, summering in coastal waters of estuaries and wintering in polynyas or in areas of shifting ice (Figure 1; 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 US waters: Beaufort Sea, eastern Chukchi Sea, eastern Bering Sea, Bristol Bay and Cook Inlet (Figure 2; Angliss and Allen 2009). The Cook Inlet population is geographically isolated from the other stocks by the Alaska Peninsula and is genetically distinct (O'Corry-Crowe *et al.* 1997, Laidre *et al*. 2000, O'Corry-Crowe *et al.* 2002, Angliss and Allen 2009). This population has the lowest abundance estimate of the five US stocks (Table 1) and was recently listed as endangered under the US Endangered Species Act (ESA; NMFS 2008a).

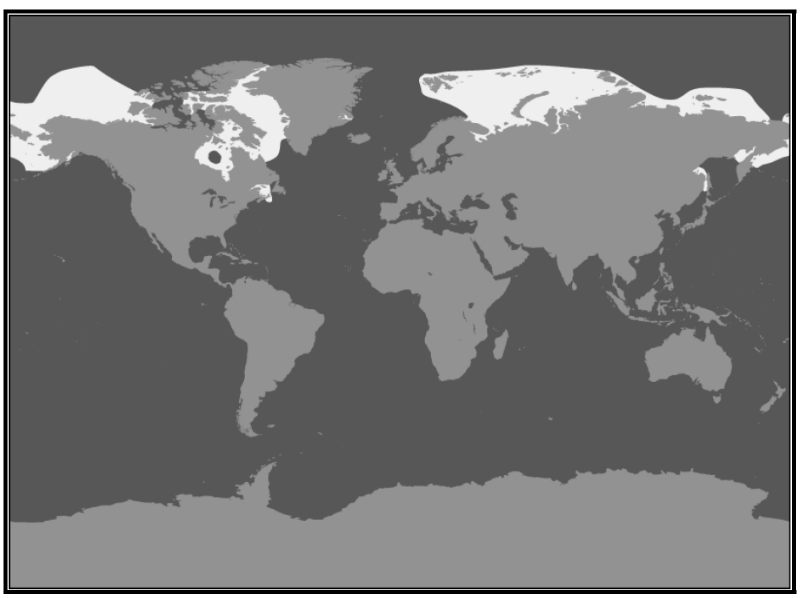

Figure 1. Worldwide beluga whale distribution (white). (Figure adapted from Whale and Dolphin Conservation Society 2010).

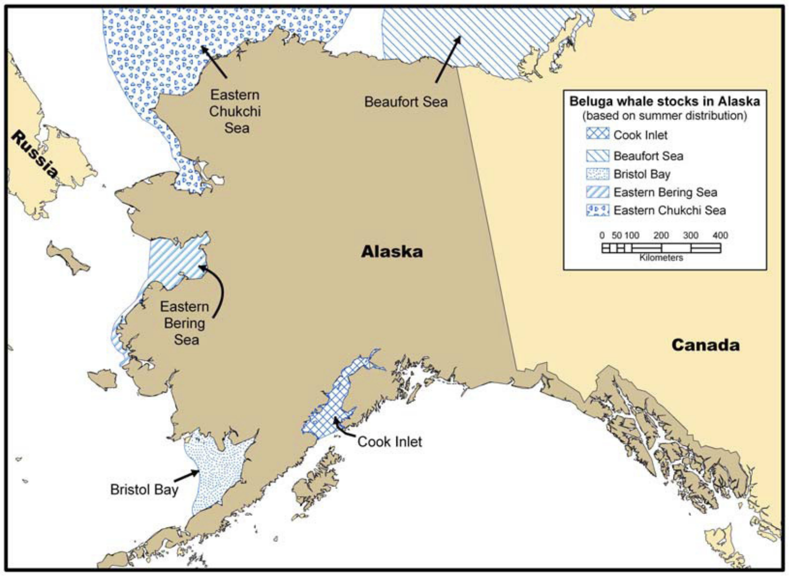

Figure 2. Distribution of beluga whales within US waters. (Figure credit: NMFS 2008b).

Table 1. Abundance estimates of the five beluga stocks found within U.S waters.

Population	Abundance Estimates[a]
Beaufort Sea	39,258
Eastern Chukchi Sea	3,710
Bering Sea	7,986
Bristol Bay	1,555
Cook Inlet	321

[a] Angliss and Allen 2009, Hobbs *et al.* 2009

Historically, the Cook Inlet beluga whale population was distributed throughout Cook Inlet, with occasional sightings in the Gulf of Alaska (Huntington 2000, Laidre *et al*. 2000, Rugh *et al*. 2000). Alaska Native hunters also observed beluga whales traveling up rivers (e.g., Beluga and Kenai Rivers; Figure 3) chasing prey (Huntington 2000). However, since the 1970s, the population has been declining and it is suggested that beluga whale distribution and habitat use has contracted to the upper reaches of Cook Inlet (Hobbs *et al.* 2005, Goetz *et al.* 2007, NMFS 2008b).

National Oceanic and Atmospheric Administration (NOAA) Fisheries Service describes the contraction of distribution and habitat use by Cook Inlet beluga whales in three phases

(Figure 3; NMFS 2008b, NMFS unpublished data). In the late 1970s, the center of the Cook Inlet beluga whale distribution was located between McArthur and Beluga Rivers with high concentrations along the shoreline between Drift and Susitna Rivers. In the 1990s, their central location shifted near the mouth of the Susitna River, with high concentrations between the Susitna Delta and the entrance to Knik Arm. The population center of beluga whales is now located between the Little Susitna River and Fire Island with high concentrations near the Sustina River and in Knik and Turnagain Arms (NMFS unpublished data). Beluga whales are no longer found in large numbers in the mid- and lower Cook Inlet (NMFS 2008b, NMFS unpublished data).

Although the distribution of beluga whales in Cook Inlet has contracted, beluga whale distribution within Cook Inlet continues to vary seasonally and tidally (Moore *et al.* 2000, Rugh *et al.* 2000, Hobbs *et al.* 2005, NMFS 2008b). During spring, beluga whales are regularly observed in Turnagain Arm, near the mouth of the Susitna River and in Knik Arm (Figure 4). In the summer, beluga whales are often observed near the Susitna Delta (Rugh *et al.* 2000, Hobbs *et al.* 2005, NMFS 2008b) and in late summer to late fall they travel between Knik Arm (Eagle River), Chickaloon Bay (Chickaloon River) and upper Turnagain Arm (Hobbs *et al.* 2005, NMFS 2008b, Cornick and Kendall 2008a, 2008b, Cornick *et al.* 2010). Winter distribution is not well understood; however, beluga whales are more dispersed and move offshore into the central areas of mid- and upper Cook Inlet (Hobbs *et al.* 2005). Tides strongly influence beluga whale movement and distribution within estuaries (Caron and Smith 1990, Smith *et al.* 1994, Moore *et al.* 2000). As with other beluga whale populations, beluga whales in Cook Inlet travel into the upper reaches of the inlet with flood tides and then leave with the ebb tides (Moore *et al.* 2000, Rugh *et al.* 2000).

The continued use of the upper reaches of Cook Inlet by beluga whales indicates the importance of this habitat. Beluga whales are known to have strong site fidelity, even after human disturbance such as hunting (Caron and Smith 1990). Site fidelity is demonstrated by the long distance seasonal migrations by many stocks (Caron and Smith 1990, NMFS 2008b). This site fidelity is likely related to foraging (Caron and Smith 1990). Although the Cook Inlet population does not embark on long distance migration, they do return to the same areas within the Inlet year after year.

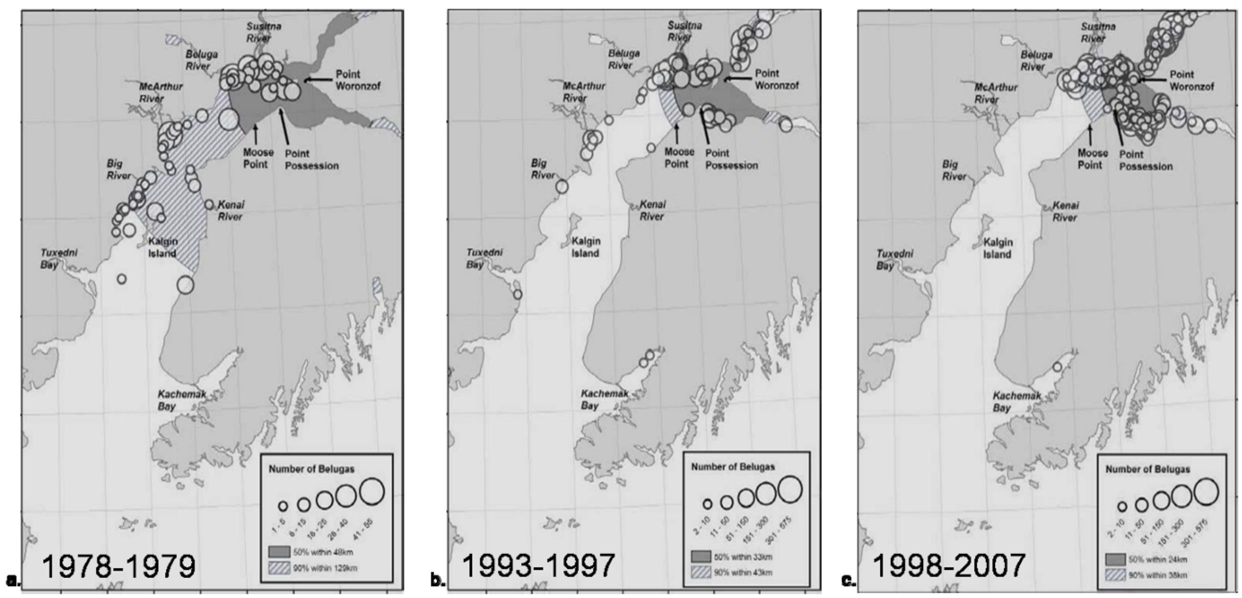

Figure 3. The Cook Inlet beluga whale range in a) 1978-1979, b) 1993-1997 and c) 1998-2007. (Figure credit: NMFS 2008b).

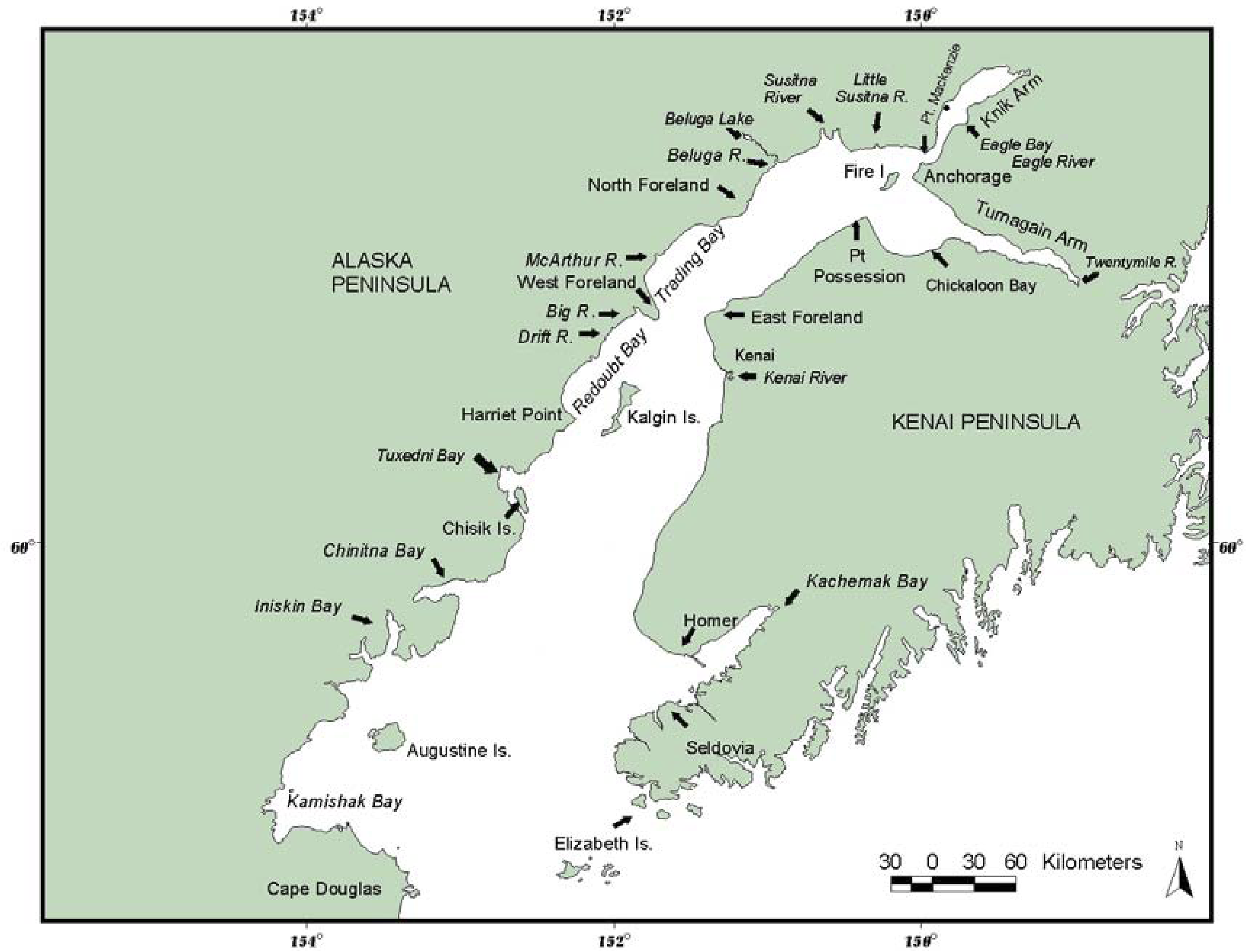

Figure 4. Map of Cook Inlet, with areas of importance to beluga whales. (Figure credit: NMFS 2008b).

Description

The beluga whale, a small cetacean in the order Odontoceti or “toothed whales” and the family Monodontidae, is often called the “white whale” because of its coloration (Figure 5; Rice 1998). They lighten from dark grey at birth to white as they age, although this process is highly variable (Kleinenberg *et al.* 1969, Nowak 1991, Reeves *et al.* 2008). Beluga whales show slight sexual dimorphism with males generally longer (4.2-4.9 m) and heavier (1,100-1,600 kg) than females (3.9-4.3 m and 700-1,200 kg). Calves are generally born 1.5-1.6 m long weighing 80-100 kg (Nowak 1991, Reeves *et al.* 2008). The body is elongated and torpedo-shaped

(Kleinenberg *et al.* 1969), with a round middle section tapering at the head and tail (Reeves *et al.* 2008). Folds of blubber are often found along the belly and sides. The pronounced, flexible melon on the head and non-fused cervical vertebrae, which allow rotation of the neck, distinguish it from other cetaceans (Kleinenberg *et al.* 1969, Reeves *et al.* 2008). The beluga whale has a pronounced dorsal ridge rather than a dorsal fin, which is likely an adaptation for traveling under sea ice (Kleinenberg *et al.* 1969). Traditionally, belugas were thought to live up to 25-30 years (Brodie 1971, Sergeant 1973); however, a change in the interpretation of dentinal growth layer groups for determining age suggests longer life span estimates of at least 60 years (Suydam 2009).

Figure 5. The beluga whale (*Delphinapterus leucas*). (Figure credit: Reeves *et al*. 2008).

Natural History

Beluga whale reproduction varies with region but is not well understood (Nowak 1991, Reeves *et al.* 2008). Females reach sexual maturity earlier than males; however, the estimated age of sexual maturity substantially varies (Kleinenberg *et al.* 1969, Brodie 1971, Sergeant 1973, Robeck *et al.* 2005, Suydam 2009). Breeding occurs in late spring (Brodie 1971). Gestation lasts approximately 14.5 months with calving intervals of approximately 3 years (Brodie 1971). The timing of calving varies, but occurs from April to September (Brodie 1971, Sergeant 1973, Huntington 2000, Nowak 1991). Lactation lasts between 20-24 months (Brodie 1971, Sergeant

1973). Alaska Native hunters in Cook Inlet suggest calving for beluga whales in the Cook Inlet occurs from April through August (Huntington 2000). Calving areas in Cook Inlet include Kachemak Bay (April-May), areas off the mouths of the Beluga and Susitna Rivers (May), and Chickaloon Bay and Turnagain Arm (June-August; Huntington 2000). Native hunters also suggest beluga whales use the upper reaches of Knik Arm as a nursery area (Huntington 2000).

Beluga whales are highly social animals, found in small groups of a dozen to large herds of thousands, but can also occur individually (Kleinenberg *et al.* 1969, Sergeant 1973, Smith *et al.* 1994, Hobbs *et al.* 2000). Group composition varies depending on gender, activity and region. Belugas are most often found in small mixed groups of approximately 10 white and grey individuals, generally females with calves or juveniles. Larger groups of 20-50 individuals usually consist of smaller sub-groups of approximately 2-5 individuals (Kleinenberg *et al.* 1964). Herds of a thousand beluga whales generally congregate during migration and at foraging locations. Males usually join mixed groups during the reproductive season, but are generally observed in separate groups of approximately 10-15 individuals (Kleinenberg *et al.* 1969, Brodie 1971, Smith *et al.* 1994). Cook Inlet beluga whale group composition is similar to other populations. They are often observed in small (2-5 individuals) and large (20-50 individuals) mixed groups (Huntington 2000, Funk *et al.* 2005, Markowitz and McGuire 2007, Cornick and Kendall 2008a, 2008b, and Cornick *et al.* 2010) and are observed in herds (100-200 individuals) near the mouths of rivers in the spring and summer, when they are likely foraging (Huntington 2000, Rugh *et al.* 2000).

Beluga whales are opportunistic feeders, foraging in estuaries, the mouth of rivers and along the benthos. Foraging strategies include herding small fish in dense schools, targeting large single fish, and mucking (sucking invertebrates from the benthos; Ridgeway and Carder

1998, Hobbs *et al.* 2000). Beluga whales use their teeth to grab their prey, capturing and swallowing it whole. They feed independently as well as cooperatively (NMFS 2008b). Foraging strategies depend on the prey species, which vary with region and season (Kleinenberg *et al.* 1969, Reeves *et al.* 2008). Cook Inlet beluga whales generally feed on fish such as cod (*Gadus* spp.), herring (*Clupea* spp.), eulachon (*Thaleichthys pacificus*) and salmon (*Oncorhynchus* spp.*)*, as well as invertebrates (NMFS 2008b).

Hearing and Vocal Ability

Sound is very important to cetaceans and other marine mammals and they generally have highly developed hearing and vocal abilities (MMC 2007, Southall *et al.* 2007, Richardson *et al.* 1995). Many cetaceans have similar ear structure; they lack external ears but likely use soft tissue channels in the lower jaw for sound capture and transmission to the middle ear (Ketten 1997). The soft tissue or fat lobes found in odontocete jaws overlap the middle ear where the sound is received. From the middle ear, the sound is directed to the inner ear (Ketten 1997). Hearing ability varies with species. Beluga whales have a wide range of hearing that extends as low as 40-75 Hz. Their sensitivity at this range, however, is poor and they are most sensitive at ranges between 10-100 kHz (Awbrey *et al.* 1988, Johnson *et al.* 1989, Richardson *et al.* 1995). Their sensitivity to high frequencies is related to their use of those high frequencies for echolocation and communication (Richardson *et al.* 1995).

Beluga whales, also known as the "canaries of the sea" because of their ability to produce a variety of sounds frequently (Reeves *et al.* 2008), were one of the first cetaceans to be recorded underwater (Schevill and Lawrence 1949). Schevill and Lawrence (1949) described the sounds produced by beluga whales as "high-pitched resonant whistles, squeals, ticking, clucking, chirps, bell-like…some sounds resembled an echo sounder, crowds of children shouting and jaw snapping." Generally, sounds produced by toothed whales such as belugas can be classified into three categories: tonal whistles, pulsed sounds of very short duration and high frequency (echolocation), and less distinct pulsed sounds of lower frequency (cries, grunts, and barks). Beluga whale whistles range between 0.26-20 kHz, noisy vocalizations between 0.5-16 kHz (Richardson *et al.* 1995), and echolocation sounds produced by beluga whales have been recorded up to 120 kHz (Au *et al.* 1985).

The types of sound produced by toothed whales vary with the behavioral state. They produce sounds to communicate with conspecifics, during social interaction, foraging, navigation, and to avoid predators (Richardson *et al.* 1995, MMC 2007, Southall *et al.* 2007). Whistles and pulsed sounds of lower frequency are generally associated with social behaviors, while echolocation clicks are generally associated with navigation and foraging or with less social species (Au *et al.* 1985, Sjare and Smith 1986a, Tyack 1986, Richardson *et al.* 1995).

Vocalizations have been studied in several beluga populations including those in Cunningham Inlet, Canada (Sjare and Smith 1986a, Sjare and Smith 1986b), St. Lawrence Estuary, Canada (Faucher 1988), Bristol Bay, Alaska (Angiel 1997), Svalbard, Norway (Karlsen *et al.* 2002), White Sea, Russia (Belikov and Bel'kovich 2006, 2007, 2008), as well as in captivity (Au *et al.* 1985, Au *et al.* 1987, Turl and Penner 1989, Lammers and Castellote 2009). Beluga whales' range of vocalization capabilities, especially echolocation clicks, is likely an adaptation to their noisy Arctic environment of shifting ice. The diverse echolocation click strategies likely allow them to navigate and find breathing holes under the ice (Au *et al.* 1985, Au *et al.* 1987, Turl and Penner 1989).

Sound production by odontocetes varies slightly among species, but generally, the sound originates in the nasal passage instead of in the larynx as with other mammals (Cranford *et al.*

1996). Air in the nasal passage is pressurized and forced through the phonic lips, whose vibrations are then captured in the air sacs and projected through the melon (Cranford *et al.* 1996). Lammers and Castellote (2009) recently described the unique production of double pulses by the beluga whale during echolocation. Two separate generators produce single pulses that are combined as they are projected through the melon. Advantages to using two generators during the production of double pulses include an increase in the total energy, a larger frequency bandwidth and better control of the echolocation beam (Lammers and Castellote 2009).

Status of the Cook Inlet Beluga Whale

On 22 October 2008, the NOAA Fisheries Service listed the Cook Inlet beluga whale as endangered under the ESA (NMFS 2008a). The Cook Inlet population was recently estimated at 321 individuals (Hobbs *et al.* 2009). The population was expected to increase 2-6 % per year following the voluntary moratorium on subsistence hunting; however, the population continued to decline from 1999-2009 approximately 1.49 % per year (Figure 6; Hobbs *et al.* 2009). According to population modeling studies, an optimal sustainable population (60 % of carrying capacity for small cetaceans) should contain no fewer than 780 individuals (NMFS 2005). Extinction risk models show a 26% probability of extinction within 100 years, and a 70% probability of extinction within 300 years (Hobbs and Sheldon 2008).

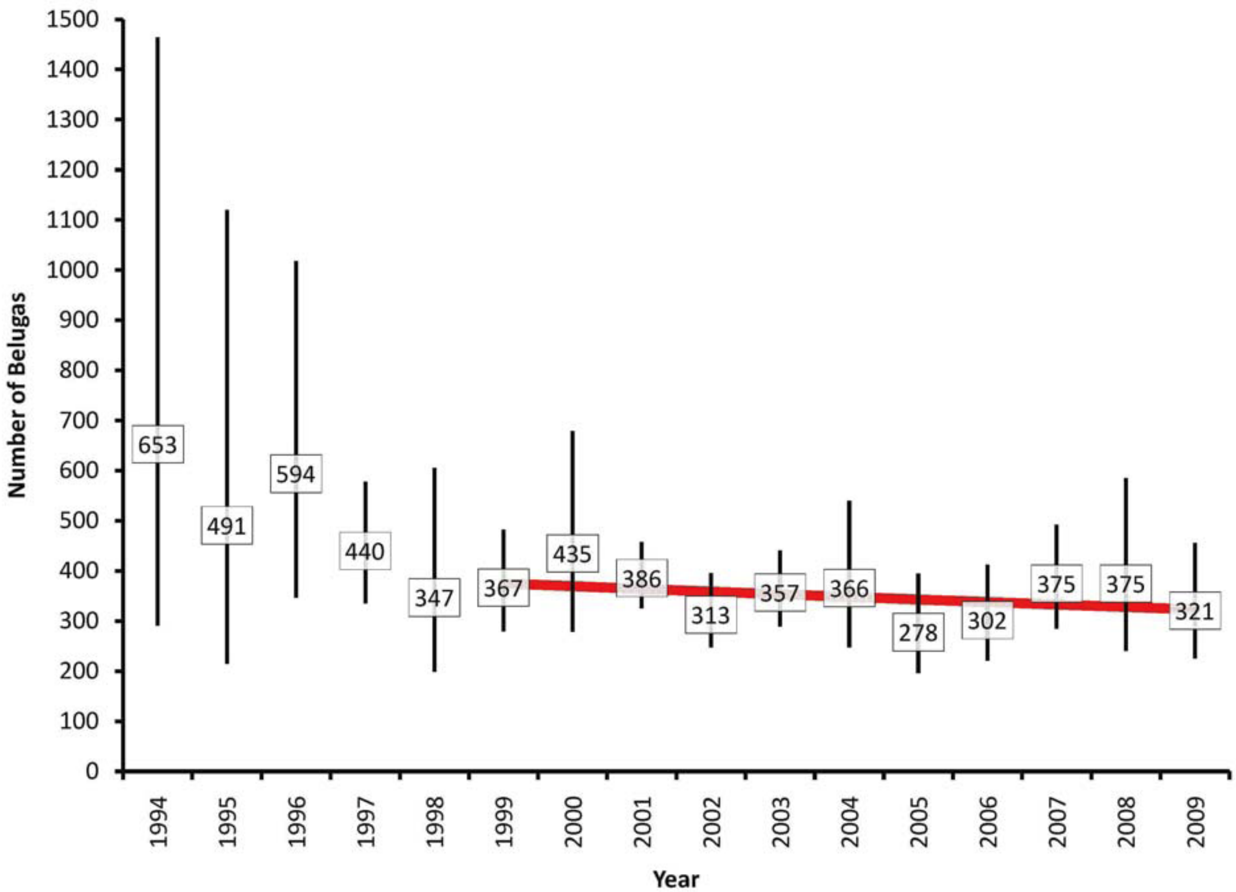

Figure 6. NOAA Fisheries Service abundance estimates for Cook Inlet beluga whales with 95 % confidence intervals (1994-2009). The red line indicates a decline of approximately 1.49 % per year since 1999 (Hobbs *et al.* 2009). (Figure credit: Hobbs *et al.* 2009).

Once a species is protected under the ESA, the NOAA Fisheries Service must designate critical habitat. The proposed critical habitat for the Cook Inlet beluga whale encompasses approximately 7,809 km^2 (Figure 7; NMFS 2009a, b). The proposed area provides for important biological needs such as summer foraging, calving, and molting areas, as well as protection from predation. The proposed area also includes fall and wintering habitat (NMFS 2008b, NMFS 2009a).

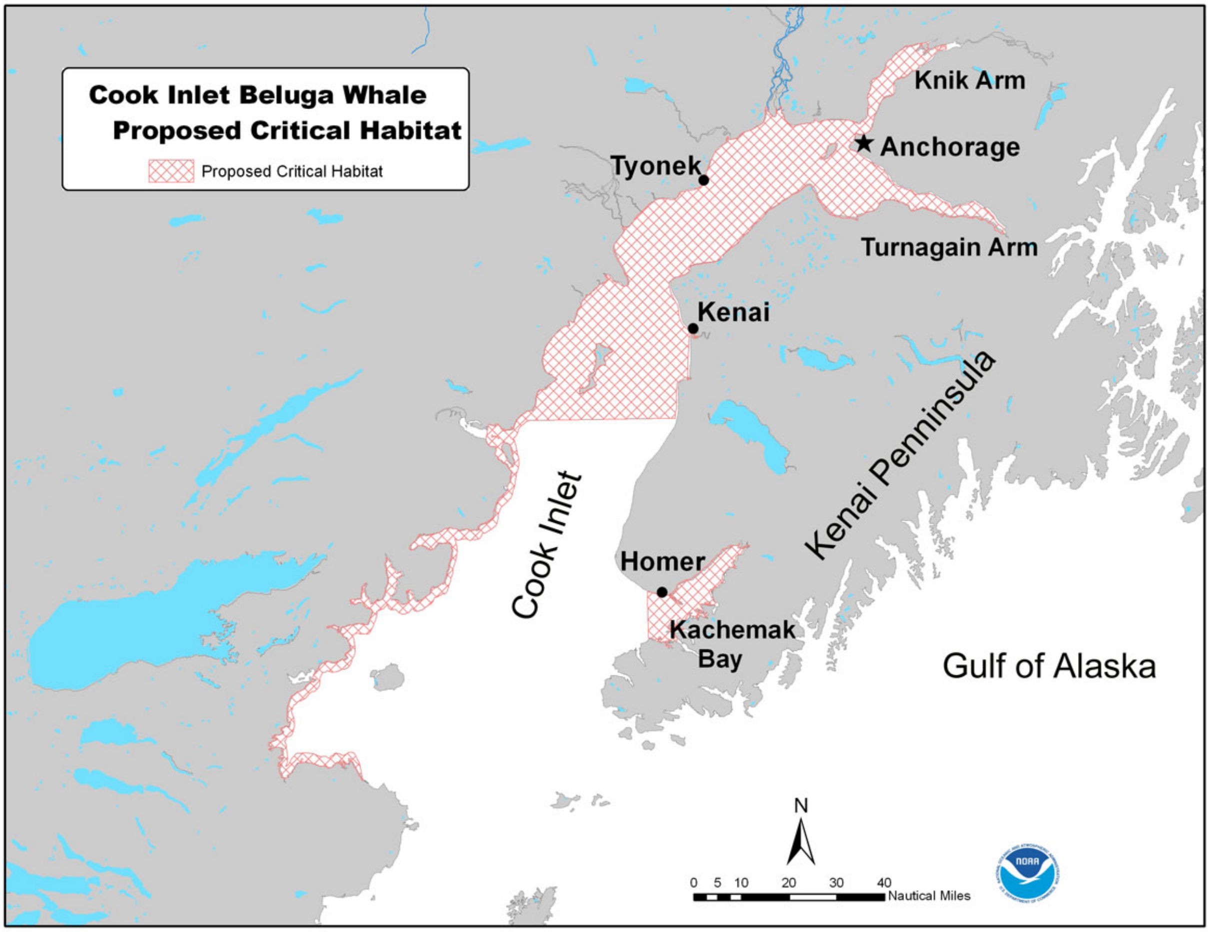

Figure 7. Map of the proposed critical habitat for the Cook Inlet beluga whale. (Figure credit: NMFS 2009b).

Potential Factors Contributing to the Decline

The *Conservation Plan for the Cook Inlet Beluga Whale* includes a review and assessment of the known and possible threats to Cook Inlet belugas (NMFS 2008b). Natural threats include stranding events, predation, parasitism, disease and environmental changes. Potential human threats include subsistence hunting, poaching, fishing, pollution, vessel traffic, tourism and whale watching, coastal zone development, noise, oil and gas development and scientific research (NMFS 2008b). Anthropogenic noise is a concern because of increased human activities in Upper Cook Inlet such as coastal zone and oil and gas development.

Anthropogenic Noise

Ocean noise levels have increased over the past four decades (Andrew *et al.* 2002, McDonald *et al.* 2006). Anthropogenic noise is contributing to this increase as human activities, such as shipping, increase (Andrew *et al.* 2002, McDonald *et al.* 2006). Concerns over the effects of anthropogenic noise on marine mammals were first raised in the 1970s, when research conducted in the Arctic revealed changes in movement patterns as well as avoidance by bowhead whales (*Balaena mysticetus*) and other marine mammals during oil and gas development (MMC 2007, Southall *et al.* 2007). The concerns resurfaced in the 1990s with projects such as the Acoustic Thermometry of Ocean Climate and the US Navy's use of low-frequency active sonar to detect and track submarines (Costa *et al.* 2003, MMC 2007, Southall *et al.* 2007). A series of worldwide stranding events involving beaked whales (*Ziphius* spp. and *Mesoplodon* spp.) that occurred after exposure to military active sonar provided support for these concerns (Frantzis 1998, Jepson *et al.* 2003 Fernandez *et al.* 2004, MMC 2007, Southall *et al.* 2007). In 2007, the Marine Mammal Commission (MMC) officially recognized the potential harmful effects of sound on marine mammals in their report to Congress and recommended additional scientific research to improve our understanding of the effects of sound on marine mammals (MMC 2007).

Anthropogenic noise can affect marine mammals behaviorally, acoustically and physiologically (Nowacek *et al.* 2007). Behavioral responses of bowhead whales (Ljungblad *et al.* 1988, Greene *et al.* 2004, Patenaude *et al.* 2002), sperm whales (*Physter macrocephalus*; Smultea *et al.* 2007), beluga whales (Blane and Jaakson 1994; Erbe and Farmer 2000, Patenaude *et al.* 2002), harbour porpoises (*Phocoena phocoena*; Carstensen *et al.* 2006, Brandt *et al.* 2009) and Indo-pacific hump-backed dolphins (*Sousa chinensis*; Würsig *et al.* 2000) exposed to anthropogenic noise (e.g., seismic airgun blasts, watercraft, aircraft, in-water construction) include sudden change in movement, travel speed, dive patterns, as well as avoidance and displacement from important habitat. Responses of bowhead whales during exposure to seismic airgun blasts diminished within one hour after disturbance (Ljungblad *et al.* 1988), while decreased activity and avoidance by harbor porpoises were observed the entire 5 mo pile driving activity took place during the installation of offshore wind turbines near Denmark (Brandt *et al.* 2009). The response and the recovery time of cetaceans depend on the species, behavioral state of species, location, type of disturbance and exposure time. Long-term behavioral impacts on cetaceans are not known.

Acoustic responses by blue (*Balaenoptera musculus*; McDonald *et al.* 2006), fin (*Balaenoptera physalus*; McDonald *et al.* 2006), beluga (Lesage *et al.* 1999, Schiefele *et al.* 2005, and killer (*Orcinus orca*; Holt *et al.* 2008) whales to shipping and other watercraft include cessation of vocalizing, increased rate of vocalizing, shift in calling frequency, or change in call types. Anthropogenic noise can cause auditory masking, which occurs when ambient noise interferes with an animal's ability to detect a sound signal, even when the sound is above the hearing threshold (Richardson *et al.* 1995). Cetaceans will often compensate for masking by calling louder, longer, or by changing the type of call (Holt *et al.* 2008). McDonald *et al.* (2006) observed a long-term shift in the calling frequency of blue and fin whales to increased shipping noise, while changes in vocal behavior of beluga and killer whales were observed during the temporary exposure to watercraft (Lesage *et al.* 1999, Schiefele *et al.* 2005, Holt *et al.* 2008).

Physiological responses to or injury from anthropogenic noise include changes in respiratory rate, auditory threshold shifts and tissue damage. Bowhead whale respiratory rates increased when exposed to seismic airgun blasts (Ljundblad *et al.* 1988). When an animal is exposed to sound that increases its hearing threshold (i.e. results in poorer sensitivity to sound), the animal experiences an auditory threshold shift (Richardson *et al.* 1995, Finneran *et al.* 2000, Schlundt *et al.* 2000). The two types of auditory threshold shifts are temporary threshold shifts (TTS) and permanent threshold shifts (PTS). During TTS, the animal's hearing ability is reduced for a short period of time; however, with PTS the animal suffers some degree of irreversible hearing loss. Studies examining auditory threshold shifts are limited to smaller, captive odontocetes such as bottlenose dolphins and beluga whales (Finneran *et al.* 2000, Schlundt *et al.* 2000, Finneran 2008). Auditory threshold shifts from underwater explosions (Finneran *et al.* 2000, Schlundt *et al.* 2000) can cause TTS in cetaceans (Schlundt *et al.* 2000). The animal can fully recover from small levels of TTS (Schlundt *et al.* 2000); however, threshold shifts depend on exposure frequency, sound pressure, duration, and temporal patterns (Finneran *et al.* 2008).

An example of physiological injury due to anthropogenic noise that ultimately resulted in death is the series of beaked whale strandings that were eventually linked to military sonar events (Frantzis 1998, Jepson *et al.* 2003, Fernandez *et al.* 2004, Nowacek *et al.* 2007). Necropsies on the stranded beaked whales provided evidence of tissue damage that indicated the formation of intravascular gas bubbles that occurred from rapid decompression (Jepson *et al.* 2003, Fernandez *et al.* 2004). The occurrence of gas bubbles is likely due to a behavioral response to the sound source, such as a rapid ascent, or from sudden exposure to the sonar (Jepson *et al.* 2003, Fernandez *et al.* 2004).

The effects of anthropogenic noise on cetaceans have been studied on beluga whales. Behavioral (Blane and Jaakson 1994, Erbe and Farmer 2000, Patenaude *et al.* 2002), acoustic (Lesage *et al.* 1999, Scheifele *et al.* 2005) and physiological (Finneran *et al.* 2000, Schlundt *et al.* 2000, Finneran 2008) responses of belugas have been investigated. In the presence of water-and aircraft, beluga whale responses included change in travel speed, dive patterns, direction and behavioral state, avoidance, increased rate of vocalizing, shift in calling frequency and change in call types (Blane and Jaakson 1994, Lesage *et al.* 1999, Erbe and Farmer 2000, Patenaude *et al.* 2002, Scheifele *et al.* 2005). TTS has been observed in captive beluga whales when exposed to underwater explosions (Finneran *et al.* 2000, Schlundt *et al.* 2000, Finneran 2008).

Researchers have examined the effects of noise from in-water construction, such as pile driving activity, on harbour porpoises (Carstensen *et al.* 2006, Brandt *et al.* 2009) and Indo-Pacific hump-backed dolphins (Würsig *et al.* 2000). Responses from these cetaceans in the presence of pile driving activity included a reduction of acoustic activity, a reduction in the number of individuals in the area and avoidance of the area (Würsig *et al.* 2000, Carstensen *et al.* 2006, Brandt *et al.* 2009). The effects of construction activity, or specifically pile driving, on beluga whales have not been examined previously to this study.

As coastal zone development increases in Upper Cook Inlet, the effects of anthropogenic noise resulting from development will continue to be of concern for the Cook Inlet beluga whale population. Current and proposed projects in the Upper Cook Inlet include the Knik Arm ferry, the Knik Arm crossing, Chuitna coal mine, Port MacKenzie expansion, dredging off the Port of Anchorage (POA) to support deep-draft vessels and the POA Marine Terminal Redevelopment (MTR) Project currently underway (NMFS 2008b). Construction activities taking place at the MTR Project include dredging, gravel fill, and pile driving (NMFS 2008c). The combination of these activities could affect beluga whales by increasing underwater sound levels, which could interfere with beluga whale communication and echolocation. Noise associated with pile driving is of greatest concern and has the potential to cause behavioral changes (e.g., increased travel speed, change in dive patterns), mask important sounds, and cause avoidance or displacement from important habitat (Richardson *et al.* 1995, NMFS 2008c). As these projects unfold it is important to monitor Cook Inlet beluga whale behavior and habitat use to understand and identify any changes.

Scope of Thesis

In this study, I investigated the impact of construction activity on the Cook Inlet beluga whale at the MTR Project using visual and acoustic surveys. Marine mammal monitoring at the MTR Project using visual observations began in 2005 and continued through 2009. Long-term monitoring at the POA has provided a unique opportunity to observe beluga whale behavior and distribution around the POA over several years and to determine if there are changes in behavior with increased construction activity. During August and September 2009, acoustic monitoring of beluga whales took place at the MTR Project and provided an opportunity to examine the effectiveness of passive acoustic monitoring in determining the presence of beluga whales in Knik Arm, and to examine the effects of construction activity on beluga whale vocal behavior.

Chapter II contains the results from the comparisons between beluga whale behavior and distribution pre- and during pile driving activity (2005-2007 and 2008-2009, respectively) at the MTR Project using visual observations. Behavior, group size, group composition, group formation, sighting rates and duration, and distribution were examined for differences between pre- and during pile driving activity.

In Chapter III, I investigate the effects of construction activity on beluga whale vocal behavior by comparing the differences in click rate during periods with and without pile driving and dredging noise.

Finally, as a synthesis of the study, I present my conclusions and suggestions for future research on examining impacts of construction on the Cook Inlet beluga whale in Chapter IV.

Chapter II

Behavior and distribution of the Cook Inlet beluga whale (*Delphinapterus leucas*) pre- and during pile driving activity at the Port of Anchorage Marine Terminal Redevelopment Project, 2005-2009

Abstract

Five stocks of beluga whales (*Delphinapterus leucas*) exist in US waters. The Cook Inlet population is genetically distinct and geographically isolated from the other stocks. It was recently listed as endangered under the US Endangered Species Act. Many factors are identified as potential threats to the Cook Inlet beluga whale population including coastal development and anthropogenic noise. The Port of Anchorage (POA) Marine Terminal Redevelopment (MTR) Project involves several types of construction activities including dredging, gravel fill, and pile driving. Pile driving is a major concern because of the potential harassment due to high source levels. In this study I investigated beluga whale behavior and distribution pre- (2005-2007) and during pile driving activity (2008-2009) at the MTR Project. Land-based visual observations were conducted to document beluga behavior and distribution in the presence and absence of pile driving activities. I compared the sighting duration of beluga whales, behavior, group size, group composition and group formation between pre- and during pile driving activity using chi-square goodness-of-fit tests and paired samples t-tests for all groups. There were significant differences in sighting duration, behavior, group composition and group formation between pre- and during pile driving periods. A Pearson's correlation coefficient (2-tailed) was used to examine the relationship between monthly sighting and pile driving rates. There was no significant correlation between monthly sighting rates and pile driving rates. Beluga whales were most frequently observed along the eastern shoreline of the study area; however, sightings increased along the western shoreline near Port MacKenzie during pile driving activity.

Introduction

Beluga whales (*Delphinapterus leucas*) are found throughout the arctic and subarctic regions of the Northern hemisphere, summering in coastal waters of 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 US waters including the Beaufort Sea, eastern Chukchi Sea, eastern Bering Sea, Bristol Bay and Cook Inlet. The Cook Inlet population is 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; Angliss and Allen 2009).

In 2008, the National Oceanic and Atmospheric Administration (NOAA) Fisheries Service listed the Cook Inlet beluga whale as endangered under the US Endangered Species Act (ESA; NMFS 2008a). The Cook Inlet population was recently estimated at 321 individuals (Hobbs *et al.* 2009). The population was expected to increase 2-6 % per year following the voluntary moratorium on subsistence hunting; however, population continued to decline from 1999-2009 approximately 1.49 % per year (Hobbs *et al.* 2009). According to population modeling studies, an optimal sustainable population should contain no fewer than 780 individuals (NMFS 2005). Extinction risk models show a 26% probability of extinction within 100 years, and a 70% probability of extinction within 300 years (Hobbs and Sheldon 2008).

The *Conservation Plan for the Cook Inlet Beluga Whale* (NMFS 2008b) includes a review and assessment of the known and possible threats to Cook Inlet belugas (NMFS 2008b). Natural threats include stranding events, predation, parasitism, disease and environmental changes. Potential human threats include subsistence hunting, poaching, fishing, pollution, vessel traffic, tourism and whale watching, coastal development, noise, oil and gas development and scientific research (NMFS 2008b).

Anthropogenic noise is of particular concern as coastal zone development increases in Upper Cook Inlet. Current and proposed development projects include the Knik Arm ferry, the Knik Arm crossing, Chuitna coal mine, Port MacKenzie expansion, dredging off the Port of Anchorage (POA) to support deep-draft vessels, and the POA Marine Terminal Redevelopment (MTR) Project currently underway (NMFS 2008b). Construction activities taking place at the MTR Project include dredging, gravel fill, and pile driving (NMFS 2008c). The combination of these activities could affect beluga whales through an increase in underwater sound levels, which could interfere with beluga whale communication and echolocation, cause behavioral changes (e.g., increased travel speed, change in dive patterns), mask important sounds, or cause avoidance or displacement from important habitat (Richardson *et al.* 1995, NMFS 2008c).

Studies evaluating impacts of construction activities such as pile driving on cetaceans are limited in numbers (Richardson *et al.* 1995, Würsig *et al.* 2000, NRC 2003, Carstensen *et al.* 2006, Brandt *et al.* 2009). Responses from Indo-Pacific hump-backed dolphins (*Sousa chinensis*; Würsig *et al.* 2000) and harbor porpoises (*Phoecoena phoecoena*; Carstensen *et al.* 2006, Brandt *et al.* 2009) in the presence of pile driving activity include a reduction of vocal activity, a reduction of the number of individuals in the area and avoidance of the area. Since the declining Cook Inlet beluga whale population frequents areas with high levels of construction, it is important to understand how pile driving activities impact these whales. Marine mammal monitoring at the MTR Project has been ongoing since 2005 and it provided an opportunity to study the potential impacts of pile driving on beluga whales.

In this study I investigated beluga whale behavior and distribution pre- (2005-2007) and during (2008-2009) pile driving activity at the MTR Project. Behavior, sighting duration, group size, group composition, group formation and distribution were examined to determine if there were differences between pre- and during pile driving activity. Using these data, I answered the following questions:

1. Is there a relationship between sighting rates and the rate of pile driving activity?
2. Are there differences in mean sighting duration of beluga whale between pre- and during pile driving?
3. Are there differences in behavior between pre- and during pile driving activity?
4. Are there differences in mean group size between pre- and during pile driving activities?
5. Are there differences in group composition between pre- and during pile driving activities?
6. Are there differences in group formation between pre- and during pile driving activities?
7. Are there differences in beluga whale distribution between pre- and during pile driving activity?

Methods

Study Area

The study area included all visible water from land-based observation stations located in Knik Arm, Upper Cook Inlet near Anchorage, Alaska (Figure 8a). The POA and Port MacKenzie are both located at the entrance to Knik Arm (Figure 8b). All observation stations were located on the east side of Knik Arm in the vicinity of the POA (Figure 8b). The main station was located at Cairn Point on Elmendorf Air Force Base facing south and overlooking the POA. From 2005-2006, three alternative sites were used in addition to the Cairn Point Station (CPS; Figure 1b). In 2005, two stations at the Petroleum, Oil and Lubricants Towers (Towers) were used in determining the best vantage point for marine mammal monitoring for the MTR Project (Prevel-Ramos *et al.* 2006). After the 2005 season, the Towers were no longer used because CPS was determined to be the best location for the study. 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 2007). CPS was the only station used during 2007-2009 seasons. The heights of the stations located at the Towers and the northeast corner of the dock at the POA were lower than CPS; therefore, beluga whale detectability from the alternative stations was lower than at CPS and likely influenced the results across years.

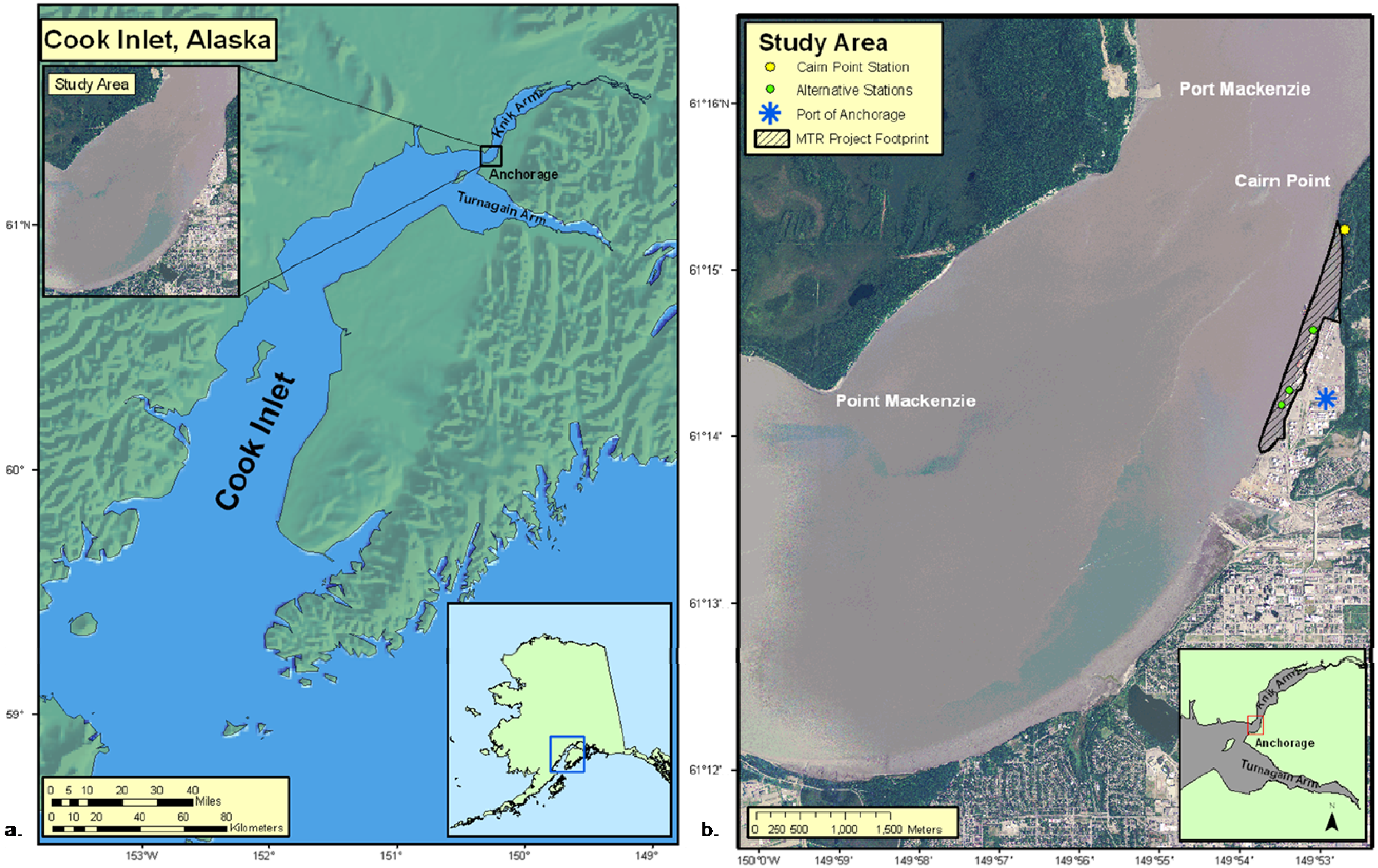

Figure 8. a) Map of Cook Inlet, Alaska with an inset of the study area near Anchorage, Alaska. b) The study area located in Knik Arm, Upper Cook Inlet adjacent to Anchorage, Alaska. Cairn Point Station (yellow) is located north of Anchorage. The 3 alternative observation stations, two at the Petroleum, Oil and Lubricants Towers and one at the northeast corner of the POA dock (green) were located at the Port of Anchorage (blue asterisk) during the 2005-2006 seasons. The MTR Project footprint is outlined and crosshatched.

Sampling Effort and Data Collection

2005-2006

Data from 2005-2006 were collected and provided by LGL Alaska Research Associates, Inc. (Prevel-Ramos *et al.* 2006, Markowitz and McGuire 2007). In 2005, observations were conducted 2 d/wk, 6 h/d, from 2 August-28 November (Table 2; Prevel-Ramos *et al.* 2006). Two observers were located at separate stations during daily observational periods, one at CPS and one at the Towers at the POA. In 2006, a single observer conducted observations 4 d/wk, 6 h/d from 26 April-3 November at CPS (Table 2; Markowitz and McGuire 2007). 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 minutes followed by 10 minutes of scanning with binoculars (Bushnell 7 x 50 with internal magnetic compass; Funk *et al.* 2005). 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 (Figure 9; Prevel-Ramos *et al.* 2006, Markowitz and McGuire 2007).

2007-2009

In 2007, observations were conducted up to 5 d/wk for 4 h shifts once or twice per day, from 9 October-23 November (Table 2; Cornick and Kendall 2008a). Twenty minute scan samples were conducted with binoculars and two observers were located at CPS during all observational periods (Bushnell 7 x 50 with internal magnetic compass; Nikon Monarch ATB 10x42; Funk *et al.* 2005). Only the 500 x 500 m grid method was used during observations (Cornick and Kendall 2008a). In 2008-2009 observation effort increased to 4 d/wk, 8 h/d in two shifts of 4 h from 24 June-14 November 2008 and from 4 May-18 November 2009 (Table 2).

Two observers were located at CPS during all observational periods (Cornick and Kendall 2008b, Cornick *et al.* 2010). During the 2008-2009 seasons, protocols were modified to 10-min scan sampling intervals using binoculars (Bushnell 7x50 with internal compass; Nikon Monarch ATB 10x42; Cornick and Kendall 2008b, Cornick *et al.* 2010). 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. 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; Altman 1974). One focal group was defined a one sighting. Observers documented the location, direction, age class or color class, number of whales, behavior and movement patterns and noted the time and location of each pattern. Any construction activity taking place was also documented (Funk *et al.* 2005, Cornick *et al.* 2010).

Descriptive statistics were calculated for sampling effort to determine monthly and annual totals. Numbers of sightings (i.e., number of days whales observed, number of whales and number of groups) were calculated by month and year.

Table 2. Summary of the 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[a]	2	6	1	2 Aug-28 Nov	Yes	Yes	374.40	No
2006	single	4	6	1	26 Apr-3 Nov	Yes	Yes	563.80	No
2007	double	5	4	1 or 2	9 Oct-23 Nov	No	Yes	139.42	No[b]
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

[a] Two observers were used each day; however, they were each at a different location thus effectively they were a single observer
[b] A test pile probing study occurred for 5 days in 2007. These data were included in the pre-pile driving time period because they were not complete events, took place periodically throughout each day and occurred for a short period of time; therefore, they were considered inconsequential.

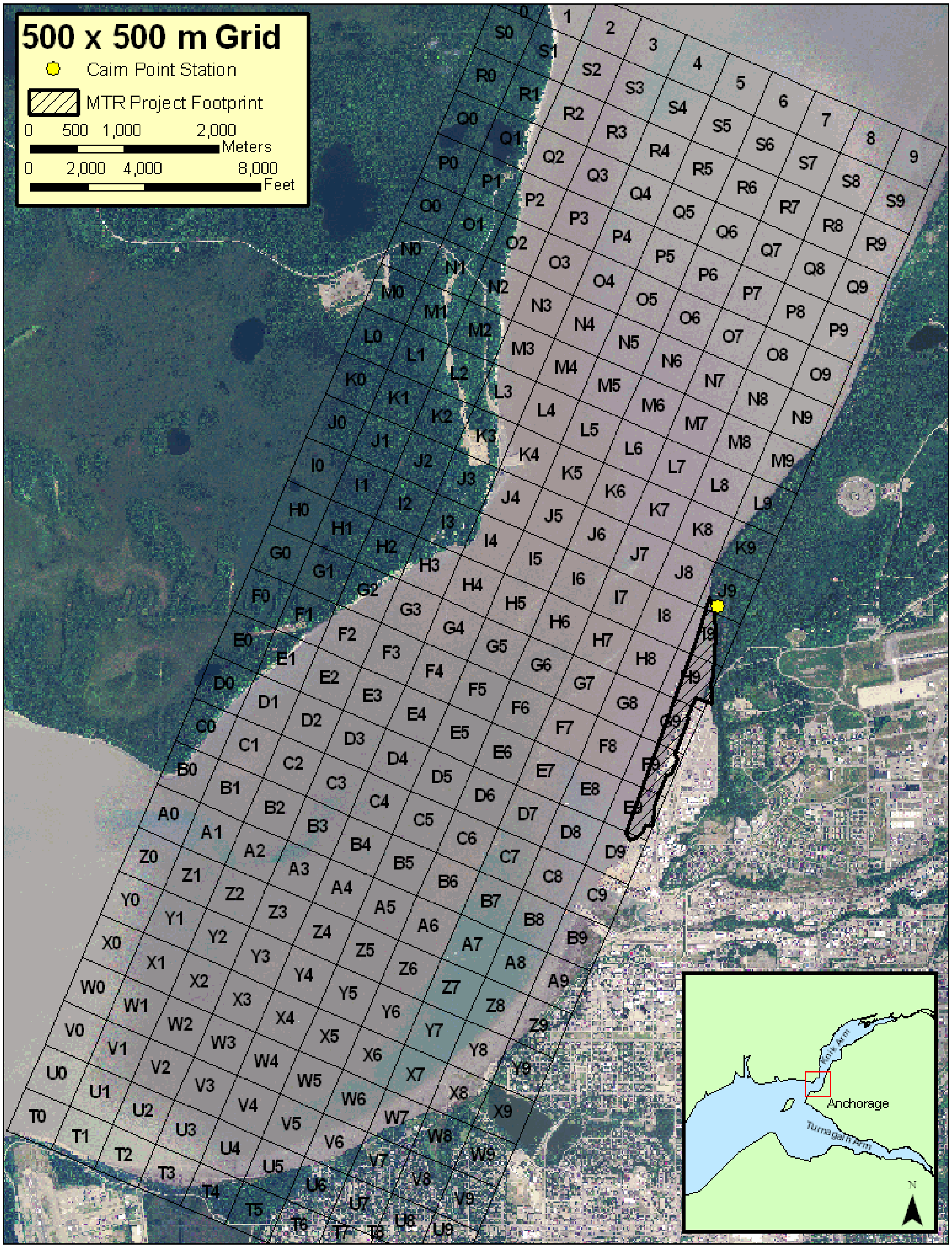

Figure 9. 500 x 500 m grid cells overlaying a map of the study area. The MTR Project footprint, outlined and crosshatched, is located in grid cells D9-J9. Cairn Point Station is represented by the yellow dot in grid cell J9.

Theodolite tracking triangulates the location of a fixed point (e.g., a whale group) by measuring 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 eye piece (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 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 the free software program *Pythagoras* (<http://www.tamug.edu/mmrp/pythagoras/index.html>). 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.

A 500 x 500 m grid overlaying a map of the study area was also used to document location and movement patterns of beluga whales in the study area (Figure 9, Funk *et al.* 2005). This method was used to maintain consistency in data collection and as a backup if the theodolite was not available or not working. Observers used a magnetic compass reading and landmarks to identify the whale group's grid cell location on the map, and then documented the time the whales were first observed, centered the binoculars' internal magnetic compass on the whale group and recorded the compass reading and grid cell. Grid cells and compass readings were continually documented as a whale group moved through the study area. The time and location of the last observation were also documented. In 2008, grid cells were extended to cover the area south of Ship Creek and Point MacKenzie to Point Woronzof (Figure 9, grid cells T-Z).

Behavior, Group Size, Group Composition and Group Formation

Focal group behavior (Mann 2000) was continuously sampled including behavioral state (e.g., traveling, diving, resting, feeding; Appendix A) and swimming formation. Milling was not included as a behavioral state from 2005-2006; therefore, it was added to the list of behavioral states in 2007. Potential indicators of negative responses to noise (i.e., approaches and then leaves, change in swimming speed and/or direction, abrupt dives or dispersal; Appendix A) were documented if observed.

Group size was 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.

Group composition was recorded continuously as the whales moved through the study area. Group composition was defined by color class or age class (white, grey or mixed) and number of individuals in a group (lone, 2-5, 6-10, 11-25, 26-50, >50 individuals). If groups consisted of only grey or unknown individuals, they were classified as mixed groups. Group composition has been described as either mixed or white groups (Kleinenberg *et al.* 1969, Brodie 1971, Sergeant 1973, Smith *et al.* 1994); therefore, it was assumed that groups documented as only grey individuals contained white individuals or calves. It was also assumed that there were both grey and white individuals in the unknown groups because color was not identifiable. Lone individuals of unknown color were excluded only from the group composition analysis (n = 3), but were included in all other analyses.

Age class (color and proximity of individuals) was changed to color class (white, grey and dark grey) in 2009 because researchers suggest that color cannot be used reliably to determine age class in beluga whales (McGuire *et al.* 2008, NMFS 2008b, NMFS unpublished data). Therefore, age class documented from 2005-2008 were reclassified into color classes as white (previously coded adults), grey (sub-adults) and dark grey in close proximity of another whale (calf). From 2005-2008, if the color of a whale was unidentifiable it was considered unknown. The unknown category was not reclassified for 2005-2008 and remained unknown. Color class from 2005-2009 was used for the group composition analysis.

Group formation was categorized as densely packed, dispersed and alone. Observations from 2006 did not document group formation; therefore, group spread data (defined as body lengths apart) were recoded to match subsequent years' classifications (Table 3). If spread was not described, no group formation was assigned and that sighting was not used in group formation analysis.

Table 3. Classifications for group formation.

Classification	Description
Densely packed	≤ 3 body lengths apart
Dispersed	≥ 4 body lengths apart
Alone	1 individual

Pile Driving and Other Construction Activities

Data from 2005-2007 were classified as pre-pile driving activity and 2008-2009 were classified as during pile driving activity. In 2005 and 2006, no in-water pile driving took place at the MTR Project. In 2007, an in-water test pile probing study took place from 15-19 October to evaluate subsurface pile driving conditions and evaluate sound levels (URS 2007, US Department of Transportation Maritime Administration 2008). Although test pile driving took place for 5 days in October of 2007, these data were included in the pre-pile driving time period because they were not complete events, took place occasionally throughout each day and occurred for a short period of time; therefore, they were considered inconsequential. 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 August 2008. Other in-water construction activities (e.g., dredging and fill placement) also took place from 2005-2009. In 2005-2007, general construction activities were noted (Prevel-Ramos *et al.* 2006, Markowitz and McGuire 2007, Cornick and Kendall 2008) and from 2008-2009, the specific type and duration of construction activity were recorded. Often construction activities were occurring simultaneously, therefore construction activities were grouped into two 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 the total 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 instance, the presence of 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

Pile Driving Activity

Monthly rates of in-water pile driving activity at the MTR Project for each year of construction were compared to monthly sighting rates. Rate of pile driving activity was determined by dividing the monthly number of hours of all pile driving activity by the monthly sampling effort. Sighting rates were determined by dividing the monthly number of sightings by the monthly sampling effort. A Pearson's correlation coefficient (2-tailed) was used to examine the relationship between monthly sighting and pile driving rates.

Behavior, Group Size, Group Composition and Group Formation

Chi-square goodness-of-fit tests were performed to compare behavior, group composition and group formation between pre- and during pile driving activity. Sampling effort increased from 2005-2009, resulting in unequal sample sizes between pre- and during pile driving activity. Therefore, calculated expected values for the chi-square tests were proportionally adjusted to correct for the difference in effort. Paired samples t-tests were used to compare mean sighting duration of beluga whales and mean group size between pre- and during pile driving activity. The alpha level was set at $p < 0.05$ and all values were reported as mean ± 1 standard error unless otherwise indicated. *SPSS* (v. 15.0 for Windows) was used for statistical analyses.

Spatial Distribution

Spatial distribution of beluga whales was determined by calculating the total number of whale groups within each grid cell for pre- and during pile driving activity. Whale group track lines obtained from theodolite fixes were formatted in *Pythagoras* for *ArcGIS ArcInfo 9.3* (ESRI, Redlands, CA). In *ArcGIS ArcInfo 9.3*, track lines were superimpose onto the grid cells to determine the location of each sighting. Grid cells were then shaded according to the total number of whale groups observed in each grid cell for pre- and during pile driving activity. Observers at the alternative sites during 2005-2006 could view portions of Knik Arm north of Port MacKenzie that were not visible from CPS; therefore, those sightings were excluded from the spatial analysis. No statistical analyses were preformed on the spatial distribution of sightings because of differential detectability of belugas within each grid cell (i.e., whales in the grid cells closest to CPS had a higher probability of detection than those in grid cells beyond 3 km from CPS or the alternative observation stations).

Results

Sampling Effort and Pile Driving Activity

A total of approximately 2,469 h of sampling effort was completed across 377 d from 2005-2009 (Table 4). Overall, 773 whales in 197 groups were documented during the 78 d whales were sighted (Table 4). A total of approximately 353 and 1,663 h of pile driving activity took place in 2008 and 2009, respectively. There was no significant relationship between monthly sighting rates and the monthly rate of pile driving activity ($r = 0.13$, $p = 0.53$; Figure 10).

Table 4. Sampling effort and sightings from 2005-2009.

Month	Sampling Effort		Sightings		
	Days	Hours	No. of Days Whales Sighted	No. of Whales	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**	**374.4**	**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**	**563.8**	**21**	**82**	**26**
			2007		
October	17	85.75	5	34	10
November	11	53.67	4	52	10
Total	**28**	**139.42**	**9**	**86**	**20**
			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	**377**	**2,468.52**	**78**	**773**	**197**

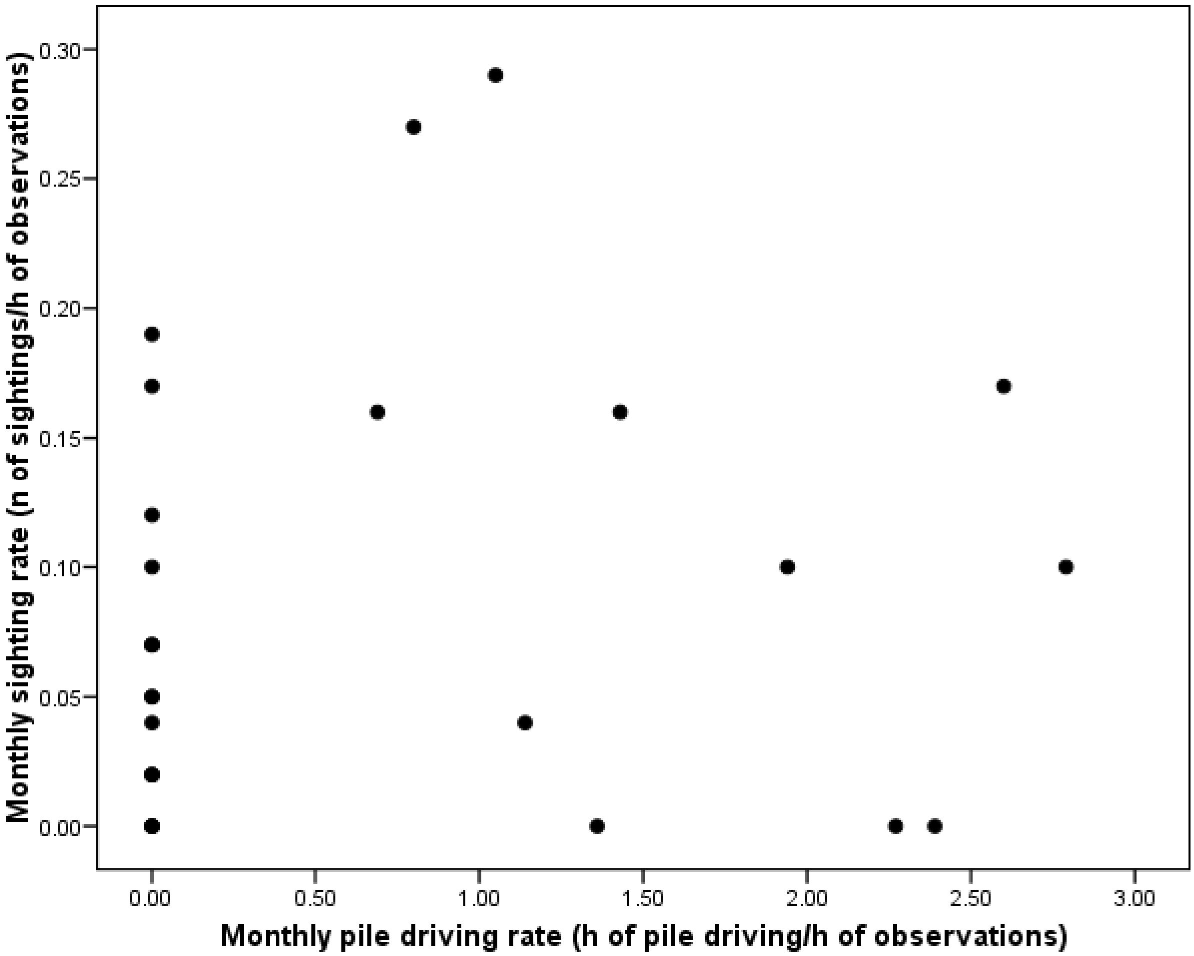

Figure 10. Monthly sighting rates compared to monthly rates of pile driving activity from 2005-2009. A total of 27 points were plotted; however, 7 points overlap including August 2005 with May 2006, October 2005 with October 2006, November 2006 with June and July 2008. No pile driving occurred from 2005-2007. There was no significant correlation ($r = 0.13$, $p = 0.53$) between the two rates.

Behavior, Group Size, Composition and Formation

Mean sighting duration of beluga whales decreased significantly ($t_{(62)} = -4.77$, $p < 0.01$) from pre-pile driving (35 ± 5 min) to during pile driving activity (18 ± 3 min; Figure 11). Overall behavior was significantly different ($\chi^2_{(2)} = 35.64$, $p < 0.01$) between pre- and during pile driving activity (Figure 12). Beluga whales primarily traveled through the study area both pre- and during pile driving activity; however, traveling increased during pile driving activity. Diving (n = 27 and n = 22 respectively) and suspected feeding (n = 12 and n = 4 respectively) decreased from pre- to during pile driving activity. Feeding was only observed on 2 occasions pre- pile driving activity and milling was only observed during pile driving activity (n = 21). No acute behavioral responses were documented.

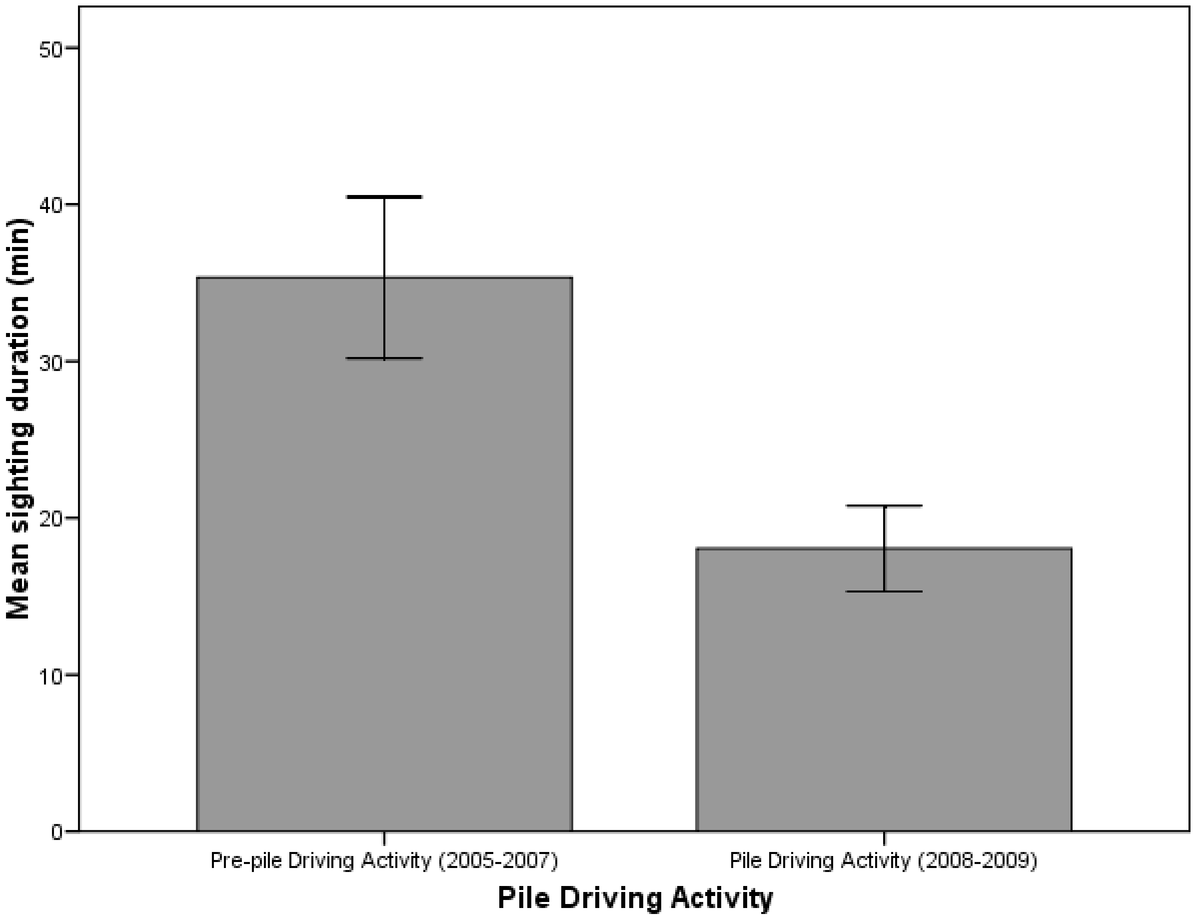

Figure 11. Mean sighting duration of beluga whales decreased significantly from pre- to during pile driving activity ($t_{(62)} = - 4.77$, $p < 0.01$).

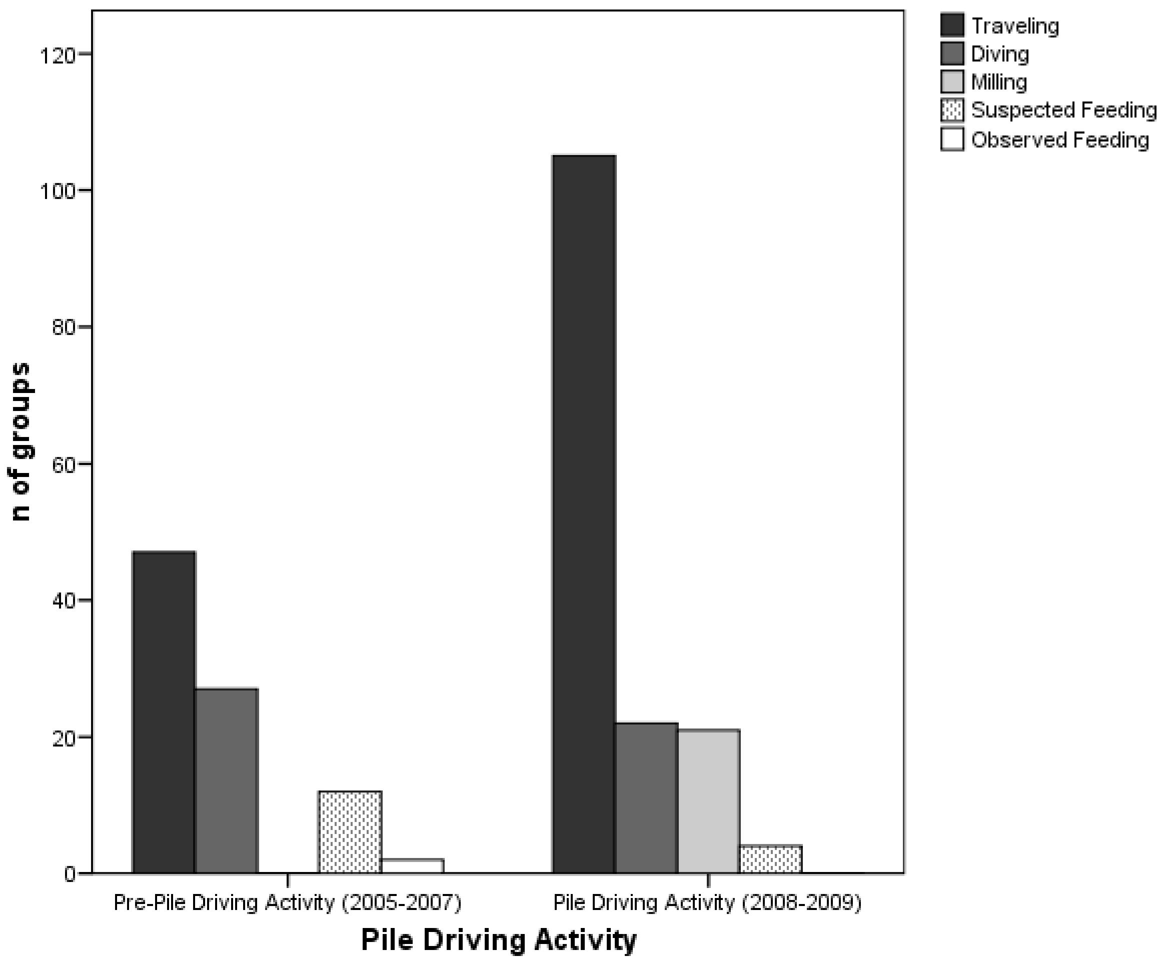

Figure 12. Beluga whale behavior pre- and during pile driving activity. Behavior was significantly different between pre-and during pile driving activity ($\chi^2_{(2)} = 35.64$, $p < 0.01$).

Mean group size was not significantly different between pre- and during pile driving activities (5 ± 1 and 3 ± 0 respectively; $t_{(62)} = 1.93$, $p = 0.06$); however there was a decreasing trend. Group composition was significantly different ($\chi^2_{(6)} = 66.18$, $p < 0.01$; Figure 6) between pre- and during pile driving activity (Figure 13). Lone white whales and mixed groups of 2-5 individuals were observed approximately 25 % of the time both pre- and during pile driving activity. There was a decrease in the percent of lone grey beluga whales between pre- (8.2 %) and during (2.5 %) pile driving activity. The percentage of groups consisting of 2-5 white individuals increased between pre- (11.5 %) and during pile (34.6 %) driving activity, while mixed groups of 11-25 whales decreased (14.8 % and 3.9 % respectively). There was a marginal increase in groups of 6-10 white individuals (1.6% to 2.4 %). Only one group of 26-50 mixed (n = 33, 0.8 %) was observed in the study area during pile driving activity. No groups > 50 were observed.

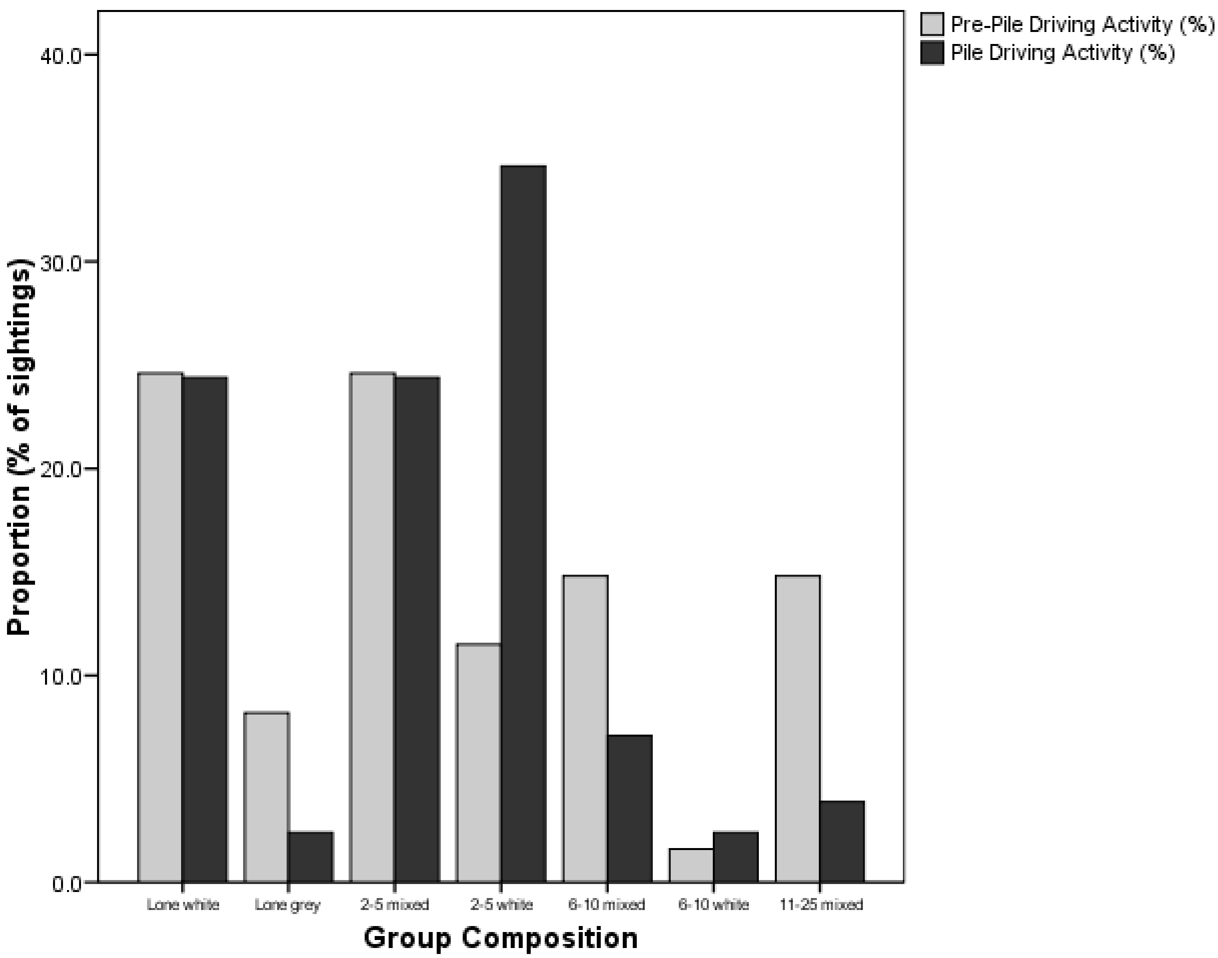

Figure 13. Beluga whale group composition pre- and during pile driving activity. Group composition was significantly different between pre- and during pile driving activity ($\chi^2_{(6)} = 66.18$, $p < 0.01$). Only one group of 26-50 mixed (n = 33, 0.8 %) was observed in the study area during pile driving activity.

Group formation was significantly different ($\chi^2_{(2)} = 7.11$, $p = 0.03$) between pre- and during pile driving activity (Figure 14). Beluga whales were primarily observed densely packed pre-and during pile driving activity (n = 29 and n = 70, respectively). Dispersed increased from pre- to during pile driving (n = 6 and n = 21, respectively), as did observations of lone individuals (n = 19 and n = 32, respectively).

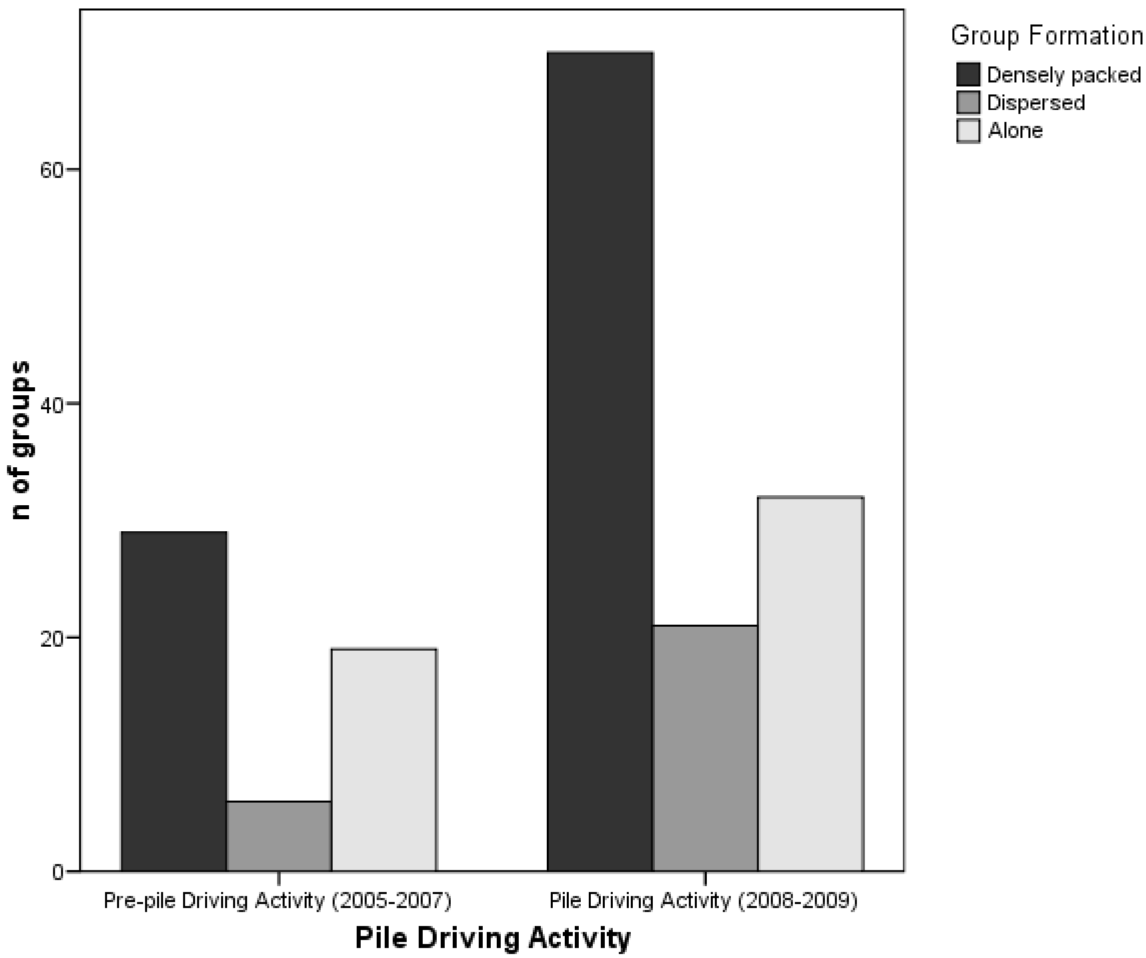

Figure 14. Beluga whale group formation for pre- and during pile driving activity periods. Group formation was significantly different between pre- and during pile driving activity ($\chi^2_{(2)} = 7.11$, $p = 0.03$).

Spatial Distribution

Beluga whales were most frequently observed along the eastern shoreline of the study area; however, sightings increased along the western shoreline near Port MacKenzie during pile driving activity (Figure 15). Throughout the study, beluga whales were also sighted along the central channel, but these sightings were less frequent than sightings along the shorelines.

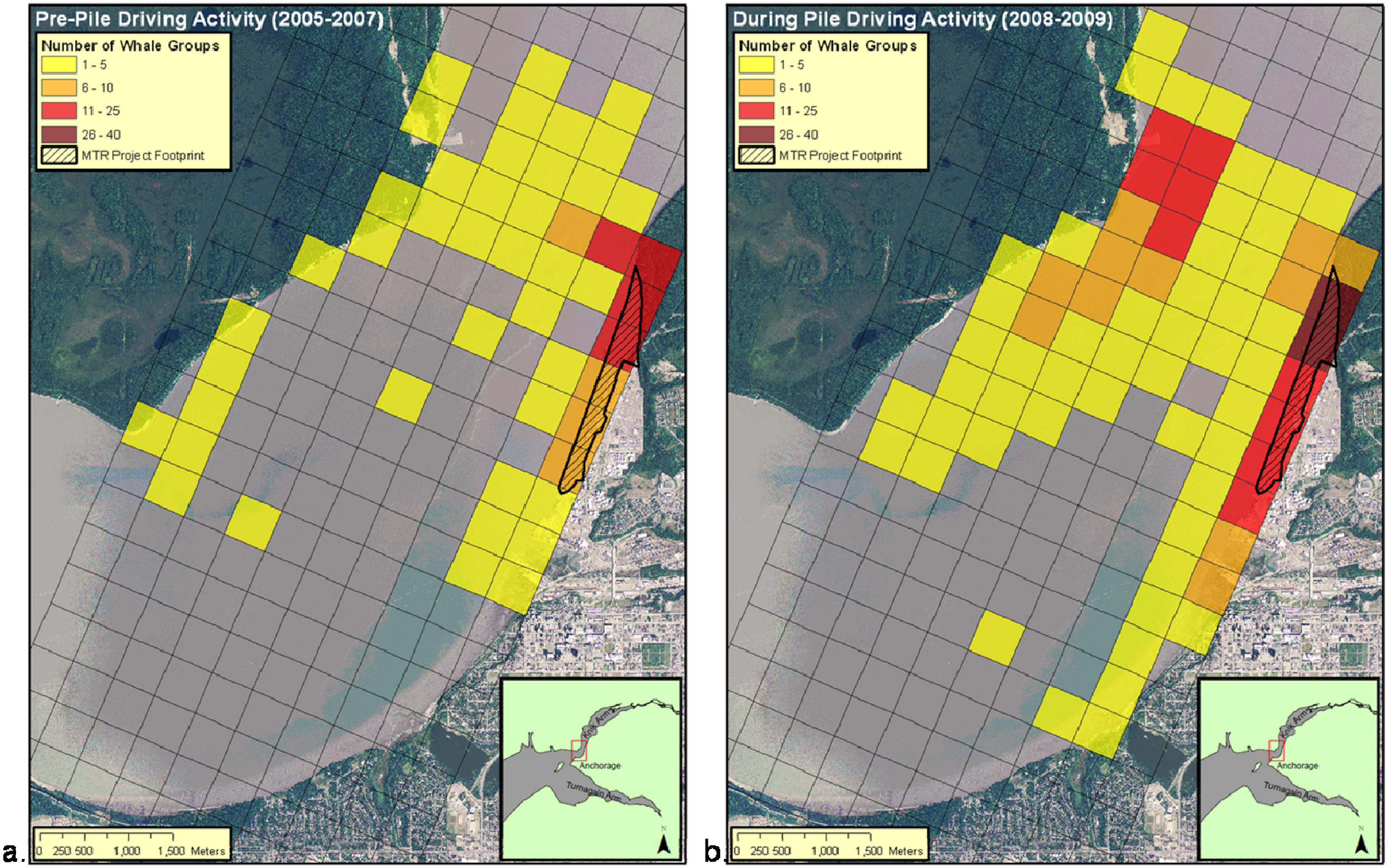

Figure 15. Beluga whale sightings a) pre-pile driving (2005-2007) and b) during pile driving activity (2008-2009). The shaded grid cells indicate the total number of beluga whale groups sighted within each grid cell for pre- and during pile driving activity. The MTR Project footprint is outlined and crosshatched.

Discussion

There was no relationship between monthly sighting rates and monthly rates of pile driving activity. Mean sighting duration of beluga whales significantly decreased from pre-pile driving to during pile driving activity. Behavior, group composition and group formation were significantly different between pre- and during pile driving activity; however, there was no significant difference in mean group size. Additionally, beluga whales were most frequently observed along the eastern shoreline of the study area near the construction activity at the MTR Project; however, there were increased sightings along the western shoreline near Port MacKenzie during pile driving activity.

Although the number of hours of pile driving activity quadrupled from 2008-2009, there was no significant relationship between sighting rates and monthly rates of pile driving activity (Figure 10). This indicates that beluga whales were continually observed in the study area even in the presence of pile driving activity.

The 2007 field season was included in pre-pile driving activity even though 5 d of test pile driving took place. Additionally, the 2007 field season was different than other season because of the abbreviated sampling effort. Both the shorten field season and the presence of pile driving activity could be problematic because it could introduce biases in the results. Therefore, the 2007 season should be excluded in further analysis.

Pile driving activity could account for the decrease in sighting duration of beluga whales from pre- to during pile driving activity. Because beluga whales can likely hear pile driving activity over great distances from the source (Erbe and Farmer 2000), beluga whales entering Knik Arm may travel quickly through the area to avoid prolonged exposure to noise associated with the MTR Project. Würsig *et al.* (2000) observed Indo-Pacific hump-backed dolphins traveling at speeds twice as fast with than without pile driving activity. Additionally, with the exception of Ship Creek, food sources are more abundant farther up Knik Arm than in the areas around the POA, creating additional impetus to move through the area.

Beluga whale behavior was significantly different from pre- to during pile driving activity (Figure 12). Beluga whales primarily traveled through the study area during both periods. Funk *et al.* (2005) also observed beluga whales primarily traveling through the entrance of Knik Arm during their baseline studies in 2005. Because beluga whales have been consistently observed traveling through the area, it could be an indication that the whales were moving into more important habitat farther up the arm. However, the number of sightings of traveling increased, while most other behavioral states decreased. The increase in traveling could be another indication that belugas were avoiding prolonged exposure to noise associated with the MTR Project. Documentation of milling began in 2007 which would explain the increase in observations of milling during pile driving activity. Observations of diving and suspected feeding decreased, while confirmed feeding was not observed during pile driving activity. The decrease in behavioral states besides traveling may indicate beluga whales were experiencing disturbance from the activity at the MTR Project; therefore, spending less time diving and feeding and more time traveling through the area.

Group size was not significantly different between pre- and during pile driving activity. Although group size was not significantly different, there was a decreasing trend from pre- to during pile driving activity. Group size could also affect sighting duration. Smaller groups would be more difficult to detect than larger groups. Therefore, smaller group would likely be observed for shorter periods of time because of their detectability.

There were marginal changes in group composition (Figure 13). White groups of 2-5 and 6-10 individuals increased during pile driving activity, while all other categories decreased. Additionally, a large proportion of sightings were of lone white whales. The white groups or white individuals could be males, or females with calves that were not visible at the time of the sighting. Beluga whales are often difficult to observe because of their coloration, particularly in poor environmental conditions, which could make it difficult for observers to identify color classes (Hobbs *et al.* 2000). Additionally, young calves may be missed entirely in poor light conditions. Therefore a higher proportion of mixed groups were likely in the area than detected by the observers. Additionally, mixed groups of 2-5 individuals accounted for approximately 25 % of groups observed in the area. A high proportion of sightings of mixed groups would be expected because Knik Arm is thought to be a nursery area, thus providing protection from predation (Huntington 2000). Caron and Smith (1990) suggest summer segregation of the sexes; therefore lower proportions of groups of white males would be expected if Knik Arm is a nursery area.

Beluga whales were commonly observed in densely packed groups both pre-and during pile driving activity. Densely packed, dispersed and sightings of lone individuals all increased from pre-to during pile driving activity; however, densely packed groups substantially increased during pile driving activity (Figure 14). Densely packed groups would be expected because it would allow for efficient group communication in noisy environments, such as Knik Arm. 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.

In general, beluga whales were most commonly observed along the eastern shoreline, with occasional sightings along the western shoreline and the central channel of Knik Arm during the entire study period. Distribution along the shorelines is consistent with other recent studies conducted in Cook Inlet (Rugh *et al.* 2000, Funk *et al.* 2005, Hobbs *et al.* 2005); however, an acoustic study on Cook Inlet beluga whales conducted adjacent to the MTR Project during August and September 2009 more often detected beluga whales near the central channel of Knik Arm (Kendall 2010a). This could indicate beluga whales use the central channel and offshore areas more frequently than indicated by visual observation studies (Kendall 2010a).

Beluga whales were observed more often along the eastern shoreline adjacent to the MTR Project, than at other locations in the study area. The sightings adjacent to the MTR Project could be the result of the proximity of the location to CPS since whales at greater distances from observers are more likely missed than beluga whales passing near observers (Buckland *et al.* 2001, Markowitz and McGuire 2007). This proximity bias, however, would not affect the sightings along the western shoreline; therefore, the increased sightings along that shoreline during pile driving activity (2008-2009) may indicate beluga whales were trying to avoid increased activity at the MTR Project.

On the other hand, the consistent sightings of beluga whales along the eastern shoreline may be related to the anadromous fish streams located along the eastern shoreline of Knik Arm. Sixmile Creek, Eagle and Eklutna Rivers are known to contain salmon runs (ADFG 2010), an important food source for Cook Inlet beluga whales (NMFS 2008b). Beluga whales are known to travel along the eastern shoreline of Knik Arm, presumably using the shortest route to their food source (Hobbs *et al.* 2005). Although pile driving activity takes place along the eastern shoreline, it may be more beneficial and energy efficient to travel near the pile driving activity at MTR Project instead of avoiding the activity because less energy would be spend traveling.

Additionally, the alternative observations stations used during 2005 and 2006 may have influenced the detectability of beluga whale groups in the study area. The three alternative stations (two the Towers and one at the north eastern corner of the POA dock) were substantially lower than the CPS. Lower observation stations decrease the likelihood of sighting whales farther away and influence the accuracy of the sighting (Würsig *et al.* 1991, Buckland *et al.* 2001); therefore, beluga whale groups near the western shoreline may have been missed during observation at the alternative sites in 2005 and 2006.

The decrease in sighting duration of beluga whales, the increase in travel and the increased sightings near Port MacKenzie may indicate avoidance behavior by beluga whales in the area around the MTR Project. Erbe and Farmer (2000) observed beluga whales in the Beaufort Sea avoiding ice breakers at distances as far away as 78 km. Würsig *et al.* (2000) observed temporary abandonment by Indo-Pacific hump-backed dolphins (*Sousa chinensis*) of the area where pile driving was taking place immediately after pile driving activity. The dolphins returned to the area once pile driving activity was completed. Carstensen *et al.* (2006) and Brandt *et al.* (2009) observed a decrease in harbor porpoises (*Phocoena phocoena*) in the presence of pile driving activity during the construction of offshore wind turbines near Denmark. Harbor porpoises returned to the construction area between pile driving events; however, the return time occasionally took several days (Carstensen *et al.* 2006). Brandt *et al.* (2009) observed the reduction of harbor porpoise activity and density at the 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.

Knik Arm is included in the proposed critical habitat for the Cook Inlet beluga whale and avoidance of this area by beluga whales could be detrimental to their recovery. The area north of the construction site is an important foraging area (Sixmile Creek and Eagle River; Hobbs *et al.* 2005, NMFS 2008b) and may also serve as a calving and nursery area (Huntington 2000; NMFS 2008b). Any avoidance of Knik Arm by beluga whales could also cause permanent displacement from the area. If beluga whales are displaced from this important habitat, it may reduce their foraging and reproductive success. The Cook Inlet population, which is not rebounding as expected, could greatly suffer from the loss of this habitat, even for a short period of time associated with construction activities at the POA.

Future Research

Monitoring of Cook Inlet beluga whales during the MTR Project is critical for the survival of this endangered species and should continue beyond the completion of the project. To better understand long-term impacts of pile driving activity at the MTR Project on Cook Inlet beluga whales, a similar study examining behavior and distribution should occur after pile driving activity is completed. Additionally, a study comparing behavior and distribution across seasons and tidal stages would give insight into overall effects on the beluga whale from pile driving at the MTR Project because these two natural factors strongly influence the presence of beluga whales in various areas of Knik Arm (Moore *et al.* 2000, Rugh *et al.* 2000, Hobbs *et al.* 2005, Funk *et al.* 2005). Studies such as these would not only provide information on general behavior, but also provide insight into potential impacts of noise as well as coastal zone development from future projects. Development projects will continue throughout Cook Inlet;

therefore, it is important to understand and reduce their impacts on Cook Inlet beluga whales, ultimately aiding in the recovery of this population.

Chapter III

The effects of construction noise on the Cook Inlet beluga whale (*Delphinapterus leucas*) vocal behavior

Abstract

Cook Inlet beluga whales (*Delphinapterus leucas*) are geographically isolated and genetically distinct from the other US beluga stocks. They were recently listed as endangered under the US Endangered Species Act. Many factors are identified as potential threats to the Cook Inlet beluga whale population, including coastal zone development and anthropogenic noise. The Port of Anchorage (POA) Marine Terminal Redevelopment (MTR) Project, taking place in Knik Arm, Cook Inlet, involves several types of construction activities including dredging, gravel fill, and pile driving. In this study I investigated the impacts of construction activity on beluga whale sound production using passive acoustic monitoring. Four moored lines were deployed near the MTR Project at the beginning of the survey and multiple sonobuoys were deployed in the array during 20 d of monitoring in August and September 2009. Data were recorded in real-time at the shore-based observation station. The energy summation method was used to automatically detect echolocation clicks. Times with and without construction noise (dredging and pile driving) were determined using long-term spectral averages. An independent samples t-test was used to determine if there was a difference in the detected hourly click rate of beluga whale clicks during periods with and without construction activity. Detected hourly click rate was not significantly different ($t_{(24)} = -0.56$, $p = 0.58$) during periods without construction noise; however, the detected click rate was higher without construction activity. The results from this study indicate potential masking of or a reduction of beluga whale vocalizations during construction activity or their possible avoidance of the area.

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, Angliss and Allen 2009). They were recently listed as endangered under the US Endangered Species Act after continued population decline following the voluntary moratorium on subsistence hunting (NMFS 2008a, Hobbs *et al.* 2009). Many factors are identified as potential threats to the Cook Inlet beluga whale, including coastal zone development and anthropogenic noise (NMFS 2008b). 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 at ranges from 10-100 kHz but their range extends as low as 40-75 Hz (Awbrey *et al.* 1988, Johnson *et al.* 1989, Richardson *et al.* 1995). Their sensitivity to high frequencies is related to their use of those high frequencies for echolocation and communication (Richardson *et al.* 1995).

Beluga whales, also known as the “canaries of the sea” because of their ability to produce a variety of sounds frequently (Reeves *et al.* 2008), were one of the first cetaceans to be recorded underwater (Schevill and Lawrence 1949). Schevill and Lawrence (1949) described the sounds produced by beluga whales as “high-pitched resonant whistles, squeals, ticking, clucking, chirps, bell-like…some sounds resembled an echo sounder, crowds of children shouting and jaw snapping.” Generally, sounds produced by toothed whales such as belugas can be classified into three categories: tonal whistles, pulsed sounds of very short duration and high frequency (echolocation), and less distinct pulsed sounds of lower frequency (cries, grunts, and barks). Beluga whale whistles range between 0.26-20 kHz, noisy vocalizations between 0.5-16 kHz (Richardson *et al.* 1995), and echolocation sounds produced by beluga whales have been recorded up to 120 kHz (Au *et al.* 1985). Whistles and pulsed sounds of lower frequency are generally associated with social behaviors (Sjare and Smith 1986a, Faucher 1988, Karlsen *et al.* 2002, Belikov and Bel'kovich 2006, 2007, 2008), while 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, Canada (Sjare and Smith 1986a, Sjare and Smith 1986b), St. Lawrence Estuary, Canada (Faucher 1988), Bristol Bay, Alaska (Angiel 1997), Svalbard, Norway (Karlsen *et al.* 2002), and the White Sea, 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). Overall, whistles and noisy vocalizations are common among different beluga whale stocks; however, differences do exist among the most common parts of the vocal repertoire of different beluga whale stocks. For example, the V-shaped contour is common in the White Sea stock, while flat whistles are more common in the repertoire of North American and Svalbard belugas (Sjare and Smith 1986b, Karlsen *et al.* 2002, Belikov and Bel'kovich 2007). Echolocation clicks have not been examined between wild stocks, but three different click patterns based on click intervals have been identified in captive beluga whales including modes 1 (click intervals were greater than two-way travel time), 2 (click intervals were less than two-way travel time but greater than 5 ms) and 3 (click intervals were less than 5 ms with a mean of 1.7 ms; Au *et al.* 1987). Beluga whales' range of echolocation click strategies is likely an adaptation to their noisy Arctic environment of shifting ice. These click strategies allow them to navigate and find breathing holes under the ice (Au *et al.* 1985, Au *et al.* 1987, Turl and Penner 1989, Turl 1990). 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). Effects from anthropogenic noise on cetaceans have been studied on blue (*Balaenoptera musculus*), fin (*Balaenoptera physalus*), bowhead (*Balaena mysticetus*), beluga, and sperm whales (*Physter macrocephalus*), harbor porpoise (*Phoecoena phoecoena*), beaked whales (*Ziphius* spp. and *Mesoplodon* spp), Indo-Pacific hump-backed dolphins (*Sousa chinensis*), as well as other species (Frantzis 1998, Erbe and Farmer 2000, Würsig *et al.* 2000, Jepson *et al.* 2003, Ljungblad *et al.* 1988, Croll *et al.* 2001, Lesage *et al.* 1999, Patenaude *et al.* 2002, Greene *et al.* 2004, Scheifele *et al.* 2005 , Carstensen *et al.* 2006, Smultea *et al.* 2007, Brandt *et al.* 2009). Behavioral responses of cetaceans to anthropogenic noise include sudden changes in direction or speed, changes in dive patterns, and avoidance or displacement from important habitat (Ljungblad *et al.* 1988, Blane and Jaakson 1994, Richardson *et al.* 1995, Erbe and Farmer 2000, Würsig *et al.* 2000, Greene *et al.* 2004, Patenaude *et al.* 2002, Carstensen *et al.* 2006, Stone and Tasker 2006, Smultea *et al.* 2007). Acoustic responses of cetaceans include cessation of vocalizing, increased rate of vocalizing, or change in call types (Lesage *et al.* 1999, Croll *et al.* 2001, Schiefele *et al.* 2005, Holt *et al.* 2008). Physiological responses to or injury from anthropogenic noise include changes in respiratory rate (Ljungblad *et al.* 1988), auditory threshold shifts (Finneran *et al.* 2000, Schlundt *et al.* 2000, Finneran 2008), and tissue damage which can result in death (Frantzis 1998, Jepson *et al.* 2003, Nowacek *et al.* 2007).

There is limited research on the impacts of construction activity on cetaceans (Richardson *et al.* 1995, Würsig *et al.* 2000, NRC 2003, Carstensen *et al.* 2006, Brandt *et al.* 2009). Documented cetacean responses in the presence of pile driving activity include changes in behavior (e.g., an increase traveling densely packed and decrease sighting duration), a reduction of acoustic activity, a reduction of the number of individuals in the area, changes in distribution and avoidance of the area (Würsig *et al.* 2000, Carstensen *et al.* 2006, Brandt *et al.* 2009, Kendall 2010b). The effects of anthropogenic noise on cetaceans have been studied on beluga whales. Beluga whale behavioral responses in the presence of anthropogenic noise (i.e., watercraft, aircraft and pile driving) include changes in swimming speed, diving patterns, direction, behavioral states, vocalizations, a change in sighting duration and avoidance (Blane and Jaakson 1994, Lesage *et al.* 1999, Erbe and Farmer 2000, Karlsen *et al.* 2002, Patenaude *et al.* 2002, Scheifele *et al.* 2005, Belikov and Bel'kovich 2007, Kendall 2010b).

To increase our understanding of the effects of anthropogenic noise on marine mammals, additional monitoring studies are needed. Passive acoustic monitoring is a rapidly developing technique that is increasingly used for cetacean surveys (Mellinger *et al*. 2007). Traditional visual surveys only record surfacing animals during daylight hours in good weather conditions, 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). Acoustic monitoring is usually conducted using dipping hydrophones, sonobuoys, towed arrays, or autonomous recorders. Sonobuoys have been used successfully for a variety of cetacean passive acoustic studies, including documenting the presence and location of calling animals and comparison with visual observations (Levenson and Leapley 1978, Clark *et al*. 1985, McDonald and Moore 2002, Laurinolli *et al.* 2003, Širović *et al.* 2006).

The Port of Anchorage (POA) Marine Terminal Redevelopment (MTR) Project 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 sound levels and could interfere with beluga whale communication and echolocation (Richardson *et al.* 1995, NMFS 2008c). As a result it is important to monitor Cook Inlet beluga whales to determine if the construction may have an impact on their acoustic behavior.

I investigated the impact of construction noise in the vicinity of the MTR Project on beluga whale sound production using sonobuoys during passive acoustic monitoring. I used an automatic detector to determine the presence of echolocation clicks. I calculated the detected click rate to determine if there are differences in the rate of detected beluga whale clicks with and without construction activity at the MTR Project.

Methods

Study Area and Design

The study was conducted in Knik Arm, Upper Cook Inlet, adjacent to the MTR Project near Anchorage, Alaska (Figure 16). The study took place from 1 August-30 September, 2009. Sonobuoys were deployed in the vicinity of Cairn Point located north of the MTR Project and close to in-water construction activities (Figure 16). Four moored lines were deployed in a rhomboid formation at the beginning of the survey period, allowing quick re-deployment of multiple sonobuoys in the array throughout the survey. After each sonobuoy deployment, observers at the Cairn Point Station (CPS) on Elmendorf Airforce Base monitored and recorded signals received from the sonobuoys in real-time. At the end of the survey period, the moorings were removed. 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 the time beluga whales are most frequently observed in the area (Rugh *et al.* 2000, Hobbs *et al.* 2005). The days and times of sonobuoy deployment and acoustic data collection were driven by tides and weather conditions, which limited the ability to launch a boat.

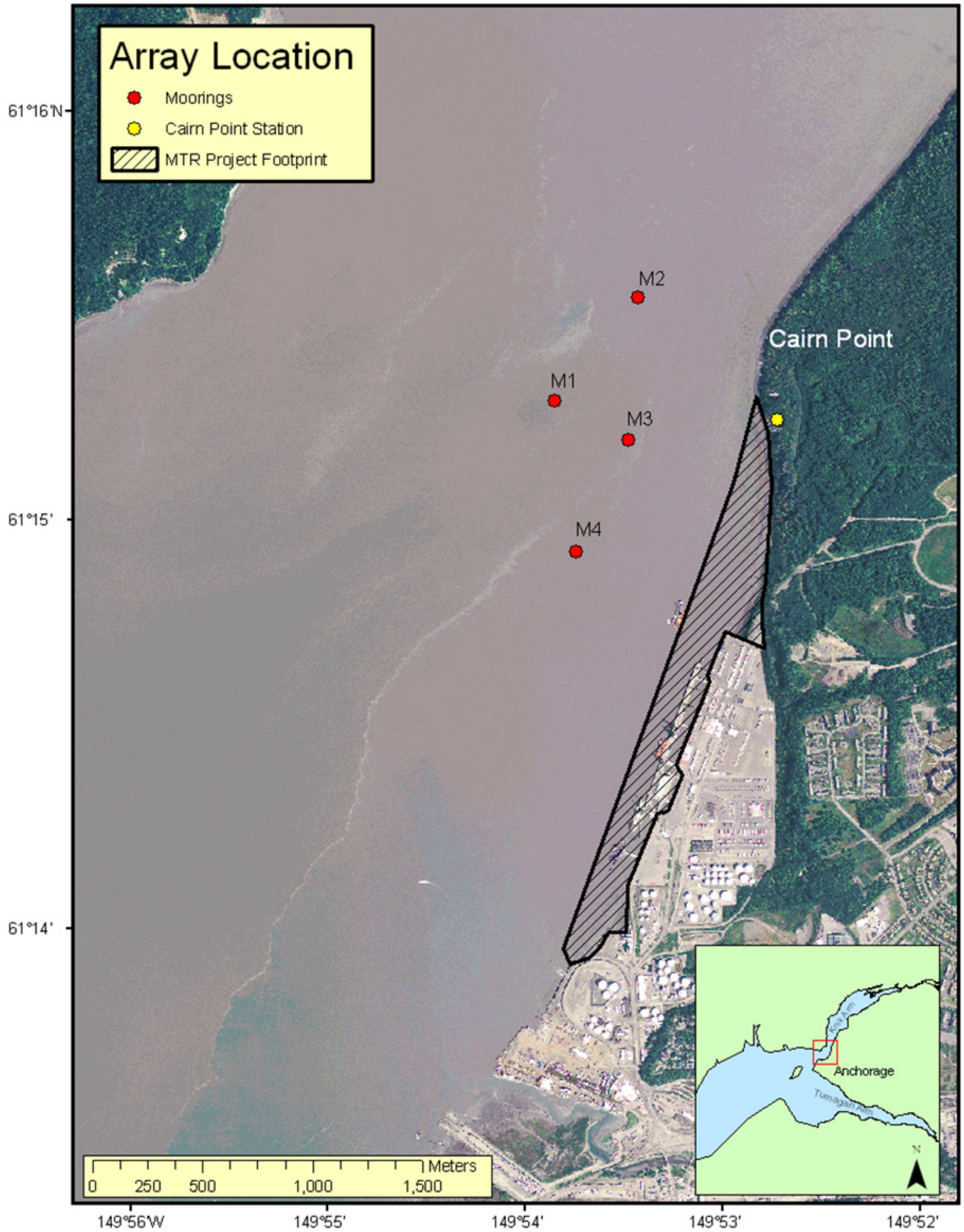

Figure 16. The location of the tightly spaced array of 4 moored lines (red dots), placed between 400 and 700 m apart and approximately 600 m off Cairn Point. Sonobuoys were attached to the moorings during each day of acoustic monitoring. The MTR Project footprint is outlined and crosshatched and Cairn Point Station is denoted by the yellow dot.

Data Collection

Sonobuoys

Sonobuoys are expendable electronic devices that consist of a hydrophone, float, radio transmitter, antenna and salt-water battery (Figure 17). Omnidirectional sonobuoys, AN/SSQ-57B, used in this study have a calibrated broadband frequency response from 10 up to 20,000 Hz, but can be used to detect signals up to 30 kHz (Horsley 1989). Signals received by the omnidirectional hydrophone are amplified and sent up a wire to the radio transmitter and antenna which are housed in the surface float. The length of the wire between the surface float and the hydrophone can be controlled and is set before deployment. Sonobuoys continuously transmit their radio signal to a remote observer for a maximum of 8 h before scuttling, thus enabling real-time monitoring and data processing.

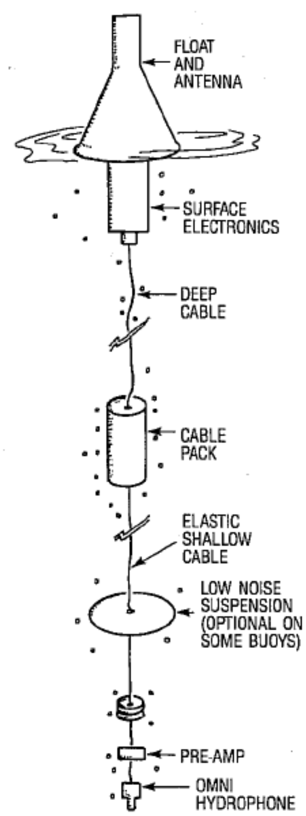

Figure 17. Type AN/SSQ-57B omnidirectional sonobuoy. (Figure adapted from Horsley 1989).

Mooring Installation

Mooring lines were installed in Knik Arm on 1 August and were left in the water until 7 October 2009. Their location (latitude and longitude) was recorded using the handheld Garmin Global Positioning System (GPS) 72 Personal Navigator at the time of installation. Four moorings (Figure 16) were deployed, each anchored with approximately 270 kg of railroad rail sections and attached to a 45-55 m long line with a surface float. A life ring flotation device was attached to each of the floats with 3 m of additional line. Strobe lights were attached to the life ring on 13 August, to increase the visibility of the moorings for passing vessels under low light conditions. The locations of the moorings were checked throughout the survey to verify they were not moved by the strong tidal currents.

Sonobuoy Deployment

Prior to deployment, sonobuoys had to be modified for deployment in the high tidal current conditions of Knik Arm. Each sonobuoy was stripped from its original casing and placed in a plastic canister attached to a life ring (Figure 18a). The life ring provided additional structural support against the fast moving currents, allowing the sonobuoy float to remain in a vertical position on the surface of the water after deployment (Figure 18b). The vertical position was important to facilitate signal transmission from the sonobuoy to the shore station. 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 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 the handheld Garmin GPS to verify the location of the moorings. The daily recorded location of each mooring was compared to its location on the day of installation, to verify the moorings did not move during the study. Once deployed, the sonobuoys continuously transmitted their radio signal to remote observers at the CPS for approximately 8-10 h before scuttling. Due to restrictions in the ability to launch a boat for sonobuoy deployment, most data collection started on the slack high tide and occurred during the ebb flow.

Two 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 sonobuoy data. The antennae received the signals and passed them to four software-controlled ICOM scanner radio receivers (IC-PCR 100 or IC-PCR1500; one per sonobuoy signal), modified to provide improved signal reception. Each radio was connected to a computer, which was connected to a MOTU Traveler mk2. 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 digitized using the software program *Ishmael* (Mellinger 2001) and saved as .WAV files on 500 GB hard disks. Reception of the sonobuoy signal was verified with the deployment team (the members of the team on the boat deploying the sonobuoys) after each deployment. In the case of a failed deployment, the deployment team immediately recovered the failed sonobuoy and deployed another one.

a.


b.


Figure 18. a) Omnidirectional sonobuoy (AN/SSQ-57B) stripped from its original casing and placed in a plastic canister attached to a life ring flotation device ready for deployment. b) A deployed sonobuoy in Knik Arm with a flotation ring and surface float. The MTR Project is in the background.

Sampling Effort

Acoustic data were collected during 20 d between 1 August and 30 September, 2009. Daily acoustic observations continued up to10 h with a mean of 7:25 ± 0:29 min; however, if sonobuoys continued transmitting after dark, the recording setup was left at CPS and the equipment and data were retrieved the following morning. Recordings were collected during periods with and without construction activity.

During the daily acoustic observation period, deployment, construction, and environmental data were collected and preliminary acoustic analysis was 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. Data were entered into *Microsoft Excel* for *Windows* for storage and subsequent analysis.

Anthropogenic Activities

All anthropogenic activities within the study area were documented during daily observation efforts. Events were categorized as: no activity, IPD, VPD, dredging, in-water fill placement, and aircraft and vessel activities. The duration of each activity was recorded.

Data Analysis

Automatic Detections of Echolocation Clicks

Sonobuoy recordings were analyzed using an automatic detection method with the software program *Ishmael* (Mellinger 2001). I used energy summation for automatic analysis due to the short duration and broadband frequency of beluga whale clicks. The energy summation method is based on the calculation of the total energy in a frequency band that contains all or a part of the sound of interest (Mellinger 2001). To reduce the number of false detections, the ratio between the energy in the frequency band of interest and that in an adjacent band of noise not containing the sound of interest is used. The frequency band used for the calculation of signal energy was 23-25 kHz, which was then compared to the energy in the adjacent "noise" frequency band from 18-20 kHz. Due to 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 for 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.

Due to the variation in sonobuoy signals during the survey period, the results of the automatic detector were visually verified and parameters were modified for different recording times. When the program signaled a detection, 2 s of the signal before and after the detection were saved into an individual .WAV file, providing information on the presence and timing of the sound of interest. Each file was visually verified for the presence of beluga whale echolocation clicks. False detections were removed from subsequent analysis.

Effects of Construction Activity on Vocal Behavior

Times with and without construction activity were determined by examining long-term spectral averages (LTSA) calculated from the original .WAV files. Calculations were done using *Triton*, a *MatLab* (MathWorks, Natick, MA) based customized sound analysis program developed by S. Wiggins. Calculated LTSAs had 10 s time resolution and 500 Hz frequency resolution and provided an overall picture of activity at the MTR Project on a daily basis (Figure 19). Only data from moorings that detected clicks were used in analysis. Each LTSA was manually examined for the start and end of construction activity. All construction activities (IPD, VPD, dredging) were pooled for analysis because they frequently overlapped and were not easily distinguishable from the LTSA. 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. 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 hourly click detection rate during time periods with and without construction was calculated for each day of observations. To avoid counting the same click twice, clicks from only the mooring with the longest recording for the day were counted if more than one mooring detected clicks on a particular day. An independent samples t-test was used to determine if there were differences in the rate of detected beluga whale clicks during periods with and without construction activity. The alpha level was set at $p < 0.05$.

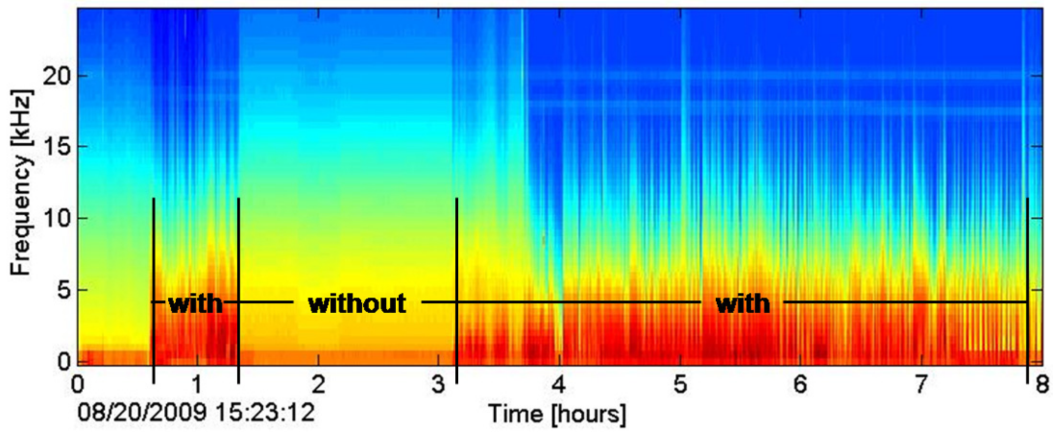

Figure 19. A long-term spectral average (LTSA) for 20 August 2009. The LTSA provides an overall picture of activity at the MTR Project on a daily basis. Example times "with" and "without" construction activity are marked.

Results

Sampling Effort

Acoustic observations were conducted for more than 148 h over 20 d in August and September 2009. Eighty-six sonobuoys were deployed during the study 8 of which failed (failure rate 9.3 %). Of the 566 h of passive acoustic data that could have been collected from the 4 moorings, only a total of 373 h of acoustic data were collected. The 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 from 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

A total of 63,392 clicks was detected during 14 d (out of 20) of the passive acoustic study, although some of those clicks were likely the same click detected on two different sonobuoys (Table 5). Most of the energy in beluga whale clicks recorded in the vicinity of the MTR Project construction site was above 15 kHz (Figure 20). Beluga whale clicks were detected most commonly on mooring M1, the westernmost mooring.

Table 5. Number of clicks detected on each mooring with detections on a given day.

Date	Mooring	No. of Clicks
04-Aug-09	M2	29
13-Aug-09	M4	1,283
18-Aug-09	M1	31
20-Aug-09	M1	16
	M2	10
22-Aug-09	M1	8,619
	M2	2,027
25-Aug-09	M2	21
01-Sep-09	M1	1,367
04-Sep-09	M1	1,382
	M2	177
08-Sep-09	M2	97
10-Sep-09	M1	399
	M2	1,094
20-Sep-09	M1	577
23-Sep-09	M1	6,256
	M4	22
25-Sep-09	M1	2,804
	M3	785
27-Sep-09	M2	15,231
	M3	3
	M4	22,505
	Total	63,392

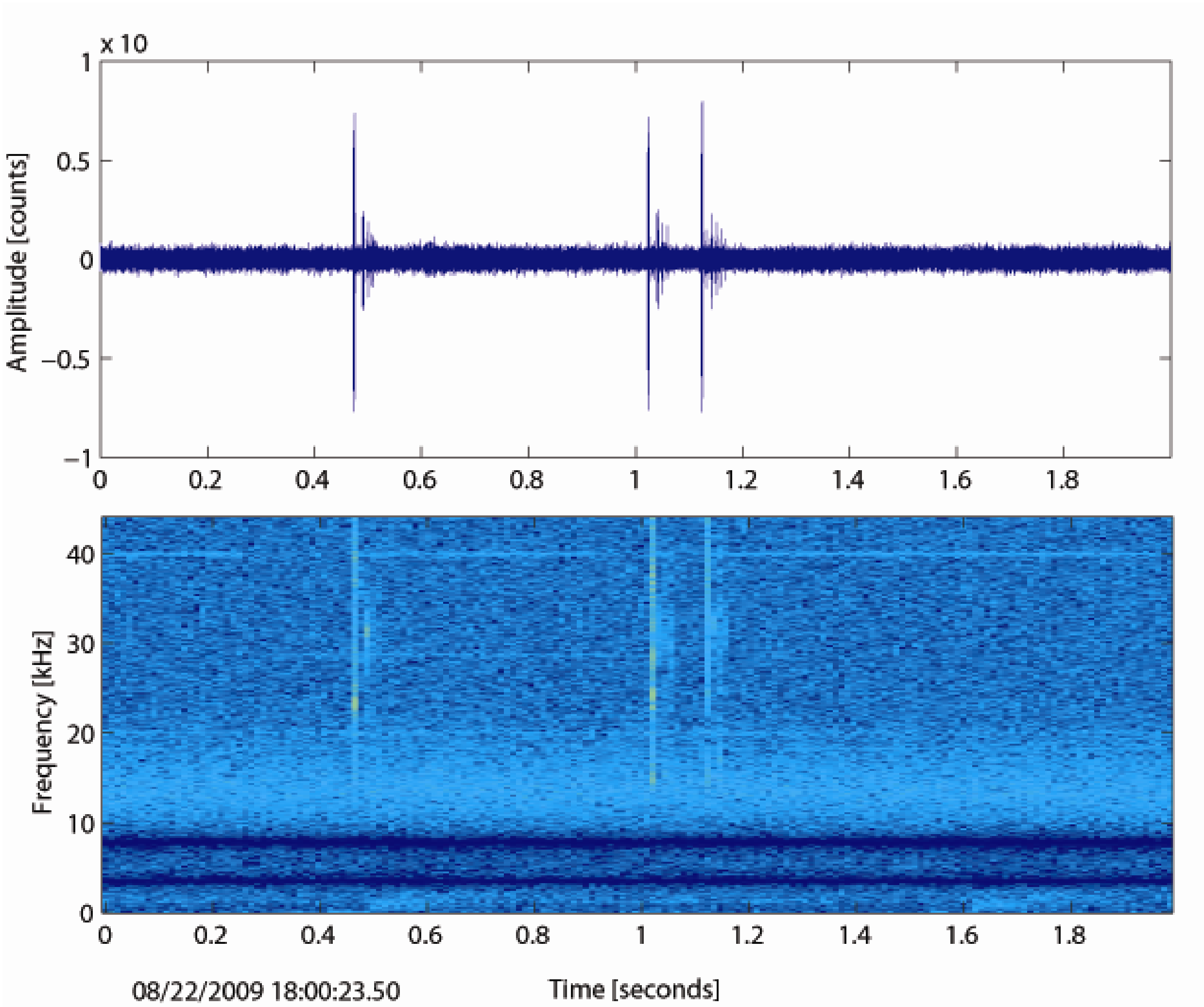

Figure 20. Time series and spectrogram of three beluga whale echolocation clicks recorded on 22 August 2009 on mooring M1. The spectrogram was plotted with 1000-point FFT, 0 % overlap, and the signal was low pass filtered at 15 kHz.

Effects of Construction Activity on Vocal Behavior

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 6). Detected hourly click rate was not significantly different ($t_{(24)} = -0.56$, $p = 0.58$) during periods with (291.12 detected clicks/h) and without (428.61 detected clicks/h) construction activity; however, detected click rate was higher without construction activity (Figure 21).

Table 6. Sonobuoy sampling effort, total time, total number of detected echolocation clicks and hourly click rate with (WITH) and without (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	Detected Click Rate WITHOUT
04-Aug-09	3:46	3:46	0:00	29	–	7.69	–
13-Aug-09	8:17	8:17	0:00	1,283	–	154.95	–
18-Aug-09	7:25	4:07	3:18	31	0	7.52	0.00
20-Aug-09	7:36	5:56	1:40	10	0	1.69	0.00
22-Aug-09	6:48	3:49	2:59	4,380	4,239	1,146.60	1,422.48
25-Aug-09	5:11	3:12	1:59	14	7	4.38	3.54
01-Sep-09	6:36	3:54	2:42	185	1,182	47.44	437.78
04-Sep-09	6:58	5:20	1:38	134	43	25.14	26.38
08-Sep-09	3:41	2:20	1:21	61	36	26.18	26.67
10-Sep-09	6:10	5:46	0:24	1,094	0	189.60	0.00
20-Sep-09	4:58	3:12	1:46	400	177	125.00	100.00
23-Sep-09	7:52	6:59	0:53	5,775	481	827.36	546.59
25-Sep-09	8:47	7:28	1:19	630	155	84.34	117.42
27-Sep-09	9:10	7:05	2:05	10,109	5,122	1427.82	2462.50
Total	**93:15:00**	**71:11:00**	**22:04:00**	**24,135**	**11,442**	**291.12[c]**	**428.61[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 day .

[c] These values represent the mean detected click rate for periods "with" and "without" construction activity.

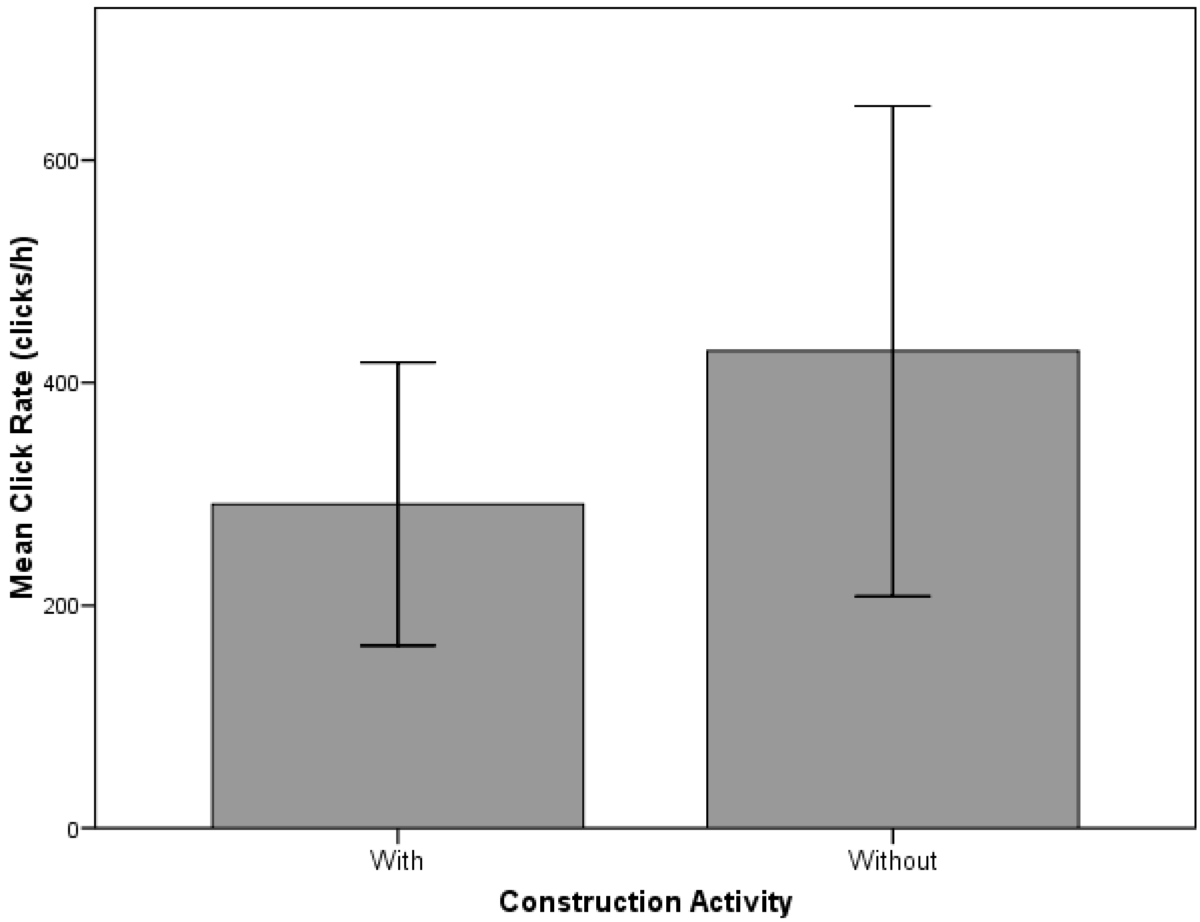

Figure 21. Detected hourly beluga whale echolocation click rates with and without construction activity near the MTR Project during the 14 d beluga whale clicks were detected between 1 August and 30 September, 2009.

Discussion

Echolocation clicks were frequently produced by beluga whales in the vicinity of the MTR Project. No other types of vocalizations (e.g., whistles) were detected with the sonobuoy array. The detected click rate was not significantly different during periods with and without construction activity; however, the detected click rate was higher without construction activity. Beluga whales were most commonly detected on M1, the westernmost mooring adjacent to the deep channel located in the center of Knik Arm.

Effects of Construction Activity on Vocal Behavior

Construction activity took place during the majority of the acoustic survey. It is likely that beluga whales are competing with the persistent noise associated with construction activity at the MTR Project which may mask their whistles and noisy vocalizations. The frequency bandwidth recorded from the noise associated with activity near the MTR Project was generally below 10 kHz; however, the frequency bandwidth recorded from impact pile driving extended to 20 kHz. Beluga whale whistles and noisy vocalizations are within the frequency bandwidth produced by the construction activity (Richardson *et al.* 1995). VPD would more likely mask beluga whale vocalizations than IPD or other construction activities at the MTR Project because it is a continuous noise and the frequency bandwidth is within the range of whistles and noisy vocalizations (up to 10 kHz). In an attempt to avoid interference from the continuous construction noise, beluga whales may not use whistles or noisy vocalization and may only rely on echolocation clicks when moving through the area. Therefore, masking could explain why no other types of vocalizations were recorded with the sonobuoy array.

Conversely, the type of vocalizations used by beluga whales is likely determined by the behavioral state of the whale (Sjare and Smith 1986a, Au *et al.* 1985). Beluga whales are highly vocal animals (Reeves *et al.* 2008). They rely on echolocation to navigate (Richardson *et al.* 1995) and are commonly observed traveling through the study area (Cornick and Kendall 2008a, 2008b, Cornick *et al.* 2010). Echolocation could be particularly important to beluga whales for navigating in the turbid waters of Cook Inlet where the whales cannot rely on eyesight for navigation. As a result, echolocation could be the primary type of vocalization required by beluga whales when in the observed study area.

In addition to the lack of whistles and noisy vocalizations used by beluga whales in the study area, click rate was higher without construction activity. This is another possible indication of a reduction in vocal activity by the beluga whales in the study area during construction. Masking would not be an issue when producing echolocation clicks because beluga whale clicks extend above the frequency bandwidth recorded for the construction activity at the MTR Project. Alternatively, the reduction in click rate with construction activity could indicate a reduction in the number of beluga whales in the area. Carstensen *et al.* (2006) and Brant *et al.* (2009) observed similar responses from harbor porpoises during the installation of offshore wind turbines. They suggest the reduction in echolocation clicks by harbor porpoises was a result of the reduction the number of harbor porpoises present in the area. The reduction of beluga whales in the study area could suggest avoidance of the area near the construction site.

Beluga whales were more commonly detected acoustically offshore near the deep channel in Knik Arm (moorings M1 and M2) 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 Scientific Program observers for the MTR Project more often observed beluga whales along the shoreline and adjacent to the MTR Project footprint than offshore (Markowitz and McGuire 2007, Cornick and Kendall 2008a, 2008b, Cornick *et al.* 2010). However, sightings are directly related to the location 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 acoustically detected beluga whales were primarily west of the moorings, they may be using a more energetically efficient method of travel through the area by taking advantage of the fast-moving current in the deep channel located in the center of Knik Arm (KABATA 2005, Smith *et al.* 2005). However, the direction and location of the acoustically detected beluga whales from the mooring is unknown because it was not feasible to localize the whales. Additionally, the location of the acoustically detected beluga whales near the central channel of Knik Arm may indicate disturbance from the construction activity.

While the noise from the construction activity may cause 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 (NMFS 2009a). Knik Arm is included in the area proposed as critical habitat for the Cook Inlet beluga whale (NMFS 2009a). Critical habitat provides areas for summer foraging, calving, molting, and predator avoidance as well as known fall and wintering areas (NMFS 2009a). Beluga whales may move through the study area more quickly and spend less time in the study area because the important habitat north of the MTR Project. The Scientific Program observers 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 2008a, 2008b, Cornick *et al.* 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. 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 Program observers (Cornick and Kendall 2008a, 2008b, Cornick *et al.* 2010) may indicate avoidance of the construction area by beluga whales. Carstensen *et al.* (2006) observed harbor porpoises returned to the construction area between pile driving events; however, the return time occasionally took several days. Brandt *et al.* (2009) observed the reduction of harbor porpoise activity and density at the 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 the Cook Inlet beluga whale's range has been contracting over the past 3 decades (NMFS 2008b, NMFS unpublished data), avoidance or displacement of the Cook Inlet beluga whale from the upper reaches of Knik Arm could be detrimental to their recovery.

Future Research

This study provided evidence that beluga whales may not use whistles and noisy vocalizations when traveling near the MTR Project, they may decrease click rates in the presence of construction noise and there may be a decrease in the number of beluga whales traveling through the area. Sound is very important to beluga whales and noise could interfere with their basic biological needs such as communicating, socializing, navigating and foraging. However, 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 by gathering baseline data. Additionally, with baseline data on the Cook Inlet beluga whale repertoire we could compare dialects between other beluga stocks around the world. This would improve our understanding of the relationship between the different stocks as well as our ability to monitor and our general knowledge of beluga whales.

Knik Arm, Cook Inlet provides a challenging environment to conduct passive acoustic monitoring of beluga whales. The strong tides and currents, with speeds over 7 knots (KABATA 2005, Smith *et al.* 2005), often inhibited signal transmission or damaged the equipment. As technological advances continue, perhaps equipment more suitable for hostile environments such as Cook Inlet will be developed. Although some cetaceans are more often detected acoustically than visually (Clark *et al.* 1985, McDonald and Moore 2002, O'Boisseau *et al.* 2007, Kimura *et* *al.* 2009), it is still important to incorporate visual observations. We do not fully understand the relationship between behavioral states and vocalizing; therefore, visual observations are paramount for identifying the calling species if it is unknown, can confirm the presence or absence of species if they are not vocalizing and can help clarify the impacts of construction activity on beluga whales. By improving our understanding of these impacts, we could also obtain a better understanding of factors causing the population decline, which could aid in the recovery of the Cook Inlet beluga whale.

Chapter IV

Summary and Conclusion

Humans impact their surrounding environment, often at the expense of other species. Anthropogenic impacts to marine systems (e.g., coastal and resource development, increased underwater noise, pollution, overfishing, etc.) are contributing to the depletion of species diversity around the world (Sala and Knowlton 2006) and it is often difficult to isolate proximate and ultimate mechanisms contributing to the decline or inhibiting the recovery of species. The Cook Inlet beluga whale population is an example of a declining species not well understood. Many contributing factors have been suggested (NMFS 2008b), but none have been identified. Therefore, it is important to investigate contributing factors, such as coastal zone development and anthropogenic noise, to help mitigate the decline.

The goal of this study was to investigate construction impacts on the Cook Inlet beluga whale at the Port of Anchorage (POA) Marine Terminal Redevelopment (MTR) Project using visual and acoustic observations. First, I examined the behavior and distribution of Cook Inlet beluga whales in years pre- and during pile driving activity at the MTR Project. I examined differences in the sighting duration of beluga whales, behavioral states, group size, group composition and group formation, as well as beluga whale distribution within the study area. In the second part of the study, I focused on the effects of construction noise at the MTR Project on beluga whale vocal behavior. I examined beluga whale clicks for differences in the detected clicks rates during periods with and without construction activity.

Understanding the behavior and distribution of beluga whales in the presence and absence of construction activity will help identify the impacts of coastal zone development on the species. I hypothesized that there would be differences in behavior and distribution between pre- and during pile driving activity. This study showed differences in the sighting duration of beluga whales, behavioral states, group composition and group formation. Group size was similar pre- and during pile driving activity; however, there was a declining trend. There was no relationship between sightings rates and the rate of pile driving activity. Additionally, while beluga whales were most frequently distributed along the eastern shoreline both pre- and during pile driving activity, there was an increase in sightings along the western shoreline near Port MacKenzie during pile driving activity, the side opposite of the MTR Project.

The sighting duration of beluga whales decreased from pre- to during pile driving activity and behavioral states were significantly different. Although sighting duration decreased it may be the results of the difficulty in observing smaller groups sizes. Traveling increased while all other activity decreased. The decrease in the behavioral states other than traveling and the decrease in the sighting duration of beluga whales may indicate beluga whales were experiencing disturbance from the activity at the MTR Project; therefore, spending less time diving and feeding and more time traveling through the area.

There were marginal changes in group composition from pre- to during pile driving activity. Although mixed groups of 2-5 individuals accounted for approximately 25 % of the groups observed in the study area, more groups with white individuals were observed than expected during pile driving activity. This could mean there may be a change in the type of groups moving into Knik Arm, but it is more likely grey beluga whales or calves were missed because of the difficulties of observing or distinguishing the coloration of beluga whales, particularly in poor environmental conditions.

Group formation changed from pre- to during pile driving activity. There was an increase in all group formation categories (densely packed, dispersed and alone); however, densely packed groups were most commonly observed. The increase in observations of densely packed groups would be expected especially in a noisy environment to maintain communication between individuals in the group. 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). If beluga whales traveled more frequently in a dispersed formation it could negatively affect beluga whales because it could inhibit their ability to maintain the beneficial dynamics of group living.

Additionally, beluga whales traveled more frequently along the eastern shoreline during both pre- and during pile driving activity; however, there were increased sightings during pile driving activity near Port MacKenzie. This could be the result of beluga whales minimizing their exposure to the noise levels produced at the MTR Project.

Beluga whales are highly vocal animals (Schevill and Lawrence 1949, Reeves *et al.* 2008); therefore, examining vocal behavior during construction activity is another useful tool to evaluate changes in behavior. During my study only echolocation clicks and no other call types (e.g., whistles) were detected from beluga whales. There were no significant differences in the detected click rate with and without construction activity; however, the detected click rate was higher without construction activity.

The lack of whistles and noisy vocalizations indicates that vocalizations were being masked by the construction noise, beluga whales were vocalizing less during construction activity or overall there was a decrease in abundance of beluga whales near the construction area. I would have expected to detect whistles and noisy vocalizations during the acoustic survey because of the talkative nature of the beluga whale (Schevill and Lawrence 1949, Reeves *et al.* 2008). Whistles and noisy vocalizations were either not used by beluga whales because the noise levels produced by the construction activity masked these call types or these types of calls were undetected due to the sound levels produced by the construction activity. I think it is more likely beluga whales are not using whistles and noisy vocalizations because the construction noise would interfere with their ability to detect these call types. This is a major concern because beluga whales rely on whistles and noisy vocalizations to communicate and socialize with conspecifics (Faucher 1988, Richardson *et al.* 1995, Karlsen *et al.* 2002, Belikov and Bel'kovich 2006, 2007, 2008). If they are unable to communicate or socialize, it could affect their ability to maintain group formation or it could decrease predator defense, cooperative foraging strategies or reproductive success.

Although there were no significant differences in detected click rate with and without construction activity, the higher detected click rate without construction activity indicates that either beluga whales vocalize less during construction activity or there or there are fewer animals present during construction activity. A lower click rate during construction could affect their ability to navigate through the turbid waters of Cook Inlet. If they are unable to navigate they may avoid the area.

Overall there were changes in the behavior of beluga whales in the presence of construction activity. Avoidance from Knik Arm could be extremely detrimental to the survival of the Cook Inlet beluga whale. Knik Arm is included in the area proposed as critical habitat for the Cook Inlet beluga whale (NMFS 2009a). Critical habitat provides areas for summer foraging, calving, molting, and predator avoidance as well as known fall and wintering areas (NMFS 2009a). Additionally, the Cook Inlet beluga whale's range has contracted over the last 3 decades to the upper reaches of Cook Inlet and they are concentrated heavily in Knik Arm. Their range is now very limited; therefore, if they avoid Knik Arm they may lose foraging and nursery areas and they would be more susceptible to predation (especially their young) because the shallow waters of Knik Arm provide protection from killer whales (*Orcinus orca*; NMFS 2008b).

Passive acoustic monitoring is an effective way to monitor beluga whales because they are highly vocal and rely on vocalizing during daily activities. As technological advances continue, equipment more suitable for hostile environments may be developed. Although some cetaceans are more often detected acoustically than visually (Clark *et al.* 1985, McDonald and Moore 2002, O'Boisseau *et al.* 2007, Kimura *et al.* 2009), it is still important to incorporate visual observations. We do not fully understand the relationship between behavioral states and vocalizing; therefore, it is important to combine the two survey methods.

Research should continue beyond the completion of construction at the POA to more clearly understand impacts from construction activity on beluga whales. Examining behavior and distribution before beluga whales are exposed to construction activity and during exposure gives insight into the short-term effects of the disturbance such as immediate changes in behavior. But to fully understand the impacts from construction activity, examining the behavior and distribution of beluga whales after exposure should be explored to determine if there are long-term effects, such as displacement from Knik Arm.

While vocalizations of other beluga whale populations have been previously investigated, little is known about the vocal behavior of the Cook Inlet beluga whale. We can use the results from other studies to assume similar behavior in the Cook Inlet population. For instance, beluga whales in Svalbard Norway have ceased vocal activity in the presence of vessel noise (Karlsen *et al.* 2002). However, until we fully understand the vocal repertoire and the associated behaviors specific to the Cook Inlet beluga whale, it is difficult to determine the actual effects of noise on vocal behavior.

If the ultimate reasons for the decline of this population are anthropogenic disturbances, it is our responsibility to make changes and mitigate our actions. This does not necessarily mean cease all activities, but we can reduce our influences on the environment by reconsidering the methods used for marine mammal monitoring (acoustic and visual observations), the safety zones and the timing windows for construction activity. By taking steps toward reducing our influences on the marine environment, we may help this population recover.

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Appendix A

Behavior	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 nearshore 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	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.