PASSIVE ACOUSTIC MONITORING OF COOK INLET BELUGA WHALES

ANALYSIS REPORT

PORT OF ANCHORAGE MARINE TERMINAL REDEVELOPMENT PROJECT

Prepared for

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Acronyms and Abbreviations

µPa	micropascal
APU	Alaska Pacific University
^{o}C	degree Celsius
cm	centimeter
dB	decibel
EAFB	Elmendorf Air Force Base
FFT	fast Fourier transform
GB	gigabyte
GPS	Global Positioning System
Hz	hertz
ICRC	Integrated Concepts and Research Corporation
IHA	Incidental Harassment Authorization
kHz	kilohertz
km	kilometer
m	meter
MMPA	Marine Mammal Protection Act
MTR	(Port of Anchorage) Marine Terminal Redevelopment (Project)
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
PAM	passive acoustic monitoring
POA	Port of Anchorage Administration
Port	the Port of Anchorage facility
PVC	polyvinyl chloride
r	Pearson’s correlation coefficient
RL	received level
SL	source level
SPL	sound pressure level
TL	transmission loss
USACE	U.S. Army Corps of Engineers

EXECUTIVE SUMMARY

A passive acoustic monitoring (PAM) study of the Cook Inlet beluga whales *(Delphinapterus leucas)* was conducted during the 2009 Marine Terminal Redevelopment (MTR) Project construction season. The purpose of the study was "to detect and localize, to the maximum extent practicable, passing whales and to determine the proportion of beluga whales missed from visual surveys … [and] characterize sound levels around the Port related to and in absence of all construction activities." This report summarizes the results of the PAM study.

The study was conducted over 20 days, from 1 August through 30 September 2009, in the waters of the Knik Arm of Upper Cook Inlet adjacent to the Port. An array of four sonobuoys was deployed to detect presence of beluga whale vocalizations. To characterize sound levels around the Port related to and in absence of all construction activities, complementary boat-based recordings were conducted using two hydrophones suspended from a boat on six survey days.

Passive acoustic data were collected for more than 148 hours in August and September 2009. Beluga whale echolocation clicks were the most common sound detected during the survey; a total of 63,392 clicks was detected during 14 (out of 20) days of the PAM study. Beluga whales were visually observed by the Scientific Monitoring Team and the Construction Observers on 9 of the 14 days the whales were acoustically detected. During periods of concurrent visual and acoustic surveys, beluga whales were detected by acoustic observations alone 55.3 % of the time, by visual observations alone 3.1 % of the time, and by both methods 15.4 % of the time. Beluga whales were not detected by either method 26.2 % of the total observation time.

Localization of calling beluga whales was not possible in this study because beluga whale echolocation clicks were not detected on more than two sonobuoys at any one time. Therefore, it was not feasible to estimate the total number of beluga whales detected during PAM study.

Average sound pressure level in the vicinity of the MTR Project during the survey was 129.4 ± 5.4 dB re: 1 μPa with construction activities, and 117.9 ± 10.5 dB re: 1 μPa without construction. The average source level of impact hammer pile driving during the survey was 196.9 ± 6.1 dB re: 1 μPa at 1 m. Individual impact pile drives lasted an average of 0.0776 ± 0.0110 s. The energy of impact hammer pile driving extended up to 20 kHz, although most of it was below 10 kHz. The average source level of vibratory hammer pile driving was 183.2 ± 4.8 dB re: 1 μPa at 1 m and the energy from vibratory pile driving was mostly contained at frequencies lower than 10 kHz.

1.0 INTRODUCTION

The Port of Anchorage Marine Terminal Redevelopment Project (MTR Project) is designed to upgrade and expand existing Port of Anchorage facilities (Port) by removing and replacing aging and obsolete structures and providing additional dock and backland areas, without disruption of maritime service during construction. The Project includes in-water construction activities that have the potential to adversely impact marine mammals within the Knik Arm of Upper Cook Inlet in Southcentral Alaska.

In compliance with Special Condition IV(1)(B)(b) of the U.S. Army Corps of Engineers (USACE) 404-10 Permit for the MTR Project and Stipulation 5(e)(2)(b) of the Incidental Harassment Authorization (IHA) issued 15 July 2008 to the Port of Anchorage Administration (POA) and the Department of Transportation, Maritime Administration, by the National Oceanic and Atmospheric Administration, National Marine Fisheries Service (NOAA/NMFS), a passive acoustic monitoring (PAM) study of the Cook Inlet beluga whale *(Delphinapterus leucas)* was conducted during the 2009 MTR Project construction season. The purpose of the study, as stated in the IHA, was "to detect and localize, to the maximum extent practicable, passing whales and to determine the proportion of beluga whales missed from visual surveys … [and] characterize sound levels around the Port related to and in absence of all construction activities."

Under contract with Integrated Concepts & Research Corporation (ICRC), Alaska Pacific University (APU) provides this *Analysis Report: Passive Acoustic Monitoring of Cook Inlet Beluga Whales*. The report analyzes and summarizes the PAM study conducted during the 2009 construction season for the MTR Project. This study was developed in consultation with ICRC, in accordance with USACE and the NOAA/NMFS guidance for compliance with the *Marine Mammal Protection Act* (MMPA).

1.1 Beluga Whale Sounds

Beluga whales, in the order Odontoceti or "toothed whales," are known as the "canaries of the sea" because of their ability to produce a variety of sounds frequently (Schevill and Lawrence 1949; Reeves *et al.* 2002), which makes them good candidates for PAM. Beluga whale sounds are classified in four categories: whistles, pulse tones, noisy vocalization (cries, grunts, barks) and echolocation clicks. Beluga whistles range between 0.26 to 20 kilohertz [kHz], the pulse tones between 0.4 to 12 kHz, and noisy vocalizations range between 0.5 to 16 kHz (Richardson *et al.* 1995). These sounds most likely function as social calls. Echolocation clicks recorded in captive belugas range between 20 and 120 kHz (Au *et al.* 1985; Lammers and Castellote 2009). Echolocation clicks are generally used by odontocetes while foraging or for navigation (Richardson *et al.* 1995). Lower frequency vocal repertoire of beluga populations has been described at a number of different locations (Sjare and Smith 1986; Faucher 1988; Angiel 1997), but to date, the full vocal repertoire of the Cook Inlet belugas has not been described.

1.2 Objectives

The purpose of the PAM study was to detect and localize, to the maximum extent practicable, beluga whales in the vicinity of the MTR Project footprint and characterize sound levels both during construction activities and in the absence of construction activities. Another objective of the study was to correlate visual and acoustic data to estimate the proportion of whales missed by visual observation. Under the supervision of Dr. Ana Širović, APU, Department of Environmental Science, the Passive Acoustic Monitoring Team (PAM Team) collected passive acoustic data necessary to answer the following questions:

1. How often are beluga whales missed during visual marine mammal monitoring?
2. What are the sound levels related to, and in the absence of, all construction activities in the area around the Port?

2.0 METHODS

The study was conducted from 1 August through 30 September, 2009, in the waters of the Knik Arm of Upper Cook Inlet adjacent to the Port (Figure 1). Sonobuoys were deployed in the vicinity of Cairn Point located on the north end of the MTR Project and close to in-water construction activities (Figure 2). 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 period. After each sonobuoy deployment, members of the acoustic study team at the Cairn Point Marine Mammal Monitoring Station (Cairn Point Station) on Elmendorf Air Force Base (EAFB), monitored and recorded signals received from the sonobuoys. At the end of the survey period, the moorings were removed. The locations of the moorings were chosen based on proximity to the Cairn Point Station, favorable bathymetric conditions, and relative safety from dredging and shipping operations. The time period when the sonobuoys were deployed corresponds to the period when beluga whales are frequently sighted in the Port area (Funk *et al*. 2005; Cornick and Kendall 2008). The days and times of acoustic data collection were chosen based on tides and weather conditions, which limited the ability to launch a boat and deploy sonobuoys.

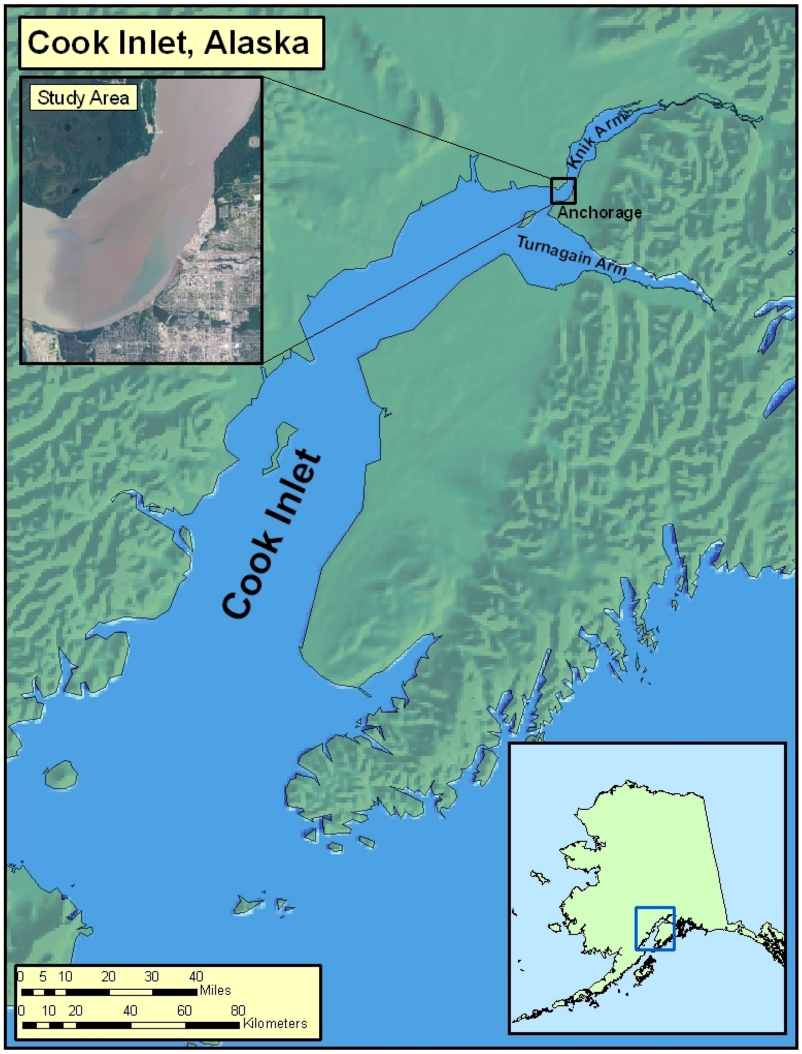

Figure 1. The map of the Cook Inlet, showing in an inset the study area surrounding MTR project, where passive acoustic monitoring was conducted.

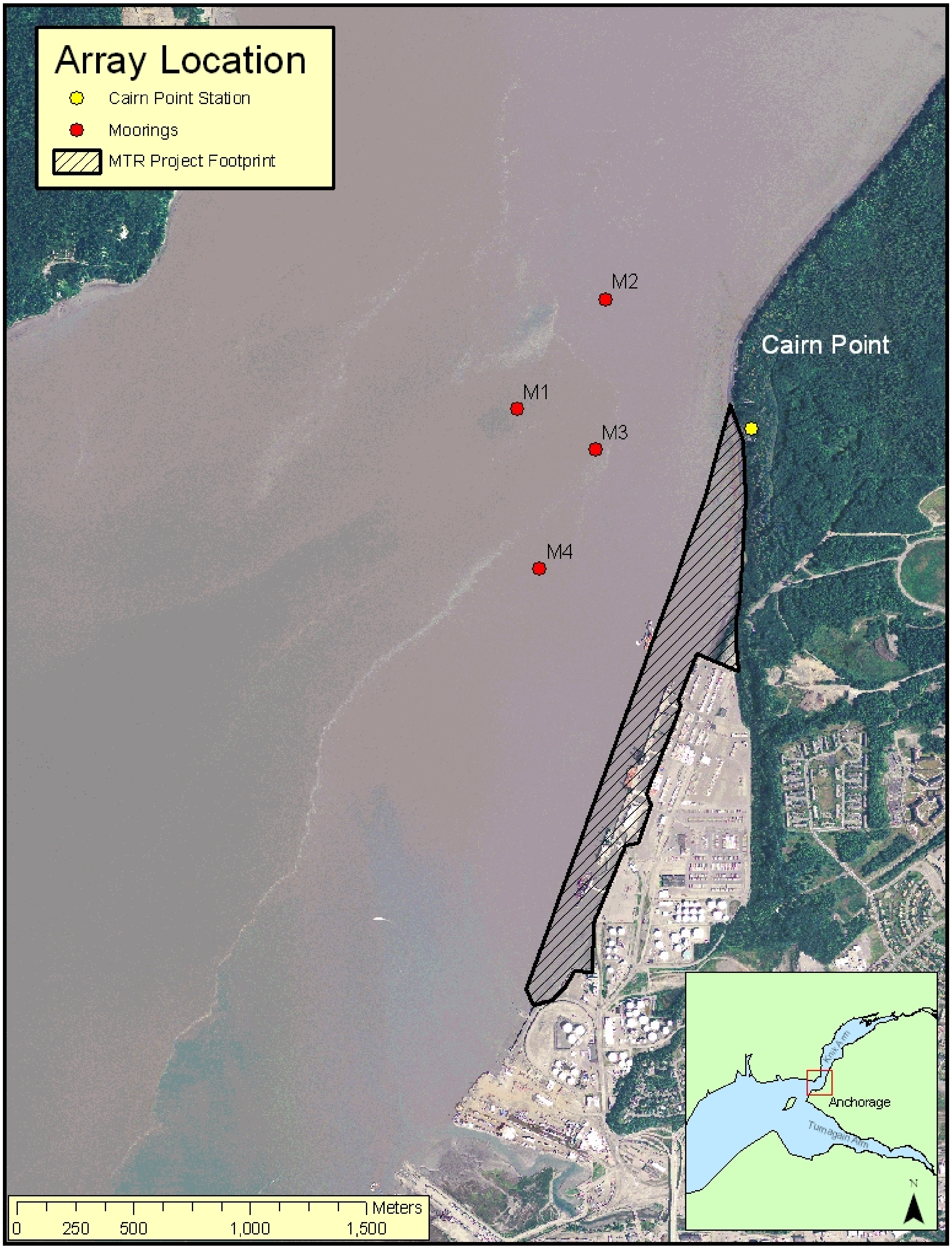

Figure 2. The location of the tightly spaced array of four moored lines, placed between 400 and 700 m apart and approximately 600 m off Cairn Point. Sonobuoys were attached to the moorings for each day of acoustic monitoring.

2.1 Sonobuoys

Sonobuoys are expendable electronic devices that consist of a hydrophone, float, radio transmitter, and salt-water battery (Figure 3). The omnidirectional AN/SSQ-57B sonobuoys used in this study have a calibrated broadband frequency response from 10 to 20,000 hertz [Hz], but can be used to detect signal 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 adjusted to meet research requirements. Sonobuoys continuously transmit their radio signal to a remote observer for a maximum of 8 to 10 hours.

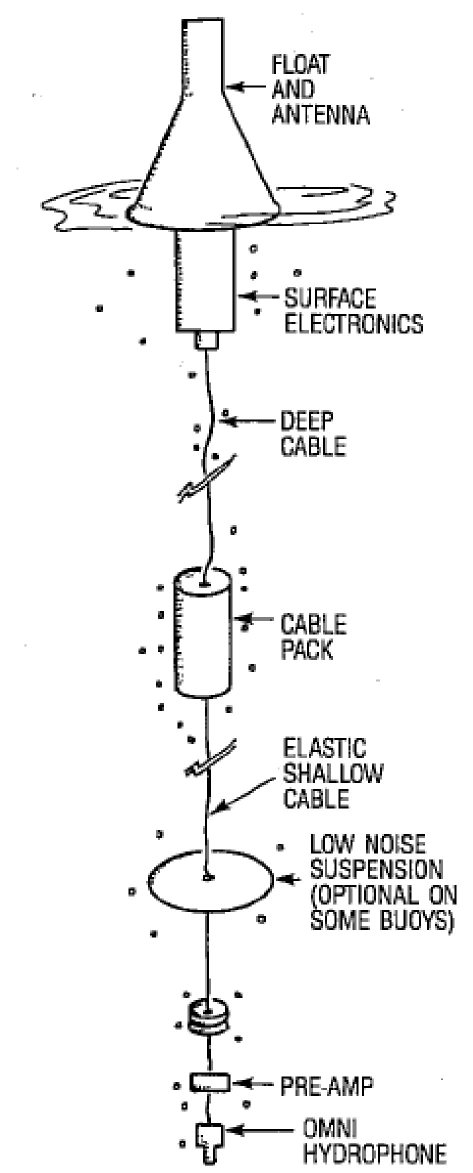

Figure 3. Type AN/SSQ-57 omnidirectional sonobuoy. (Figure adapted from Horsley 1989).

2.2 Array Setup

Before permanent moorings were installed, a one-day pilot study was conducted. The purpose of the pilot was to test the array setup under the environmental conditions of Knik Arm.

2.2.1 Pilot Study

On 24 July, 2009, the PAM Team conducted calibration and initial testing of the system. A mooring line was placed at the location of one of the permanent moorings to test the equipment and make adjustments to deployment protocols. The mooring was tested using a 130-pound section of railroad rail as the anchor, attached to a 5/8-inch nylon line, approximately 25 meters (m) long, and a surface float. The location of the mooring was recorded using a handheld Garmin Global Positioning System (GPS) 72 Personal Navigator. The test mooring was removed after the test deployment. No sonobuoys were deployed during the pilot study.

2.2.2 Mooring Installation

Permanent moorings were installed on 1 August and were left in the water until 7 October, 2009. Their location (latitude and longitude) was recorded using the handheld GPS at the time of installation. The team deployed four moorings with sides between 400 and 700 m long (Figure 2), each anchored with approximately 600 pounds of railroad rail sections and attached to a 5/8-inch nylon line approximately 45 to 55 m long 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, as requested by the USACE, on 13 August, to increase the visibility of the moorings to passing vessels under low light conditions. The locations of the moorings were checked throughout the survey period to verify they were not moved by the strong tidal currents.

The U.S. Coast Guard was notified of the proposed acoustic monitoring program and continuously updated during project implementation. The PAM Team notified the U.S. Coast Guard prior to the deployment of mooring lines and reported the GPS coordinates of the deployed moorings. The PAM Team also provided coordinates of the moorings to ICRC for relay to the USACE and their dredging team. Additionally, all parties were notified when the study was complete and the moorings were removed.

Members of the PAM Team cooperated with POA and EAFB personnel and participated in all necessary training to ensure compliance with POA and EAFB safety and security policies. During each day of acoustic monitoring, the PAM Team notified ICRC, the POA, and the dredging team of their activities adjacent to the Port.

2.2.3 Sonobuoy Deployment

Prior to deployment, sonobuoys were stripped from their original casing and placed in a plastic canister attached to a life ring (Figure 4). The life ring provided additional structural support in the fast moving currents of Knik Arm, allowing the sonobuoy float to remain at the surface of the water in a vertical position after deployment (Figure 5). The vertical position of the sonobuoy float was important to facilitate signal transmission from the sonobuoy to the shore station. Ninety feet 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 freely 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 GPS to verify the location of the moorings. The moorings did not move during the duration of the study. Once deployed, the sonobuoys continuously transmitted their radio signal to remote observers at the Cairn Point Station for approximately 8 to 10 hours.

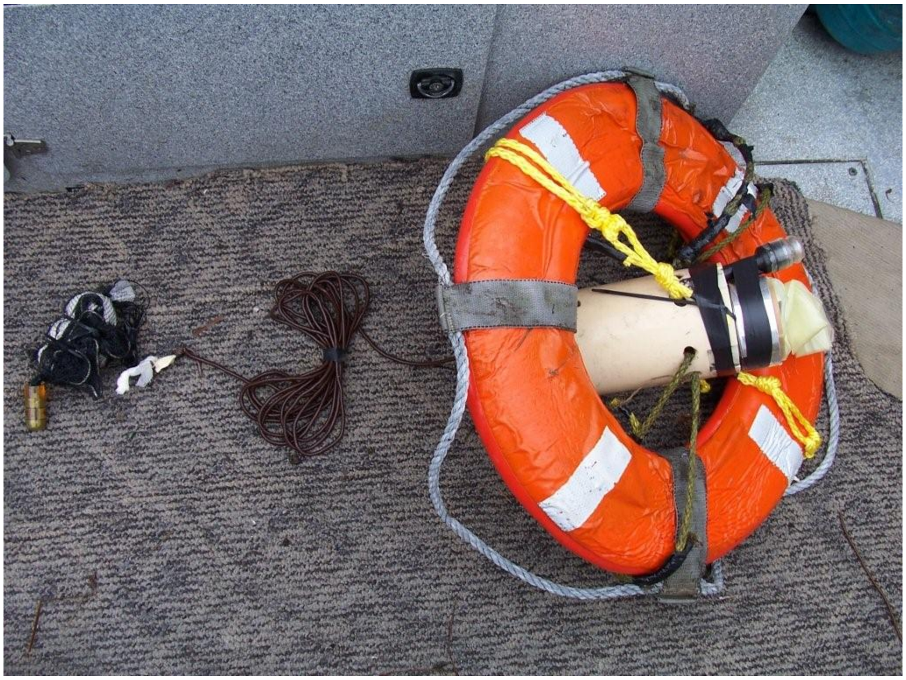

Figure 4. Omnidirectional sonobuoys (AN/SSQ-57B) used for this study were stripped from their original casing and placed in a plastic canister attached to a life ring flotation device, which added structural support and allowed the sonobuoy float to remain at the surface of the water in a vertical position after deployment.

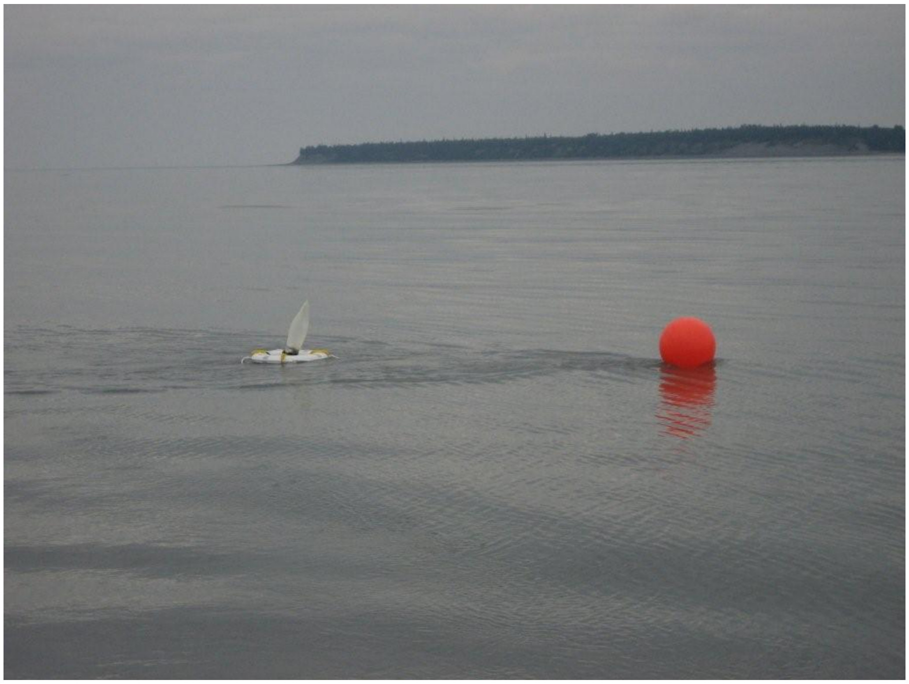

Figure 5. Omnidirectional sonobuoy (AN/SSQ-57B) deployed in Knik Arm with flotation ring and surface float.

Two antennae were mounted on the conex at the Cairn Point Station to receive radio signals from the sonobuoys. A set of custom electronics and software were used to record and analyze sonobuoy data. The antennae received the signals and passed them to four software-controlled ICOM scanner radio receivers (one per sonobuoy signal), modified to provide improved reception of sonobuoy signal. Each radio was connected to a computer, which was connected to a MOTU Traveler, a high-quality sound card that enables sampling at a high sample rate (88.2 kHz). Data were digitized using the software program *Ishmael* (Mellinger 2001) and saved as .WAV files on 500 gigabyte (GB) hard disks. On 3 August, data were sampled at 44 kHz, from 4 to 18 August the sampling rate was 48 kHz, and from 20 August to 30 September the sampling rate was 88.2 kHz. The sample rate was increased during the study to ensure capture of the maximum possible bandwidth of beluga whale echolocation clicks given the recording setup. Reception of the sonobuoy signal was verified with the deployment team after each deployment. In the case of a failed deployment, the deployment team immediately recovered the failed sonobuoy and deployed another one. The expected failure rate of less than 15 percent, based on previous experiences with this type of sonobuoy (Širović *et al.* 2006), was encountered during this study.

2.3 Sampling Efforts

Acoustic data were collected during 20 days spread out between 1 August and 30 September, 2009 (see Appendix A for summary of the deployments and sampling efforts). To ensure full 8 hour coverage of sonobuoy transmission during daily acoustic monitoring periods, monitoring was conducted at the Cairn Point Station in two shifts, each of approximately 4 hours duration. If sonobuoys continued transmitting after the PAM Team shifts were over, or it was after dark, the PAM Team left the recording setup at Cairn Point Station and returned the following morning to collect the equipment and data. Recordings were collected during periods with and without construction activity.

The time of acoustic surveys was coordinated, to the maximum extent practicable, with the time of marine mammal observations by the Scientific Marine Mammal Monitoring Team (Scientific Monitoring Team), in an effort to ensure concurrent visual and acoustic data collection. However, to ensure independent sampling, the two groups worked independently and were not aware of any beluga detections by the other group. Two members of the PAM Team were present inside the conex listening to the recordings on speakers during each monitoring session. To avoid biasing the observations of both teams, the PAM Team did not share their findings with the Scientific Monitoring Team during the study.

The PAM Team collected deployment and environmental data, and conducted preliminary acoustic analysis during the daily acoustic monitoring period. Data collected included the following: deployment date, time, latitude, longitude, and transmission channel for each sonobuoy, as reported by the deployment team; beginning and end of acoustic observation period; start and end time of vocalizations (if detected), the species detected, channel(s) with vocalizations; environmental conditions; type of construction (e.g., pile driving with either vibratory or impact hammer); and duration of construction activity (see Appendix B for examples of the data log sheets). Members of the PAM Team entered the data into *Microsoft Excel* for *Windows* for storage and analysis. Sections 2.4 and 2.5 provide additional information on the collection of data on environmental conditions and anthropogenic activities.

2.4 Sound Level Characterization

To estimate sound levels in a region, the characteristics of the sound sources in the area, as well as transmission loss characteristics of the medium, must be understood. The PAM Team estimated sound transmission loss coefficient for the Knik Arm off Cairn Point using recordings collected from complementary boat-based recordings. Observers used a 27-foot vessel provided by Alaska Divers Underwater Salvage to collect acoustic data using two calibrated HTI-96-MIN hydrophones suspended from a cable at the bow and the stern of the boat at approximately 2 m depth (Blackwell and Greene 2002). The hydrophones were suspended from the boat through polyvinyl chloride (PVC) pipe to keep the hydrophones as vertical as possible in the current and to reduce flow noise. Signals from each hydrophone were recorded continuously using an Edirol R-09 digital recorder at a sample rate of 48 kHz. Once the hydrophones were placed in the water, the boat engines were turned off to reduce the ambient noise and allow the boat to drift with the current (Figure 6). Recordings took place in approximately 3-kilometer (km) long transects (current dependent) along the main channel of Knik Arm, during different tidal stages and construction activities (e.g., vibratory hammer pile driving, impact hammer pile driving). GPS positions were recorded continuously during sampling to document the drift pattern. Sampling took place in nine drift transects on six days during the study. Data from these transects were used to determine the transmission loss characteristics by documenting sound levels at a range of distances from the sound source.

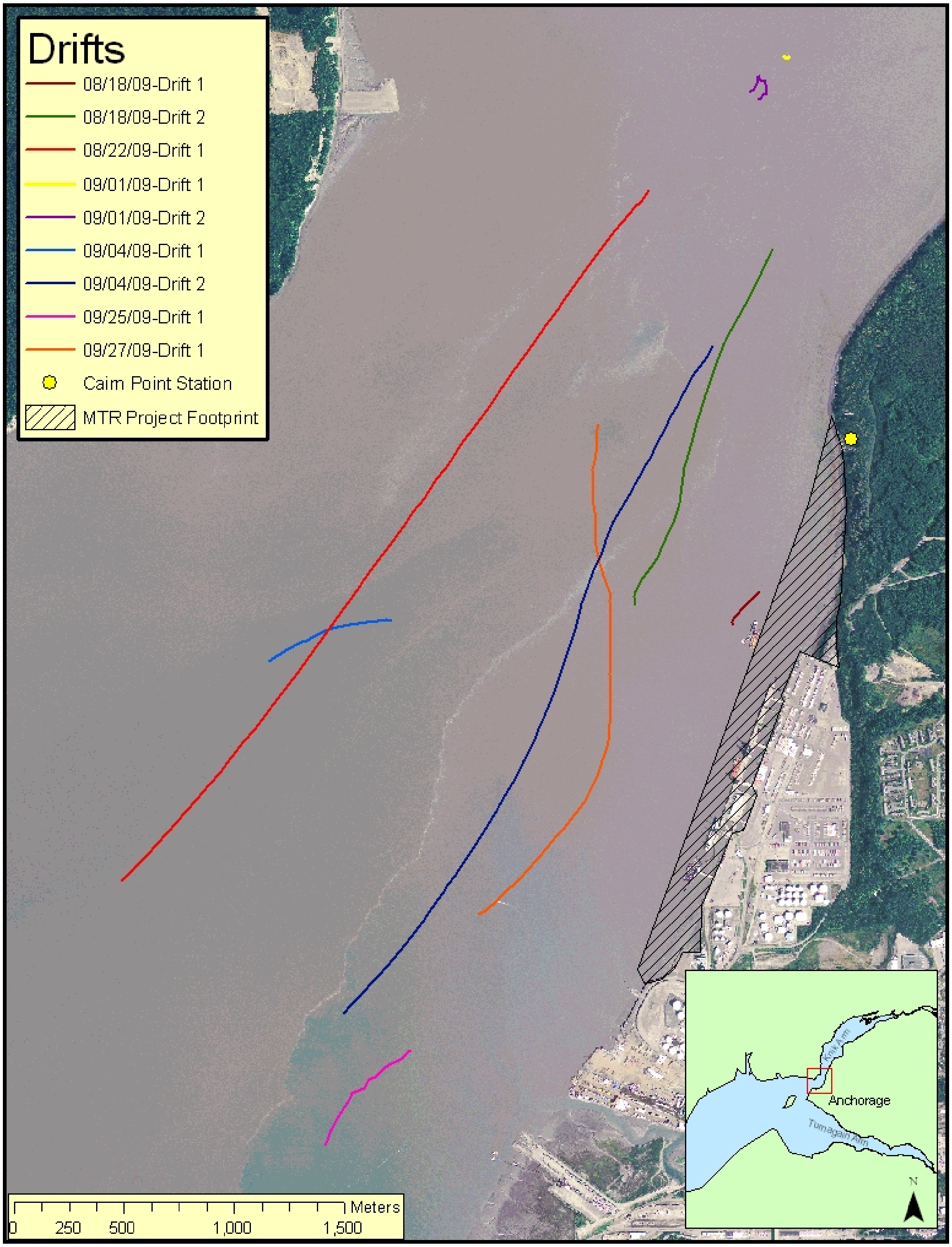

Figure 6. Boat-based recordings took place on six days during the survey period for a total of nine drifts (1 or 2 drifts/day). GPS positions were continuously recorded to document the drift pattern. Drifts provided a range of distances from the sound source.

2.5 Environmental Conditions in the Study Area

Environmental conditions were logged every hour during daily sonobuoy deployment and monitoring efforts (Appendix B). These conditions included: wind speed, sea state (Beaufort scale), swell height, and precipitation. Water temperature, salinity, and turbidity were documented at the time of sonobuoy deployment. In addition, all anthropogenic activities within the study area were documented during daily monitoring efforts. Events were categorized as: no activity, impact hammer or vibratory hammer pile driving, dredging, in-water fill placement, and aircraft and vessel activities. The duration of the activity was recorded.

Environmental conditions for the months of August and September were summarized to better understand ambient and anthropogenic noise, in addition to sound propagation characteristics and their effects on detecting calls. Mean wind speed, swell height, surface water temperature, salinity and turbidity were calculated, as well as the mode of the sea state. The sound speed was calculated based on the formula given by Medwin (1975) using the measurements of Cook Inlet temperature and salinity recorded by the PAM Team.

2.6 Data Analyses

Data analyses were conducted during collection and also during report preparation. All data were backed up on a hard disk each day of the deployment. MatLab (MathWorks, Natick, MA) based sound analysis software was used for preliminary sound analysis, such as characterization of beluga sound frequency and temporal characteristics. To optimize the data analysis process, automatic detectors were developed after the completion of the field implementation phase of the study.

2.6.1 Automatic Detection

Several automatic detection methods for efficient detection of calls (e.g. spectrogram correlation, energy summation, and acoustic power level analysis) were investigated using the software program *Ishmael* (Mellinger 2001). Short duration and broadband frequency of beluga whale clicks indicated that energy summation is a good tool for automatic analysis. Energy summation method is based on the calculation of the total energy in a frequency band that contains a part or entire sound of interest. 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 that does not contain sound of interest was calculated. The frequency band used for the calculation of signal energy was 23 to 25 kHz, and it was compared to the energy in the adjacent “noise” frequency band from 18 to 20 kHz. Due to initial variation in sampling rate from 3 to 18 August, the energy summation parameters were adjusted to account for the difference in sample rate (44 kHz and 48 kHz). Files for 3 August were manually scanned for echolocation clicks. Detections for 4 to 18 August were based on the energy ratio between the energy in the signal band from 23 to 23.9 kHz and the noise band from 15 to 18 kHz.

Detection threshold was set iteratively to optimize the ratio of false alarms to missed detections. Due to the variation in sonobuoy signal over the course of the data collection, the results of the automatic detector were visually verified and parameters were modified for different recording times. When the program signaled a detection, 2 seconds of the signal before and after the detection were saved into an individual .WAV file. Each file was visually verified for the presence of beluga whale echolocation click. False detections were removed from subsequent analysis. Automatic detections provided information on the presence and timing of the beluga whale sounds.

2.6.2 Visual and Acoustic Comparison

Acoustically detected presence of beluga whales was compared with the number of beluga whale sightings recorded by the Scientific Monitoring Team stationed at the Cairn Point Station. When visual sightings data were not available from the Scientific Monitoring Team, whale presence data recorded by the MTR Project Construction Observers (Construction Observers) at the construction site were used. Beluga whale sightings and beluga whale acoustic detections were pooled into 30-minute bins centered at the time of the first acoustic detection for all times during which both acoustic and visual data were available. Since visual observations indicate that beluga whales mostly pass near the Port area (Cornick and Kendall 2008), if visual and acoustic detections were more than 30 minutes apart, it was assumed that they represent different groups. Beluga whale acoustic detections were mapped onto the same grid cells used by the Scientific Monitoring Team, assuming a detection range for echolocation clicks of 400 m (Figure 7). This detection range was based on the fact that high frequency sounds, like echolocation clicks, attenuate very quickly. The presence of clicks in a grid cell was compared to presence of beluga whales from visual surveys in the same cell. For periods during which visual sightings were available from the Scientific Monitoring Team, visual sightings were counted only during times when whales were present in one of the grid cells monitored by the acoustic survey. It was noted, however, if there were beluga whale sightings in an area outside the acoustic survey range and they were considered as different groups. When visual data were available only from the Construction Observers, the entire duration of the sighting was considered to be within the acoustic detection range if beluga whales passed through at least one grid cell monitored by the acoustic survey. This was necessary because the sighting maps from Construction Observers data showed approximate sighting locations in each grid, but there was no indication of the exact location of the whales at all times. Percent of time beluga whales were missed by visual observations alone and by acoustic observations alone was determined.

Additionally, number of acoustic detections and individual sightings within the same 500-m grid cell was determined for each 30-min bin. These two time-series of detections were correlated to determine if the number of acoustic detections is correlated to the number of visual sightings. Pearson's correlation coefficient (r) was calculated.

To localize calling beluga whales, a call has to be recorded concurrently on three or more instruments. The areas of the array where an echolocating beluga could have been localized are shown in Figure 7 as the areas where three circles intersect. Since echolocation clicks propagate over very short distances, and they were the only beluga whale vocalization regularly recorded, localization of calling beluga whales was not conducted, since no clicks were detected on three moorings at the same time.

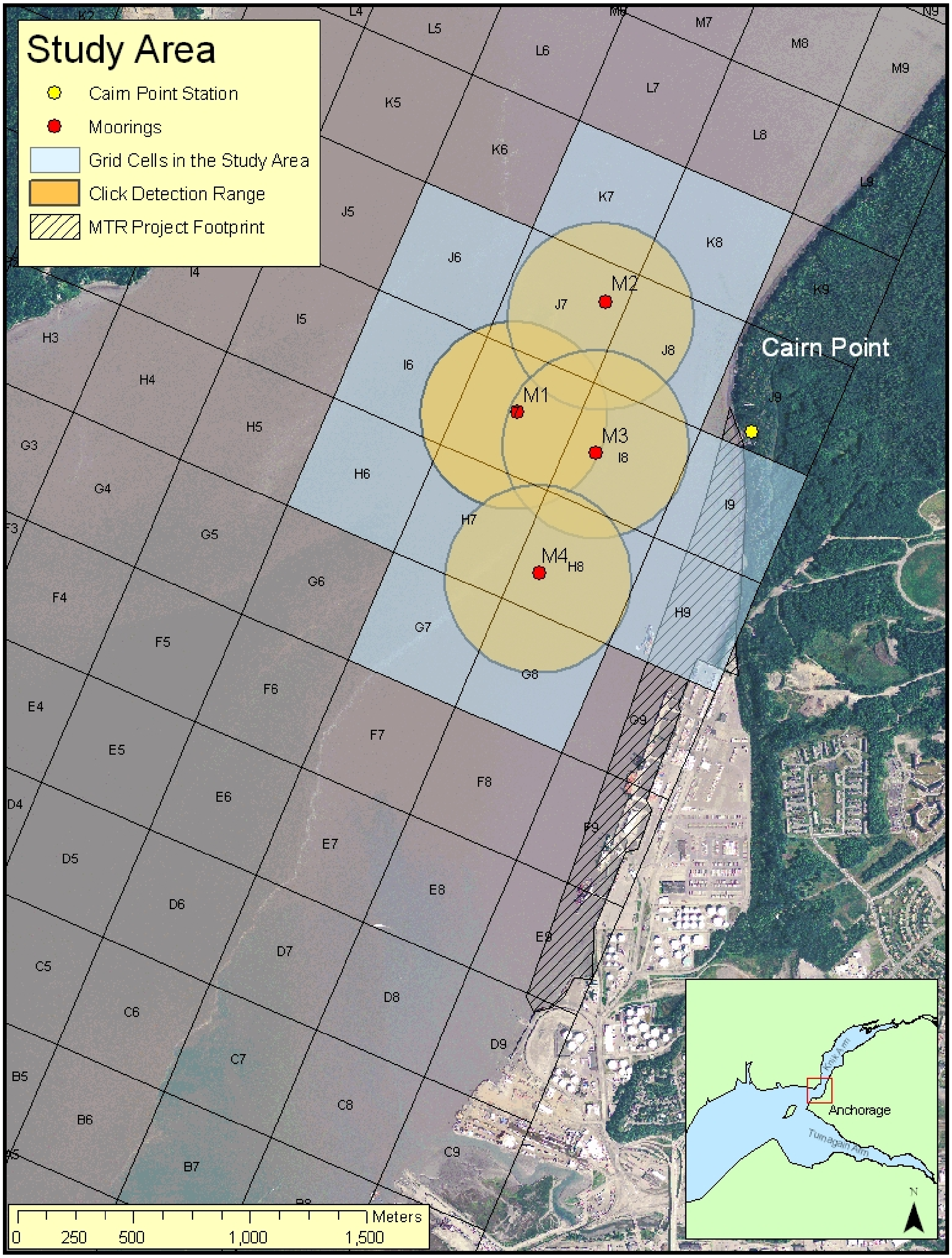

Figure 7. The area monitored during the study is represented by the light blue grid cells. If a part of the grid cell was within the 400-m acoustic detection range for echolocation clicks it was considered that the echolocating beluga could be located anywhere within those cells. Only visual sightings observed within one of the grid cells monitored by the acoustic survey were used for analysis.

2.6.3 Sound Level Characteristics

The PAM Study characterized sound levels within the study area relating to, and in the absence of, all in-water construction activities within the MTR footprint. Ten-second recordings with and without construction activities were examined. Measurements derived from the recordings of impact hammer pile driving included two parameters: pulse duration and received level. These measurements were conducted in a way consistent with earlier studies on transient pulses (e.g. McCauley *et al.* 1998; Blackwell 2005). Pulse duration was measured as the time interval during which 90 % of the total estimated sound energy in the pulse arrived at the receiver, measured in seconds. Received level (RL) is the total energy of the signal averaged over the pulse duration and its units are decibels relative to 1 micropascal [dB re: 1 µPa]. The mean of each parameter was calculated from 15 recordings.

Also, the mean RL from vibratory hammer pile driving was measured. The RL was measured from 10 seconds of recording, after the signal was low-pass filtered at 200 Hz to remove the low-frequency flow noise that dominated this part of the spectrum during tidal drifts. A total of 15 recordings was used to calculate the average RL of vibratory pile driving.

To calculate source levels (SL) of each of these sounds, propagation loss characteristics of the environment and range to the source have to be determined. SL is calculated as the sum of the RL and the transmission loss (TL). A simple propagation model of transmission loss can be expressed as a product between the propagation loss coefficient (X) and the logarithm of the range (r) between the recording and the source, $TL = X \log(r)$. Empirical data were used to estimate the propagation loss coefficient X (Section 3.4). In order to obtain this estimate, a scatter plot of received levels versus estimated range was made for all analyzed recordings of impact pile driving. The range was estimated using ArcGIS (ESRI, Redlands, CA) as the difference between the GPS location of the drifting boat and the location of pile driving activity. The propagation loss coefficient was calculated as the slope of the best-fit line through the plotted points of received levels versus logarithm of estimated range (Blackwell 2005; Širović *et al.* 2007). The standard unit of SL is expressed as dB re: 1 µPa at distance of 1 m from the source [dB re: 1 µPa at 1 m].

Additionally, sound propagation modeling was used to theoretically verify the empirical result of the propagation loss coefficient. The PAM Team modeled incoherent transmission loss[1] using BELLHOP software developed by M. Porter and available from the Ocean Acoustics Library (http://oalib.hlsresearch.com/). Since Cook Inlet is a well-mixed estuary, the sound speed was assumed to be homogenous through the water column. (This assumption was verified with the environmental measurements.) Separate model runs were conducted for August and September sound speed profile characteristics. The depth was assumed to be flat out to 1 km from shore, and then it dropped additional 20 m. The model was run for high tide and low tide conditions, with depth in the flat area assumed to be 25 and 15 m, respectively. The model was run for frequencies ranging from 10 to 15,000 Hz, which are the frequencies with prevalent energy content for construction activities.

To understand the noise levels from construction activities within the MTR Project footprint, sound pressure levels (SPLs) were calculated from 10 second recordings containing dredging and other general construction activity noises. The average was calculated from 15 recordings made throughout the area of the drift dives. Finally, 10 second recordings from periods without construction noise were used to calculate SPLs in the absence of construction noise and the average was calculated. All signals were band-pass filtered between 200 and 20,000 Hz. The unit of SPL is dB re: 1 µPa.

3.0 RESULTS

Results of data analysis are presented as sampling efforts, automatic detections, visual and acoustic comparison, localization, sound level characteristics, and environmental conditions in the study area.

3.1 Sampling Efforts

Acoustic monitoring was conducted for more than 148 hours over 20 days in August and September 2009 (Appendix A). Eighty-six sonobuoys were deployed during the study and there were 8 failed sonobuoy deployments, giving a sonobuoy failure rate of 9.3 %. A total of 373 hours of passive acoustic data were collected from the four moorings. The signal reception

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[1] Incoherent transmission loss is calculated by ignoring the phase of the sound pressure wave (Jensen *et al.* 2000).

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 to 60 minutes. During the recovery of sonobuoys in subsequent days, it was discovered that the hydrophone was often ripped off from the sonobuoy cable because of the fast moving currents. Occasionally, this resulted in abbreviated daily sampling efforts.

3.2 Automatic Detections

Beluga whale echolocation clicks were the most common sound detected during the PAM survey at the MTR Project. Most of the energy in beluga whale clicks recorded in the vicinity of the MTR Project construction site was above 15 kHz (Figure 8). A total of 63,392 clicks was detected during 14 (out of 20) days of the passive acoustic survey, although some of those clicks were likely the same click detected on two different sonobuoys (Table 1). Of the total number of detected clicks, 39,500 were detected during times when there were concurrent visual observer efforts by the Scientific Monitoring Team or the Construction Observers. Beluga whale clicks were detected most commonly on mooring M1, the westernmost mooring.

Table 1. Number of clicks detected

Date	Mooring[1]	# of Clicks[2]
04-Aug-09	M2	29
13-Aug-09	M4	1,283
18-Aug-09	M1	31
20-Aug-09	M1	16
20-Aug-09	M2	10
22-Aug-09	M1	8,619
22-Aug-09	M2	2,027
25-Aug-09	M2	21
01-Sep-09	M1	1,367
04-Sep-09	M1	1,382
04-Sep-09	M2	177
08-Sep-09	M2	97
10-Sep-09	M1	399
10-Sep-09	M2	1,094
20-Sep-09	M1	577
23-Sep-09	M1	6,256
23-Sep-09	M4	22
25-Sep-09	M1	2,804
25-Sep-09	M3	785
27-Sep-09	M2	15,231
27-Sep-09	M3	3
27-Sep-09	M4	22,505
	Total	63,392

[1] The mooring location clicks were detected.
[2] The total number of clicks detected on the mooring during that day of acoustic observations.

One beluga whale whistle was recorded during a drift recording on 4 September, 2009 (Figure 9). The whistle was recorded while the boat was outside of the array monitoring area and it was not recorded on any of the moorings. This was the only beluga sound that was not an echolocation click recorded during the PAM Study and therefore no whistle detector was developed.

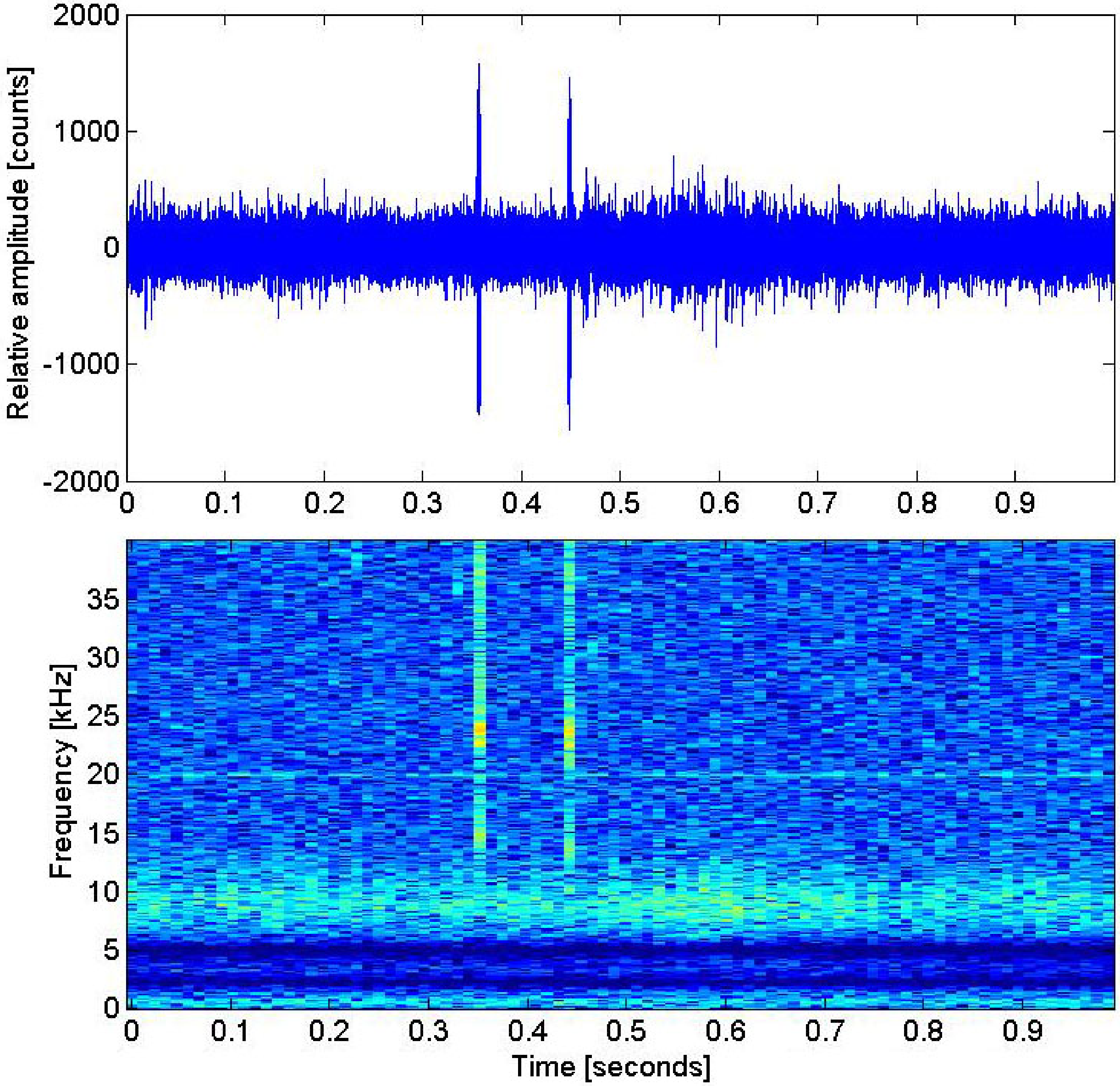

Figure 8. Time series and spectrogram of two beluga whale echolocation clicks recorded on 23 September, 2009 on mooring M1. The spectrogram was plotted with 1000-point Fast Fourier Transform (FFT) and the signal was low-pass filtered at 10 kHz.

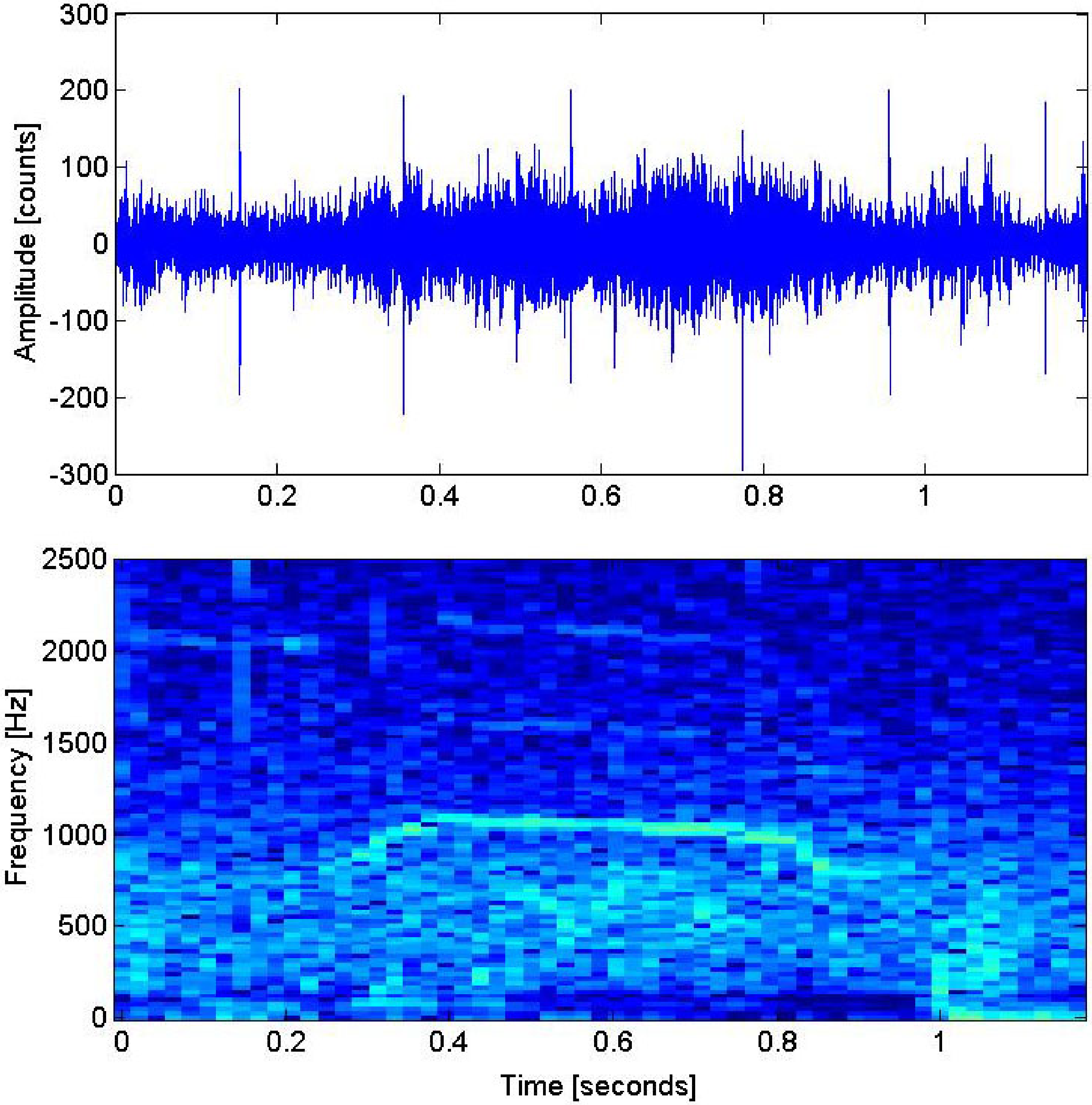

Figure 9. Time series and spectrogram of beluga whale whistle recorded during a drift recording on 4 September, 2009. The spectrogram was plotted with 1000-point FFT and low-pass filtered at 300 Hz to eliminate low-frequency flow noise.

3.3 Visual and Acoustic Comparison

Beluga whales were visually observed by the Scientific Monitoring Team and the Construction Observers on 9 of the 14 days the whales were acoustically detected. During periods of concurrent visual and acoustic surveys, beluga whales were detected by acoustic observations alone 55.3 % of the time, by visual observations alone 3.1 % of the time, and by both methods 15.4 % of the time (Figure 10). Beluga whales were not detected by either method 26.2 % of the total observation time. Visual and acoustic detections were weakly positively correlated (r = 0.148).

Using the assumption that all acoustic detections less than 30 minutes apart represent a single group of beluga whales passing through the area, the PAM Team estimated a total of 18 groups of beluga whales detected acoustically during the survey period (8 in August and 10 in September; Figure 11). Based on the same 30 minute period assumption, during the same time the acoustic survey was taking place, the Scientific Monitoring Team sighted 11 groups of beluga whales within their survey area (4 groups in August and 7 in September).

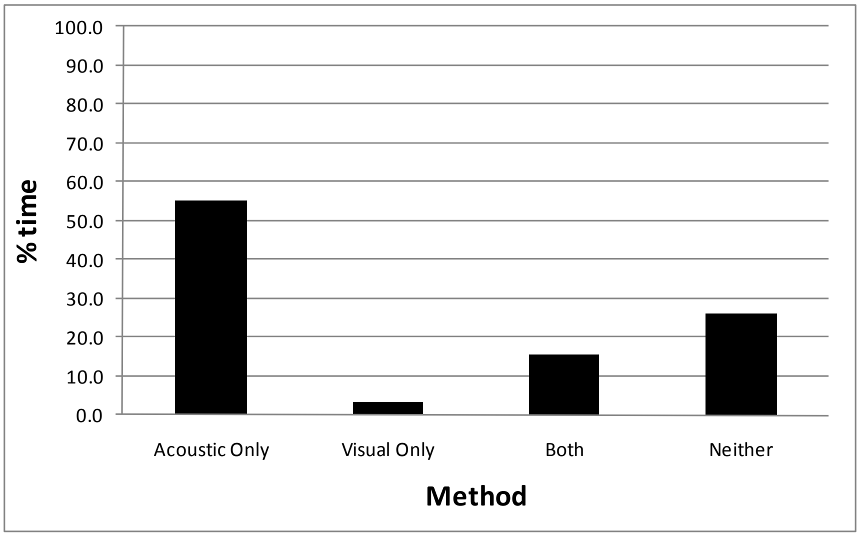

Figure 10. Proportion of time beluga whales were detected by two different observation methods within the area monitored by the acoustic array on 20 days of acoustic effort from 1 August to 30 September, 2009.

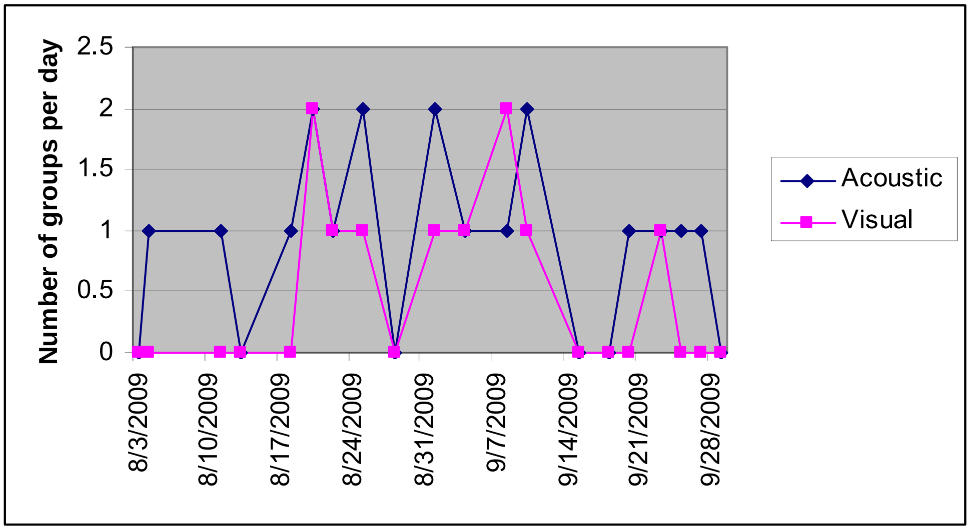

Figure 11. Number of beluga whale groups visually sighted and acoustically detected each of the 20 days of acoustic effort from 1 August to 30 September, 2009.

Two examples of beluga whale acoustic detections and visual sightings on 25 August and 8 September, 2009 are given in Figures 12a and 12b, respectively. Beluga whales were visually and acoustically detected from 11:03 to 14:02 and 15:18 to 18:47 on 25 August, and from 09:34 to 13:33 on 8 September. On both days beluga whales were detected on the sonobuoy deployed at mooring M2, but were not detected on M1, M3 or M4. On 25 August, beluga whales were visually observed in grid cells E9, F9, G9, H9, I9 and G7. On 8 September, they were visually observed in grid cells I4, J4, K7, K8, H9, I9 and J9.

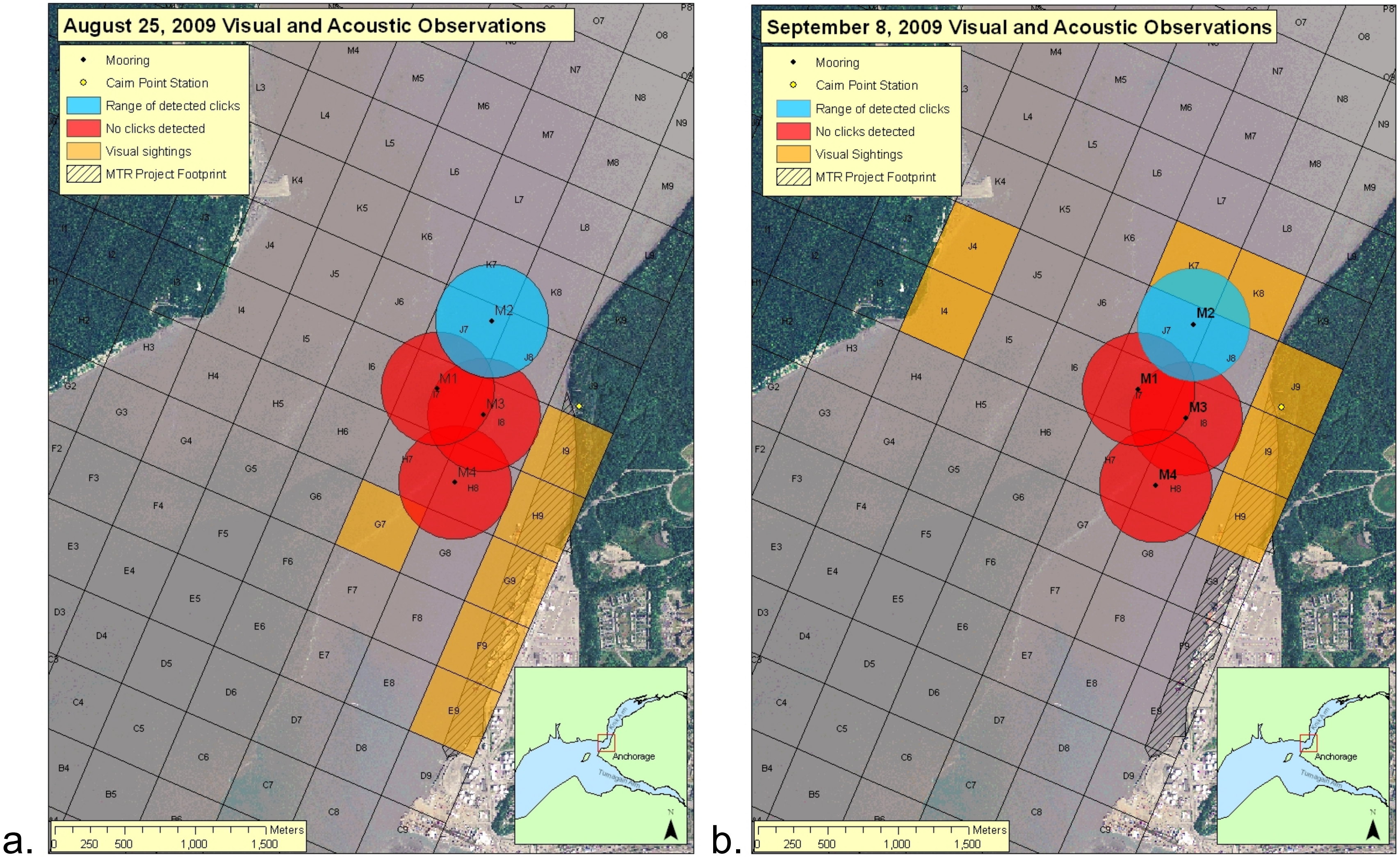

Figure 12. Visual and acoustic observations of beluga whales on two different days during PAM. Acoustic detections are in blue and visual sightings are in orange. a. Observations on 25 August, 2009 from 11:03 to 14:02 and 15:18 to 18:47. b. Observations on 8 September, 2009 from 09:34 to 13:33.

3.4 Localization

Localization of calling beluga whales was not possible in this study because beluga whale echolocation clicks were not detected on more than two sonobuoys at any one time. Since individual whales could not be localized based on the vocalizations they produced in the vicinity of the MTR Project, it was not feasible to estimate the total number of beluga whales detected during the PAM study.

3.5 Sound Level Characteristics

Approximately 4 hours of acoustic data were recorded during boat drifts with and without construction activities (Table 2). Recordings included periods with impact and vibratory hammer pile driving, dredging, aircraft and vessel noise, and also some periods without construction activities (Figures 13 though 16).

Table 2. Boat drifts during the PAM study

Date[1]	Drift[2]	Start Time[3]	End Time[4]	Duration[5]
18-Aug-09	1	17:11	17:15	0:04
18-Aug-09	2	17:20	17:43	0:23
22-Aug-09	1	10:30	11:01	0:31
01-Sep-09	1	11:12	11:18	0:06
01-Sep-09	2	11:28	12:03	0:35
04-Sep-09	1	8:19	8:34	0:15
04-Sep-09	2	9:39	10:16	0:37
25-Sep-09	1	11:39	12:15	0:36
27-Sep-09	1	13:37	14:34	0:57
			Total	**4:04**

[1] Nine drifts took place during the study.
[2] 1=first drift of the day; 2=second drift of the day
[3] The start time of the drift (local time).
[4] The end time of the drift (local time).
[5] The total recording time of each drift.

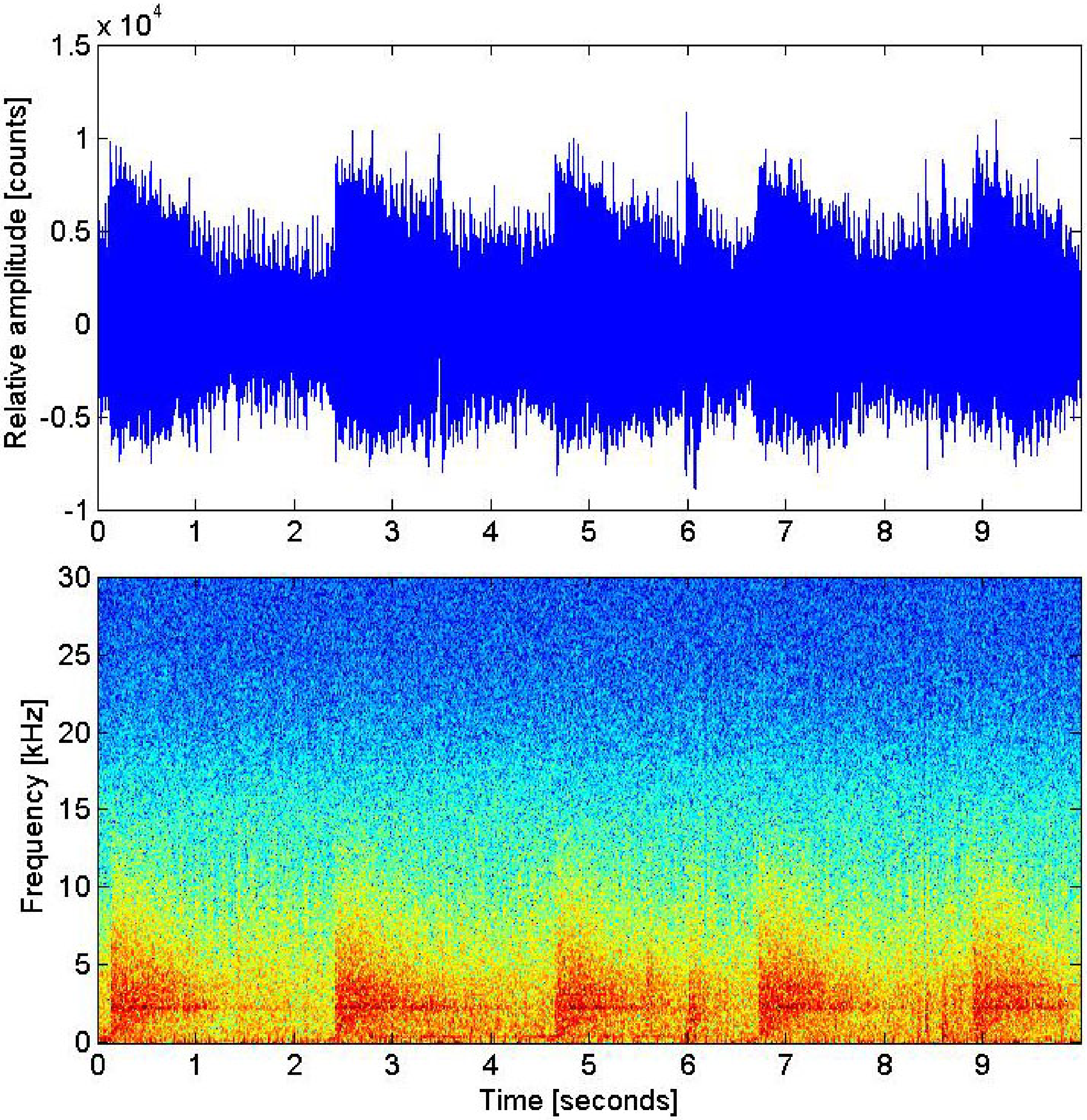

Figure 13. Time series and spectrogram of impact hammer pile driving recorded on 28 August, 2009 on mooring M1 and plotted with 1000-point FFT and 0% overlap.

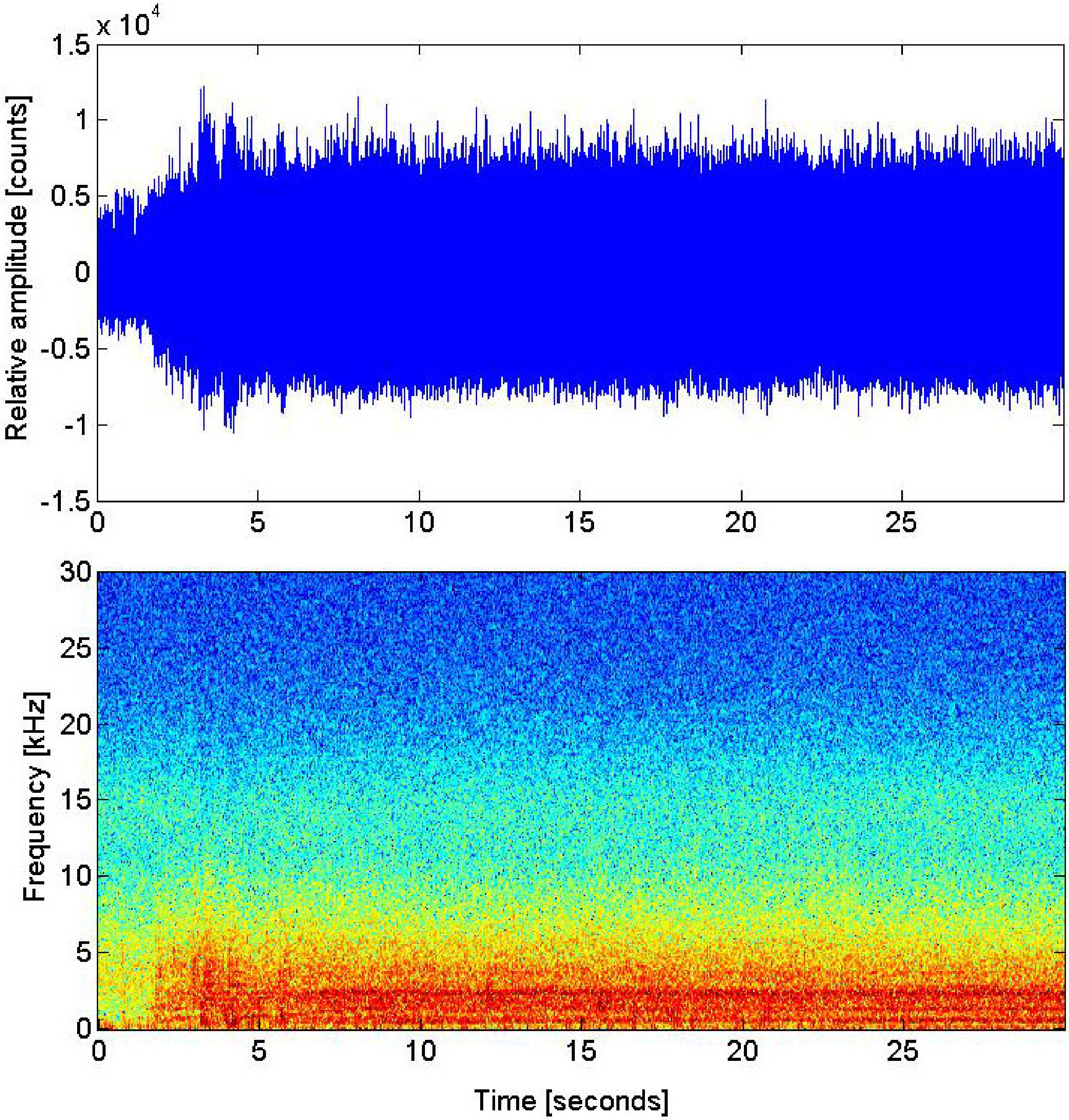

Figure 14. Time series and spectrogram of vibratory hammer pile driving recorded on 28 August, 2009 on mooring M1 and plotted with 1000-point FFT and 0% overlap.

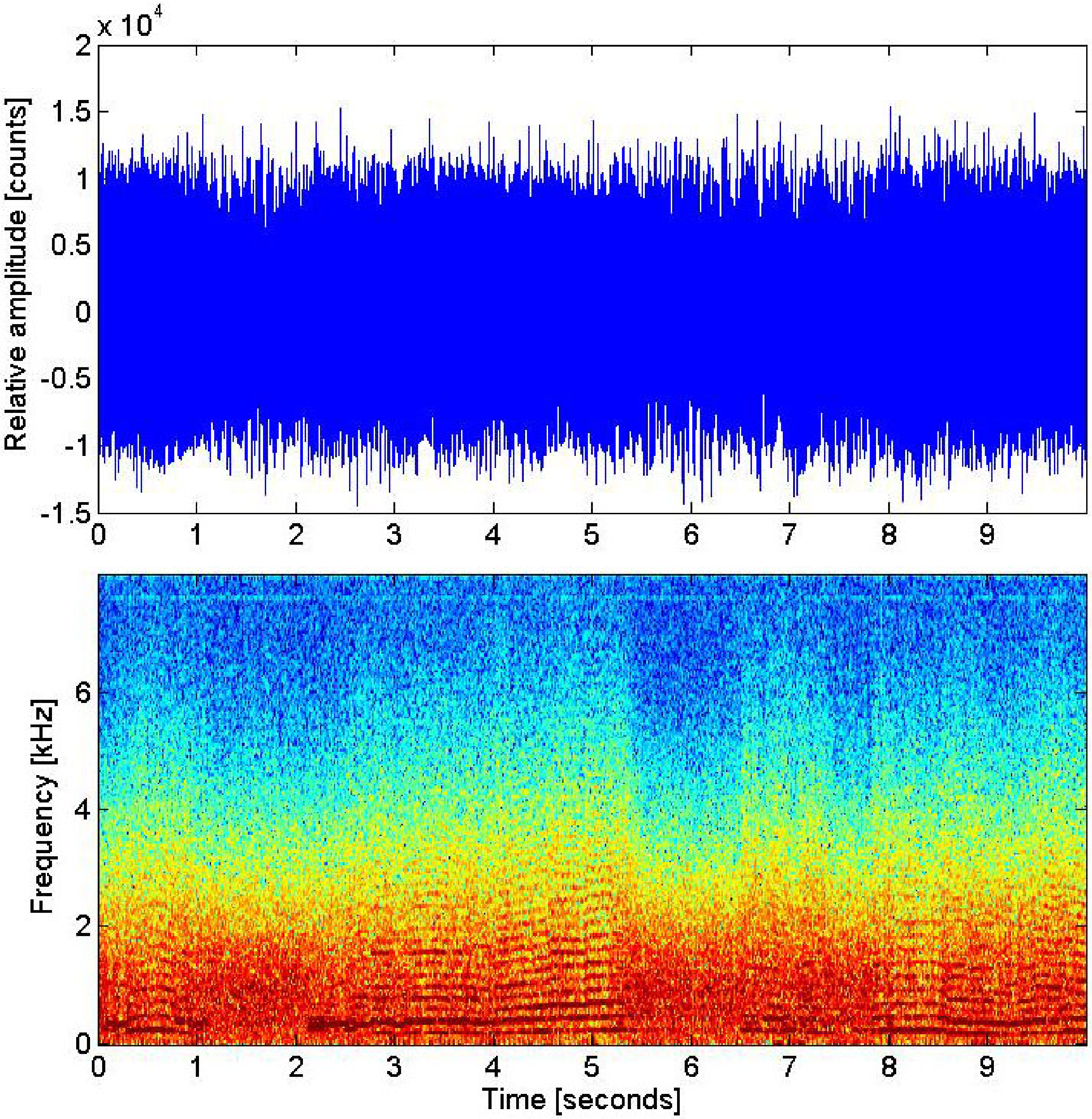

Figure 15. Time series and spectrogram of sound from the dredge recorded on 23 September, 2009 on mooring M2. Spectrogram was plotted with 1000-point FFT and 0% overlap.

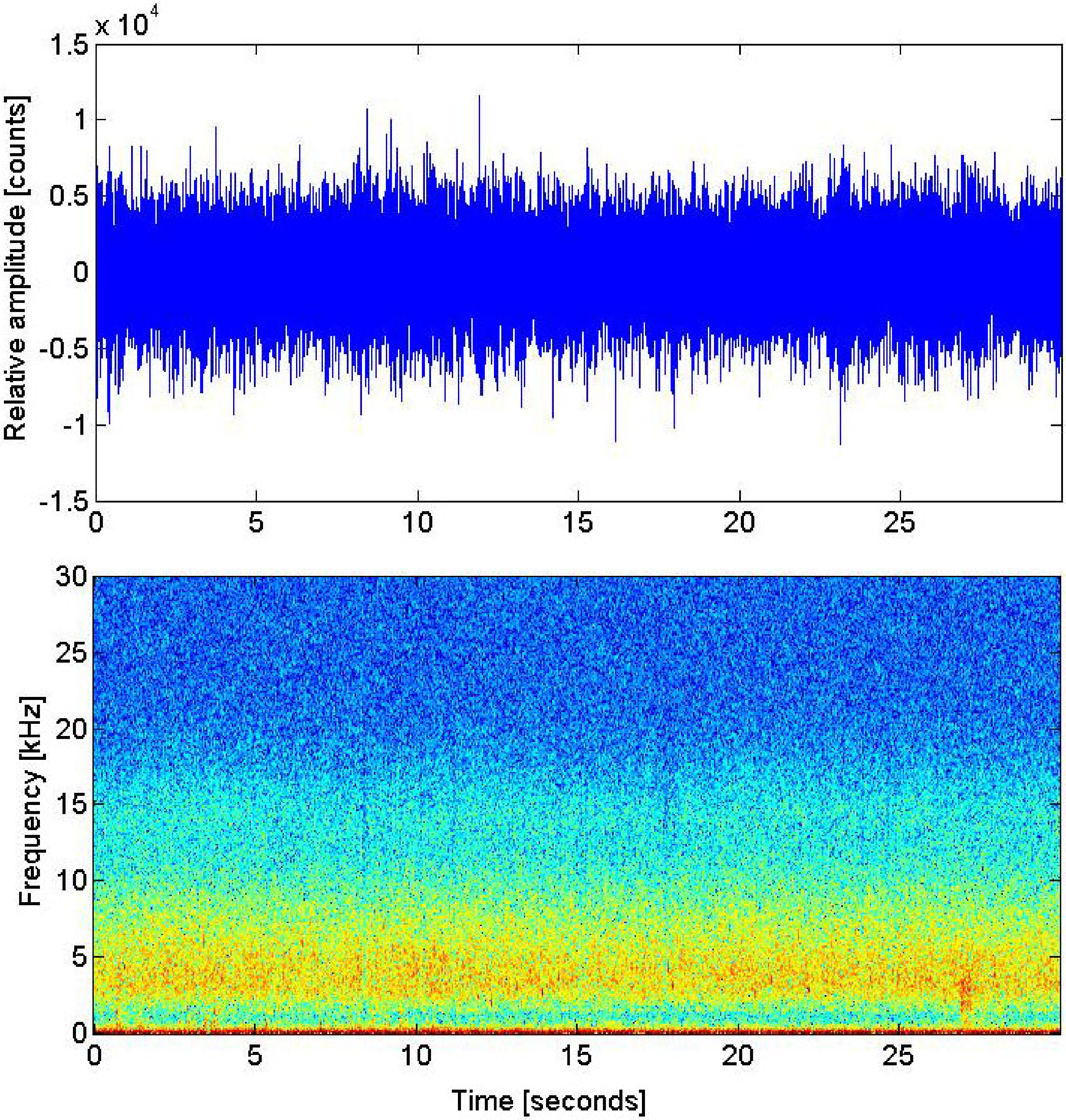

Figure 16. Time series and spectrogram during a period without construction activities recorded on mooring M4 on 28 August, 2009. Spectrogram was plotted with 1000-point FFT and 0% overlap.

Received levels of impact hammer pile driving varied with distance from the pile driver at which the recording was taken (Figure 17). The slope of the best-fit line fitted through the scatter plot of received levels versus the logarithm of range, which is the empirical value of the transmission loss coefficient, was found to be 16.4. This value falls between the theoretical values for cylindrical and spherical spreading loss (10 and 20, respectively). The PAM Team compared this value with the results of theoretical transmission loss modeling and found that it corresponds well to the modeled loss at high tide at ranges over 200 m (Figure 18). In general, transmission loss characteristics did not change over the range of modeled frequencies (10 to 15,000 Hz) and the change in TL characteristics between August and September conditions was minor. Transmission loss was, however, approximately 2 dB lower during low tide than during high tide conditions at ranges greater than 20 m (Figure 18), indicating that sound propagates somewhat better during low tide.

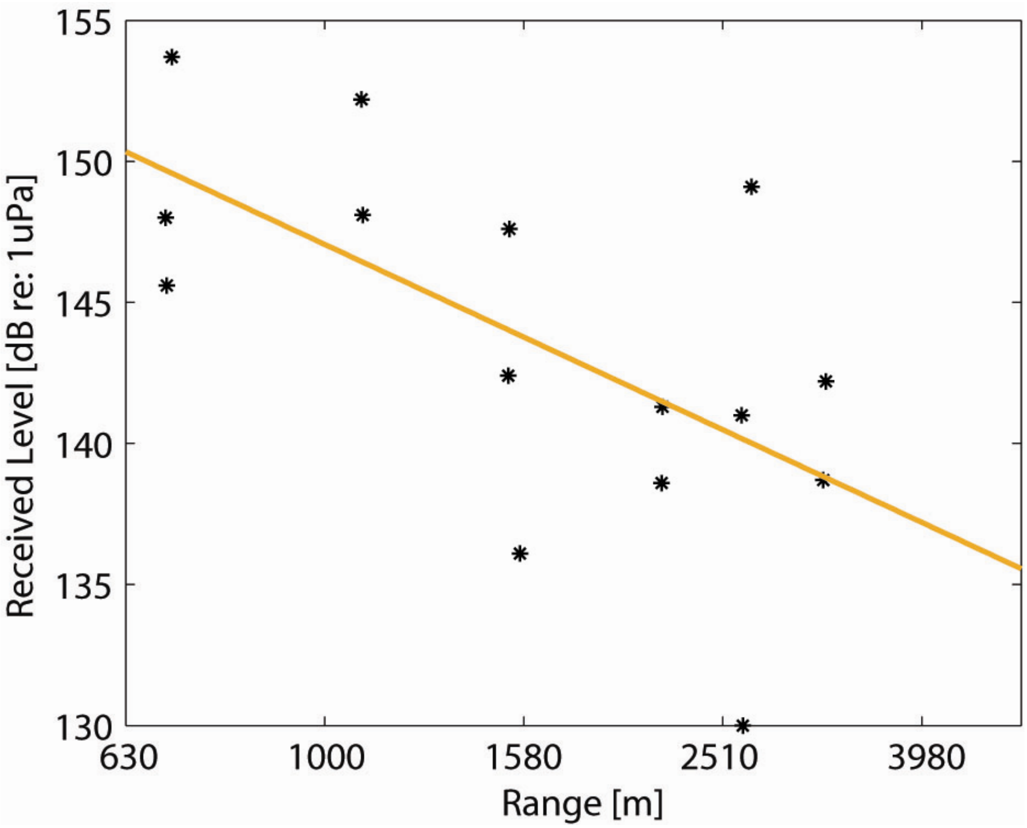

Figure 17. Measured received levels of impact hammer pile driving sounds recorded during four drifts plotted against the log-range. The slope of the best-fit line (shown in orange) gives the coefficient of transmission loss, X = 16.4.

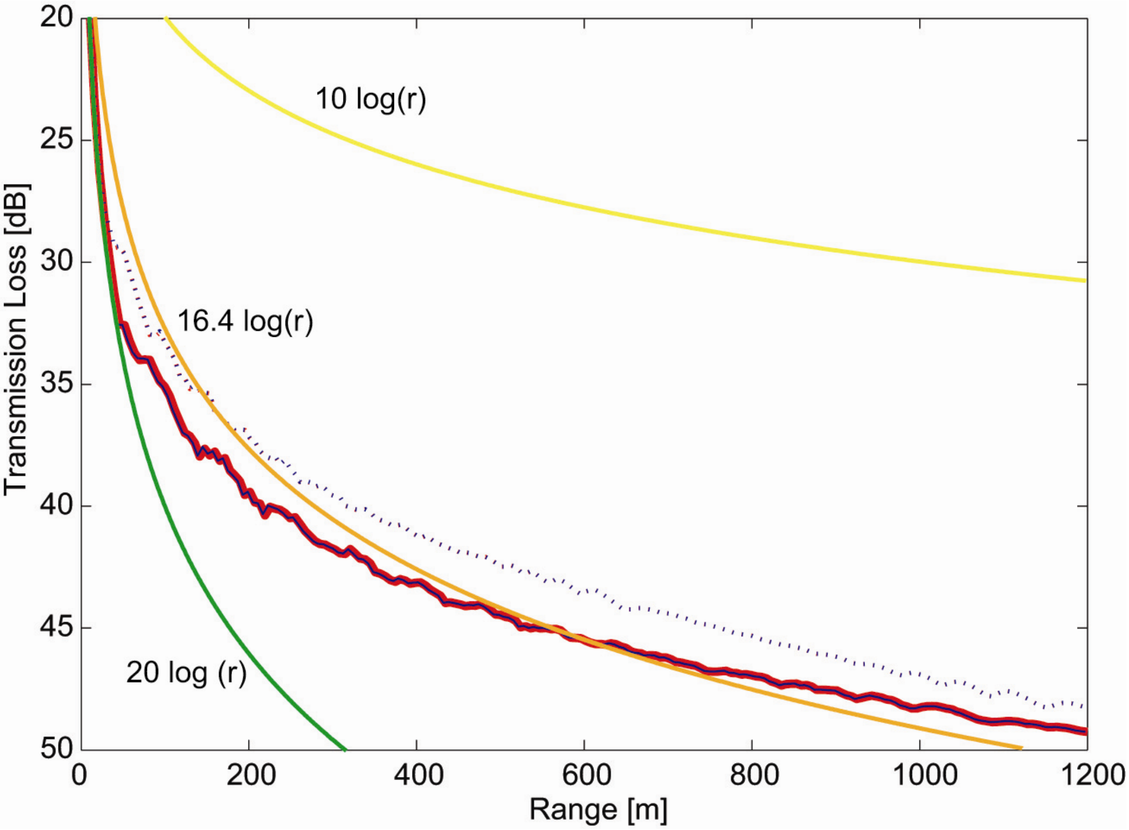

Figure 18. Results of propagation modeling compared to empirical transmission loss model. The transmission loss results are shown for 500 Hz at 2 m (depth of the hydrophone during drifts). Thick red line is showing September condition and overlapping thin blue line August conditions. Dotted lines show transmission loss during low tide and solid lines show high tide conditions; the difference is <2 dB. Green and yellow lines show theoretical transmission loss for spherical and cylindrical spreading, respectively.

Average sound pressure level in the area of the drift survey during August and September 2009 was 129.4 ± 5.4 dB re: 1 μPa with construction activities, and 117.9 ± 10.5 dB re: 1 μPa without construction (Table 3). Pile driving occurred frequently during the PAM Team's study. The average source level of impact hammer pile driving during period of drift recordings in August and September 2009 was 196.9 ± 6.1 dB re: 1 μPa at 1 m. Individual impact pile drives lasted an average of 0.0776 ± 0.0110 s. The energy of impact hammer pile driving extended up to 20,000 Hz, although most of it was below 10,000 Hz (Figure 13). The average source level of vibratory hammer pile driving was 183.2 ± 4.8 dB re: 1 μPa at 1 m and the energy from vibratory pile driving was mostly contained at frequencies lower than 10,000 Hz (Figure 14).

Table 3. Sound levels of different construction activities in the vicinity of the MTR Project

	IPD		VPD	Construction	No construction
	Pulse duration (s)[1]	SL (dB re: 1µPa-1m)[2]	SL (dB re: 1 µPa - 1m)[3]	SPL (dB re: 1 µPa)[4]	SPL (dB re: 1 µPa)[5]
Average	0.0776	196.9	183.2	129.4	117.9
St.dev.[6]	0.0110	6.1	4.8	5.4	10.5

[1] The duration of the pulse from the impact hammer pile driving (IPD).
[2] The source level of IPD.
[3] The source level of vibratory hammer pile driving (VPD).
[4] The sound pressure levels (SPL) of general construction noise for frequency band from 200 to 20,000 Hz.
[5] The SPL of ambient noise without construction for frequency band from 200 to 20,000 Hz.
[6] St.dev. = standard deviation

3.6 Environmental Conditions in the Study Area

Environmental conditions in the survey area during the period of the study are summarized in Table 4. The sea state had a mode of 1 on the Beaufort scale (ripples without foam crests). Rain was reported on six days during acoustic observations; however, clicks were observed on five of the rain days, suggesting it did not interfere with detections. Anthropogenic activities observed during the survey period included impact and vibratory hammer pile driving, dredging, and aircraft and vessel traffic.

In August, the average surface water temperature was 13.2 degrees Celsius (°C), mean salinity was 9, and mean turbidity was 2.7 centimeters (cm). In September, the average surface water temperature decreased to 11.8 °C, with a low of 9 °C. The mean salinity and turbidity slightly increased to 10 and 7.2 cm, respectively. On 25 September, temperature and salinity were taken at the surface, 6 m, 12 m and 18 m. Temperature and salinity were consistent throughout the water column measuring 10 °C and 10 respectively, suggesting Knik Arm is a well-mixed body of water.

Table 4. Environmental conditions in the vicinity of the MTR Project by month

Month	Sea State[1]	Mean Wind Speed (km/h)[2]	Mean Swell Height (m)[2]	Mean Surface Water Temperature (°C)[2]	Mean Salinity[2]	Mean Turbidity (cm)[2]	Sound speed (m/s)[2]
August	1	2	0	13.2	9	2.7	1470
September	1	3	0	11.8	10	7.2	1466

[1] Mode value.
[2] Mean value.

4.0 DISCUSSION

Beluga whale echolocation clicks with most acoustic energy at frequencies higher than 15 kHz were commonly recorded in the vicinity of the MTR Project construction site, but other types of beluga whale vocalizations (e.g. whistles) were very rare. Common anthropogenic noise recorded during the survey period included impact and vibratory hammer pile driving, dredging, and aircraft and vessel traffic. Most of these anthropogenic sounds have energy at frequencies below 10 kHz, but occasionally extend up to 20 kHz in the case of impact hammer pile driving.

4.1 Visual and Acoustic Comparison

Beluga whales were detected more frequently by acoustic observations than by the two visual observation teams. Based on the assumption of beluga whales passing through the Port area, and given the average group size of 3 animals recorded by the Scientific Monitoring Team, 21 beluga whales were missed by visual observation alone during the survey period. This discrepancy between visual observation and acoustic detection is expected because visual observation relies on the brief period of time when the animal surfaces (Mellinger *et al.* 2007). It is often difficult to visually observe beluga whales due to their coloration, especially when environmental conditions are not favorable. On the other hand, beluga whales are highly vocal animals (Reeves *et al.* 2002) and rely on echolocation to navigate (Richardson *et al.* 1995). Echolocation could be particularly important in the turbid waters of Cook Inlet where the whales cannot rely on eyesight for navigation, resulting in a greater chance of detecting them acoustically than by visual observation. Beluga whales have been observed diving for approximately 20 minutes (Martin and Smith 1999) and could feasibly dive without surfacing throughout the MTR Project construction site monitoring area.

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), indicating beluga whales may use areas offshore more frequently than originally believed (Moore *et al.* 2000). Over the past several years, marine mammal 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 2008). However, Markowitz and McGuire (2007) note that 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 to be missed than beluga whales passing near the shoreline adjacent to the observation station.

The differences in the behavioral state of the beluga whales, i.e. whether the whales are feeding, traveling, or socializing, may make them more or less suitable for a particular survey method during a certain time period. The direction and location of the acoustically detected beluga whales from the mooring is unknown because it was not feasible to localize the whales. 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. This behavioral strategy may also make those beluga whales less readily available for visual observation. Conversely, beluga whales traveling closer to shore may be surfacing more and thus be detected more easily by visual observation. Currently there are no baseline data on Cook Inlet beluga whale vocalizations; capturing the full range of beluga whale vocalizations under a variety of behavioral conditions would increase understanding of the potential impacts of construction noise on the Cook Inlet beluga whale.

4.2 Sounds Levels in the Vicinity of the MTR Project

The sound levels recorded during this study in the vicinity of the MTR Project are comparable to those recorded by earlier studies in the Knik Arm (Blackwell and Greene 2002, Blackwell 2005, URS 2007; Scientific Fishery Systems, Inc. 2009). The PAM Team found that the overall ambient sound levels in this part of Cook Inlet are relatively high in comparison to other areas with high levels of anthropogenic noise (Richardson *et al.* 1995; McDonald *et al.* 2006), even in the absence of specific construction noise. It is important to consider that a part of the high ambient noise can likely be explained by high flow noise resulting from strong tidal currents.

The PAM Team's empirical and modeled transmission loss coefficients were very similar to each other over the investigated ranges (10 to 1200 m). The empirical value was likely an underestimate at close ranges (<50 m), which is expected, given that the recordings used for the determination of the transmission loss were collected at ranges >500 m to the source. However this underestimate at low range means that the overall estimate of transmission loss is likely to be low and therefore the calculations of source levels for vibratory and impact hammer pile driving may be biased low, as well.

Most of the energy recorded from anthropogenic noise in the vicinity of the MTR Project was lower than 10 kHz. One exception was impact hammer pile driving, noise from which extended up to 20 kHz. At these high sound levels, over a broad range of frequencies, the use of vocalizations by beluga whales could be affected by masking. Masking occurs when noise interferes with a sound of interest because both the noise and sound of interest have similar frequencies (Richardson *et al.* 1995). These construction noises, though, do not mask echolocation clicks, and it is possible that this is the primary vocalization produced by beluga whales in this area because they are trying to avoid other loud frequency bands.

4.3 Implications for Future Studies

Knik Arm of the Upper Cook Inlet in general, and the area in the vicinity of the MTR Project in particular, provide a challenging environment for successful PAM of beluga whales. Strong tidal currents caused occasional losses of sonobuoy signal during survey days with high tidal fluctuations. It is likely that any other real-time monitoring setup would suffer from similar problems, or other problems caused by sedimentation and flow. Deployment of long-term moored recorders would require special adaptation of such equipment. Additionally, such long-term moorings generally do not provide opportunity for real-time monitoring that was possible during this study.

An additional problem encountered during PAM in the area was loud, broadband anthropogenic noise. The sources of most of this noise were transient, but the PAM Team was able to collect recordings with relatively low noise levels during periods when beluga whales were sighted. Even in these recordings, however, background noise levels were relatively high (average 118 dB re: 1 µPa). The paucity of beluga whale vocalizations in the lower frequency band (<10 kHz) thus may indicate that beluga whales are not producing lower frequency sounds (whistles, pulse tones or noisy vocalizations) while transiting through this area. Alternatively, these sounds may be masked by other noises at lower frequencies and may only be detectable by nearby conspecifics or observers. Generally, to improve the recordings of the most common beluga whale sounds in this area, echolocation clicks, the use of recording gear specifically designed to record larger bandwidth would be advisable.

Visual and acoustic survey methods operate over different spatial and temporal scales. Visuals observations cover a much larger area, especially in Knik Arm, where sounds may be masked by noise or do not propagate far from the sender. Nevertheless, this study indicates that visual observation alone can potentially miss over one-third of the beluga whale groups passing through the area. Acoustic method alone missed beluga whales 3 percent of the time and provided coverage over a small area. However, if a long-term acoustic monitoring program were implemented, the program would need to use acoustic equipment such as autonomous recorders specifically adapted for rough conditions of Upper Cook Inlet that are capable of recording the full range of beluga whale vocalizations for extended periods of time. Given the difficulties associated with the implementation of a real-time, broad bandwidth recording system in Knik Arm, a combination of the two methods would increase the ability to determine the overall effects of MTR Project in-water construction on Cook Inlet beluga whales.

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APPENDIX A: Daily Sonobouy Deployments and Sampling Efforts

Date	Mooring	Channel	Start Time (hh:mm)	Lat/degrees	Decimals	Long/degrees	Decimals	Depth (m)	Sonobuoy Sampling Efforts (hh:mm)	Daily Sampling Effort (hh:mm)
1-Aug-09	1	0	9:49	61	15.286	-149	53.840	19.8	**Mooring Installation**	
	2	0	9:23	61	15.542	-149	53.416	7.9		
	3	0	10:47	61	15.196	-149	53.464	15.8		
	4	0	10:15	61	14.921	-149	53.733	15.1		
3-Aug-09	1	31	6:22	61	15.312	-149	53.850	27.4	0:00	3:20
	2	28	6:16	61	15.569	-149	53.427	12.2	0:00	
	3	5	6:26	61	15.210	-149	53.469	23.6	3:20	
	4	14	6:30	61	14.945	-149	53.721	20.4	0:26	
4-Aug-09	1*	4	7:11	61	15.315	-149	53.315	26.8	–	5:40
	1$^{\diamond}$	6	12:18	61	15.278	-149	53.838	19.8	–	
	2	31	7:22	61	15.562	-149	53.472	22.9	3:46	
	3	14	7:36	61	15.182	-149	53.502	25.4	1:19	
	4	28	7:02	61	14.950	-149	53.698	20.8	0:00	
11-Aug-09	1	26	11:07	61	15.309	-149	53.830	27.7	4:10	6:48
	2	31	11:26	61	15.571	-149	53.439	13.7	4:41	
	3	28	11:32	61	15.193	-149	53.465	23.3	5:30	
	4	14	11:36	61	14.937	-149	53.732	21.9	1:36	
13-Aug-09	1	28	12:40	61	15.318	-149	53.839	26.2	4:18	8:17
	2	30	12:27	61	15.574	-149	53.427	12.2	0:06	
	3	31	12:21	61	15.206	-149	53.470	22.3	7:41	
	4	14	12:17	61	14.951	-149	53.730	21.0	8:17	

Date	Mooring	Channel	Start Time (hh:mm)	Lat/degrees	Decimals	Long/degrees	Decimals	Depth (m)	Sonobuoy Sampling Efforts (hh:mm)	Daily Sampling Effort (hh:mm)
18-Aug-09	1	31	19:11	61	15.317	-149	53.834	27.2	7:25	8:25
	2	14	18:41	61	15.572	-149	53.428	12.8	2:26	
	3*	12	18:51	–	–	–	–	–	–	
	$3^{\Diamond}$	12	19:46	61	15.181	-149	53.496	26.5	0:02	
	4	28	19:28	61	14.946	-149	53.718	21.9	5:45	
20-Aug-09	1	14	7:58	61	15.303	-149	53.854	30.2	7:36	8:07
	2*	31	7:17	61	15.577	-149	53.410	13.4	–	
	$2^{\Diamond}$	31	8:10	61	15.534	-149	53.465	20.1	5:48	
	3	12	7:33	61	15.207	-149	53.472	25.9	1:10	
	4	28	7:38	61	14.928	-149	53.777	22.9	0:53	
22-Aug-09	1	14	9:38	61	15.283	-149	53.859	30.2	6:48	7:01
	2*	31	9:06	–	–	–	–	–	–	
	$2^{\Diamond}$	20	10:02	61	15.511	-149	53.442	21.1	1:21	
	3	28	9:45	61	15.217	-149	53.466	24.1	0:34	
	4	12	9:25	61	14.908	-149	53.744	–	3:09	
25-Aug-09	1	28	11:31	61	15.315	-149	53.839	26.7	5:31	7:34
	2	14	11:05	61	15.576	-149	53.409	12.8	5:11	
	3	12	11:39	61	15.214	-149	53.474	24.3	3:26	
	4	31	11:10	61	14.957	-149	53.705	21.6	5:15	
28-Aug-09	1	31	13:45	61	15.321	-149	53.833	25.0	4:29	9:01
	2	28	14:04	61	15.569	-149	53.413	11.5	8:14	
	3	14	14:08	61	15.218	-149	53.476	23.1	8:34	
	4	12	14:12	61	14.943	-149	53.702	21.0	8:07	

Date	Mooring	Channel	Start Time (hh:mm)	Lat/degrees	Decimals	Long/degrees	Decimals	Depth (m)	Sonobuoy Sampling Efforts (hh:mm)	Daily Sampling Effort (hh:mm)
1-Sep-09	1	31	10:39	61	15.281	-149	53.827	21.1	6:36	8:57
	2	28	10:47	61	15.532	-149	53.416	11.0	3:11	
	3	14	10:43	61	15.213	-149	53.408	18.2	5:24	
	4	12	10:31	61	14.918	-149	53.719	16.4	7:22	
4-Sep-09	1	14	8:46	61	15.274	-149	53.858	28.3	5:21	6:55
	2	31	9:14	61	15.510	-149	53.479	23.8	6:06	
	3	28	9:08	61	15.174	-149	53.498	25.8	6:32	
	4	6	9:22	61	14.907	-149	53.751	22.5	5:52	
8-Sep-09	1	20	10:13	61	15.315	-149	53.854	29.1	6:36	8:33
	2	28	9:54	61	15.562	-149	53.417	13.9	3:41	
	3*	31	–	–	–	–	–	–	–	
	3◊	4	10:34	61	15.204	-149	53.478	24.8	6:17	
	4*	31	–	–	–	–	–	–	–	
	4◊	14	10:03	61	14.947	-149	53.714	22.3	8:26	
10-Sep-09	1	31	11:12	61	15.318	-149	53.852	27.4	5:25	7:38
	2	20	10:51	61	15.572	-149	53.416	12.1	6:10	
	3	28	11:18	61	15.214	-149	53.485	22.9	6:22	
	4	14	11:04	61	14.951	-149	53.737	21.8	5:30	
15-Sep-09	1	14	12:02	61	15.324	-149	53.830	22.3	3:04	9:41
	2	31	12:05	61	15.553	-149	53.459	11.1	0:40	
	3	28	12:07	61	15.212	-149	53.481	15.0	5:08	
	4*	29	12:10	61	14.944	-149	53.741	13.4	–	
	4◊	6	12:36	61	14.946	-149	53.736	14.2	8:26	

Date	Mooring	Channel	Start Time (hh:mm)	Lat/degrees	Decimals	Long/degrees	Decimals	Depth (m)	Sonobuoy Sampling Efforts (hh:mm)	Daily Sampling Effort (hh:mm)
18-Sep-09	1	28	14:48	61	15.314	-149	53.852	19.9	0:04	0:26
	2	31	14:38	61	15.556	-149	53.474	23.5	0:20	
	3	14	14:43	61	15.213	-149	53.490	15.4	0:13	
	4	–	–	–	–	–	–	–	–	
20-Sep-09	1	28	9:18	61	15.312	-149	53.844	29.0	4:58	6:41
	2	0	0	0	0.000	0	0.000	0.0	–	
	3	31	8:52	61	15.213	-149	53.493	26.1	2:23	
	4	14	9:11	61	14.947	-149	53.718	22.8	2:18	
22-Sep-09	1	–	–	–	–	–	–	–	–	0:00
	2	–	–	–	–	–	–	–	–	
	3	–	–	–	–	–	–	–	–	
	4	14	9:45	61	14.946	-149	53.721	21.9	0:00	
23-Sep-09	1	31	11:03	61	15.311	-149	53.852	29.1	7:52	8:05
	2	–	–	–	–	–	–	–	–	
	3	14	10:51	61	15.203	-149	53.469	23.5	7:21	
	4	28	10:54	61	14.946	-149	53.714	22.0	7:27	
25-Sep-09	1	4	12:35	61	15.317	-149	53.845	27.6	7:50	8:57
	2	14	12:50	61	15.553	-149	53.404	12.2	8:45	
	3	28	12:59	61	15.199	-149	53.501	25.0	8:47	
	4*	31	13:01	61	14.932	-149	53.729	22.0	–	
	4$^{\lozenge}$	26	13:27	61	14.922	-149	53.770	23.5	8:22	

Date	Mooring	Channel	Start Time (hh:mm)	Lat/degrees	Decimals	Long/degrees	Decimals	Depth (m)	Sonobuoy Sampling Efforts (hh:mm)	Daily Sampling Effort (hh:mm)
27-Sep-09	1	4	15:08	61	15.300	-149	53.862	28.4	4:50	9:10
	2	26	15:31	61	15.545	-149	53.408	11.6	9:10	
	3	14	15:17	61	15.206	-149	53.479	22.9	8:20	
	4	28	15:21	61	14.942	-149	53.723	21.1	7:50	
29-Sep-09	1	4	17:26	61	15.298	-149	53.841	27.1	1:39	9:10
	2	5	17:29	61	15.555	-149	53.401	13.1	8:33	
	3	14	17:37	61	15.200	-149	53.471	23.2	8:54	
	4	28	17:41	61	14.944	-149	53.735	22.1	8:39	
									Total	**148:26:00**

* Failed

◊ Redeployed

− No data

APPENDIX B: Data Log Sheets

Boat Data Sheet

Date:
Crew:

Time on Water:

Time	**Notified**
	Sam Cunard (ICRC)
	Port Security
	Harry M

Recovery:

M1:

M2:

M3:

M4:

Deployment:

	M1	**M2**	**M3**	**M4**
Deployment Time				
Latitude				
Longitude				
Sonobuoy Channel				
Depth				
Added Weight				
GPS Point				

Water Environmental:

Temperature		
Salinity		
Turbidity		

Time off Water:

Time	**Notified**
	Sam Cunard (ICRC)
	Port Security

Cairn Point Data Sheet

Date:
Observer:
Arrival Time:
Time Generator Started:

	M1	**M2**	**M3**	**M4**
Deployment Time				
Sonobuoy Channel				
Frequency				

Notes:

Time	**Comments**

Activities:

Activity	**Start**	**End**	**Species**	**Channel**	**Comments**

Acronyms
IPD = impact pile driving
VPD = vibratory pile driving
o.h. = overhead

Time Left CP:

Environmental Data Sheet

Date:

Time	**Precipitation**	**Sea State (Beaufort Scale)**	**Wind Speed (km)**	**Swell (m)**

APPENDIX C: Passive Acoustic Monitoring Plan for Cook Inlet Beluga Whales

PASSIVE ACOUSTIC MONITORING PLAN FOR COOK INLET BELUGA WHALES

PORT OF ANCHORAGE MARINE TERMINAL REDEVELOPMENT PROJECT

Prepared for

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Maritime Administration
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July 31, 2009

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Acronyms and Abbreviations

APU	Alaska Pacific University
EAFB	Elmendorf Air Force Base
GB	gigabyte
GPS	Global Positioning System
Hz	hertz
ICRC	Integrated Concepts and Research Corporation
IHA	Incidental Harassment Authorization
kHz	kilohertz
km	kilometer
m	meter
MMPA	Marine Mammal Protection Act
MTR	(Port of Anchorage) Marine Terminal Redevelopment (Project)
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
PAM	passive acoustic monitoring
POA	Port of Anchorage Administration
Port	Port of Anchorage Facility
TOAD	time of arrival difference
USACE	U.S. Army Corps of Engineers

1.0 INTRODUCTION

The Port of Anchorage Marine Terminal Redevelopment (MTR) Project (Project) is designed to upgrade and expand existing Port of Anchorage facilities (Port) by removing and replacing aging and obsolete structures and providing additional dock and backland areas, without disruption of maritime service during construction. The Project includes in-water construction activities that have the potential to adversely impact marine mammals within the Knik Arm of Upper Cook Inlet in Southcentral Alaska.

In compliance with Special Condition IV(1)(B)(b) of the U.S. Army Corps of Engineers (USACE) 404-10 Permit for the MTR Project and Stipulation 5(e)(2)(b) of the Incidental Harassment Authorization (IHA) issued 15 July 2008 to the Port of Anchorage Administration (POA) and the Department of Transportation, Maritime Administration, by the National Oceanic and Atmospheric Administration, National Marine Fisheries Service (NOAA/NMFS), a passive acoustic monitoring study of the Cook Inlet beluga whale *(Delphinapterus leucas)* will be conducted during the 2009 MTR Project construction season. The purpose of the study, as stated in the 404-10 Permit and the IHA, is to "detect and localize, to the maximum extent practicable, passing whales and to determine the proportion of beluga whales missed from visual surveys. This study shall characterize sound levels around the Port related to and in absence of all construction activities."

Under contract with Integrated Concepts and Research Corporation (ICRC), Alaska Pacific University (APU) provides this *Passive Acoustic Monitoring Plan for Cook Inlet Beluga Whales* to be implemented at the Port. This Plan sets forth the methodology that will be used for beluga whale monitoring and data collection during passive acoustic monitoring. This Plan has been developed in consultation with ICRC, in accordance with USACE and the NOAA/NMFS guidance for compliance with the *Marine Mammal Protection Act* (MMPA).

2.0 OBJECTIVES

As stated in Section 1.0, the purpose of the passive acoustic monitoring study is to detect and localize beluga whales in the vicinity of the MTR Project footprint and characterize sound levels both during construction activities and in the absence of construction activities. Another objective of the study is to correlate visual and acoustic data to estimate the proportion of whales missed by observation, i.e., visual marine mammal monitoring alone. Under the supervision of Dr. Ana Širović, APU, Department of Environmental Science, the acoustic monitoring team will collect the data necessary to answer the following questions:

1. How often are beluga whales missed during visual marine mammal monitoring?
2. What is the estimated proportion of beluga whales missed during visual monitoring?
3. What are the sound levels related to, and in the absence of, all construction activities in the area around the Port?

3.0 FIELD STUDY APPROACH

The study will be conducted from 1 August through 30 September 2009, in the waters of the Knik Arm of Upper Cook Inlet adjacent to the Port. Four moored lines will be deployed in a square formation at the beginning of the survey period, allowing quick re-deployment of multiple sonobuoys, electronic devices capable of transmitting passive acoustic data, in the array during implementation of the Plan. After each sonobuoy deployment, a member of the acoustic study team will be at the Cairn Point Marine Mammal Monitoring Station (Cairn Point Station) on Elmendorf Air Force Base (EAFB) to monitor and record signals received from the sonobuoys. Sonobuoys will be deployed in the vicinity of Cairn Point (Figure 1). Four moored lines will be deployed in a rhomboid formation (sides between approximately 400 and 700 meters [m]) at the beginning of the survey period and removed at the end of the survey period. The locations of the moorings were chosen based on the proximity to the Cairn Point station, favorable bathymetric conditions, and relative safety from dredging and shipping operations. The time period when the sonobuoys will be deployed corresponds to the period when beluga whales are frequently sighted in the Port area (Funk *et al*. 2005). The days of acoustic data collection will be chosen based on tides and weather conditions, which limit the ability to launch a boat and deploy sonobuoys.

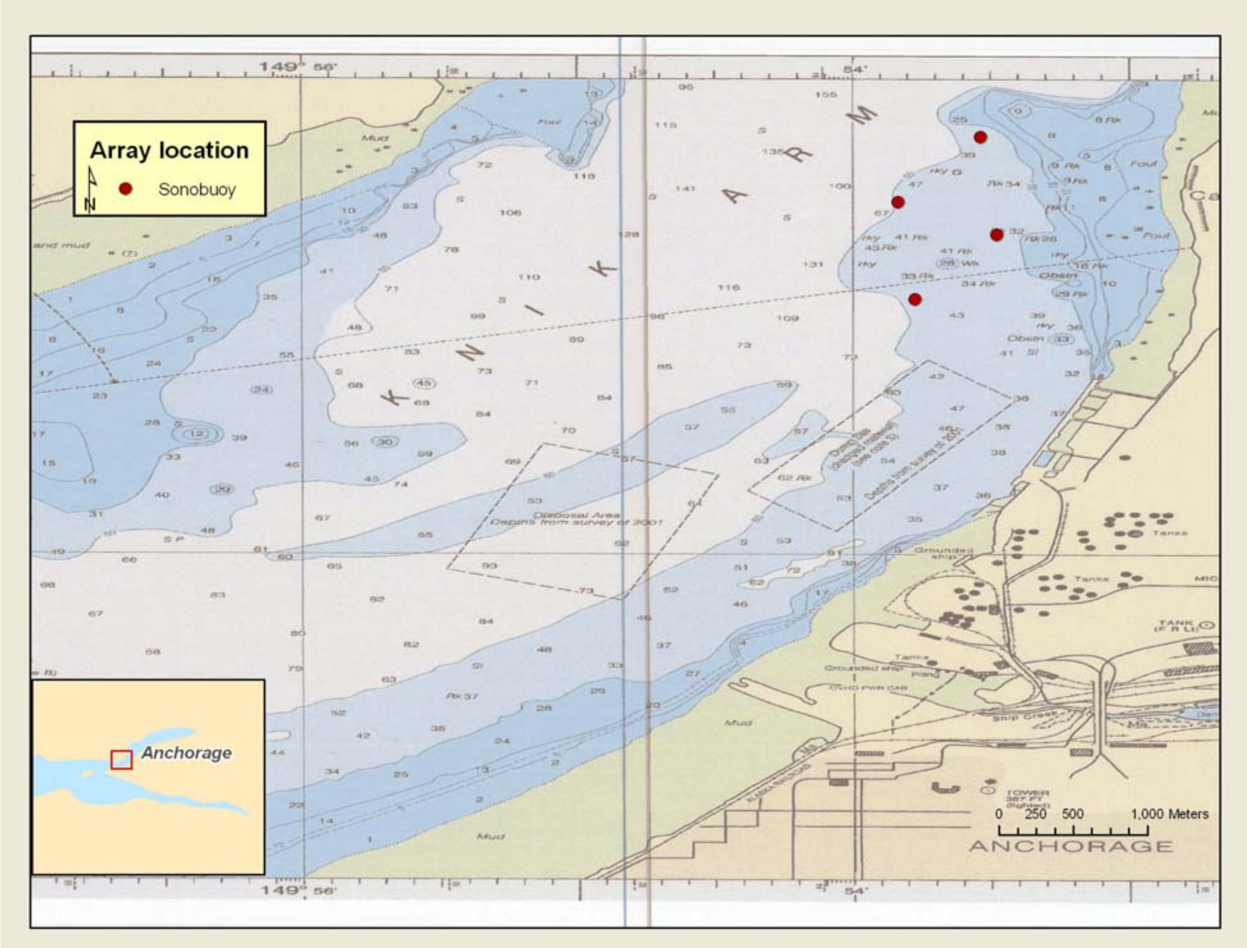

Figure 1. Approximate location of the tightly spaced array of four moored lines, placed between 400 and 700 m apart and approximately 600 m off Cairn Point. Sonobuoys will be attached to the moorings for each day of acoustic monitoring.

3.1 Passive Acoustic Monitoring with Sonobuoys

Sonobuoys are expendable electronic devices that consist of a hydrophone, float, radio transmitter, and salt-water battery (Figure 2). Omnidirectional sonobuoys (AN/SSQ-57B), with a broadband frequency response from 10 up to 35,000 hertz (Hz), will be used for the study. Signals received by the hydrophone are amplified and sent up a wire to the radio transmitter that is housed in the surface float. The length of the wire between the surface float and the hydrophone can be controlled and adjusted to meet research requirements. Sonobuoys continuously transmit their radio signal to a remote observer[2] for a maximum of 8 hours before scuttling[3].

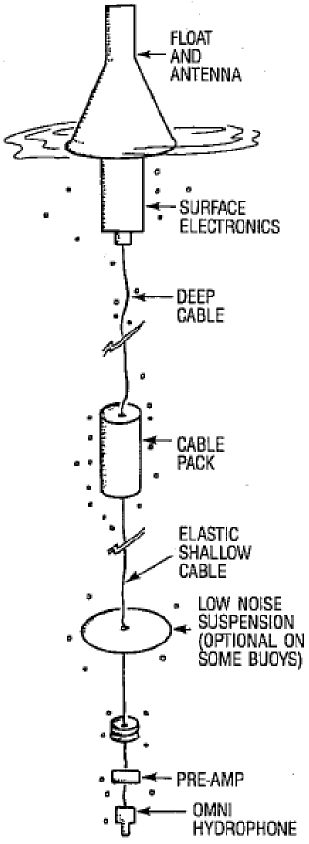

Figure 2. Type AN/SSQ-57 Omnidirectional Sonobuoy. (Figure adapted from Horsley 1989).

Two antennae will be mounted on the conex at the Cairn Point station[4] to receive radio signals from the sonobuoy. A set of custom electronics and software will be used to record and analyze sonobuoy data. The antennae will transmit the received signals to software-controlled ICOM scanner radio receivers, modified to provide improved reception of sonobuoy signal, and then to a computer with a high-quality sound card that enables sampling at a high sample rate (96 kilohertz [kHz]). Data will be digitized using the software program *Ishmael* and saved on 500 gigabyte (GB) hard disks. In the case of a failed deployment, the observer at the Cairn Point

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[2] Sonobuoys are not capable of data recording or analysis. Instead, they transmit a signal that is recorded and analyzed remotely.

[3] Sinking by making a hole in the surface float.

[4] In addition to its proximity to the deployed sonobuoys, the Cairn Point Marine Mammal Observation station was chosen because the elevation of the station allows adequate reception of radio signals from the sonobuoys.

station will contact the deployment team by radio to notify them of a failure. The deployment team will immediately recover the failed sonobuoy and deploy another one. The expected failure rate, based on previous experiences with this type of sonobuoy, is less than 15 percent (Širović *et al.* 2006).

Dr. Širović and her team will monitor and collect deployment, environmental, and preliminary acoustic analysis data during the daily acoustic monitoring period. Data collected will include the following: deployment date, time, latitude, longitude, and transmission channel for each sonobuoy, as reported by the deployment team; beginning and end of acoustic observation period; start and end time of vocalizations (if detected), the species detected, channel(s) with vocalizations; environmental conditions; type of construction (e.g., pile driving with vibratory or impact hammer); and duration of construction activity (Appendix 1). They will enter the data into Microsoft Excel for Windows and/or SPSS v. 15.0 for Windows for storage and analysis. Section 3.7 provides additional information on the collection of data on environmental conditions and anthropogenic activities.

3.2 Array Setup and Testing

During the week of 20 July, the acoustic monitoring team will conduct calibration and initial testing of the system. A mooring line will be placed at the location of one of the permanent moorings to test the equipment and make any necessary adjustments to protocols. Using a test 130 pound anchor attached to approximately 25 m line and a surface float, one sonobuoy will be attached to the mooring and the signal from the sonobuoy will be recorded and monitored from the deployment vessel. The location of the mooring will be recorded using a handheld Garmin GPS 72 Personal Navigator and shipboard GPS.

3.3 Environmental Conditions in the Study Area

Environmental conditions will be logged every hour during daily deployment and monitoring efforts. These conditions include: wind speed, sea state (Beaufort scale), swell height, and precipitation. Water temperature, salinity and turbidity will be documented at the time of sonobuoy deployment. In addition, all anthropogenic activities within the study area will be documented during daily monitoring efforts. Events will be categorized as: no activity, impact hammer or vibratory hammer pile driving, dredging, in-water fill placement, and aircraft and vessel activities. The duration of the activity will be recorded.

3.4 Mooring Installation and Sonobuoy Placement

After the permanent moorings are installed, their location (latitude and longitude) will be recorded using the handheld Garmin GPS. The team will deploy four anchors, each attached to a line approximately 25 m long with a surface float. One sonobuoy will be attached to each float at the beginning of each day of acoustic observations. Previously deployed sonobuoys will be collected each time before the deployment of new sonobuoys, and moorings will be checked for integrity prior to deployment of new sonobuoys. Once the sonobuoy is attached, the hydrophone will be released to anchor depth, allowing the hydrophone to settle on the bottom; this will reduce the flow noise created by currents and tidal fluctuation. The deployment location will be recorded on each day of acoustic observations using the handheld GPS to verify the location of the moorings.

Ambient noise is not expected to be problematic. Noise created by strumming[5] from the line is not expected because this noise becomes a problem only on a taut line. Since the hydrophone will be resting on the bottom with a loose line, strumming should not affect the ability to collect useful data. Furthermore, sonobuoy hydrophones are suspended by a thin, elastic wire that is designed to minimize strumming under high flow conditions. Sonobuoys have been successfully deployed and improved for acoustic data acquisition since the early 1940s. In conditions similar to those of Cook Inlet, sonobuoys were deployed in the Bay of Fundy to collect acoustic data on right whales (Laurinolli *et al.* 2003). If background noise or sediment load prove to be problematic on the bottom, different hydrophone locations in the water column can be attempted for maximum noise reduction. Likewise, since the frequency range of flow noise is different from the frequency range of beluga vocalizations, masking[6] of beluga sounds by flow noise should not affect this study (Richardson *et al.* 1995).

The Coast Guard has been notified of the proposed acoustic monitoring program and will be continuously updated throughout the duration of the project. The acoustic monitoring team will notify the Coast Guard prior to the deployment of mooring lines and will report the GPS coordinates of the deployed moorings. The acoustic monitoring team will also provide

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[5] Creation of sound by vibration.

[6] Noise interfering with a sound of interest because both the noise and sound of interest have similar frequencies (Richardson *et al.* 1995).

coordinates of the moorings to ICRC for relay to the USACE and their dredging team. Additionally, the acoustic monitoring team will notify all parties when the study is complete and the moorings have been removed.

Members of the acoustic monitoring team will cooperate with POA and EAFB personnel and undergo all necessary training to ensure compliance with POA and EAFB safety and security policies. The location of the acoustic monitoring team at the Cairn Point Station may be changed in consultation with ICRC and POA should this area become unavailable due to EAFB operational or security needs.

3.5 Sound Level Characterization

To estimate sound levels in a region, the characteristics of the sound sources in the area, as well as transmission loss characteristics of the medium, must be understood[7]. APU will estimate sound transmission loss coefficient for the Knik Arm off Cairn Point using recordings collected from sonobuoys and complementary boat-based recordings. Observers will use a 27-foot vessel provided by Alaska Divers Underwater Salvage to collect acoustic data using two calibrated HTI-96-MIN hydrophones suspended from a cable at the bow and the stern of the boat approximately at 2 m depth (Blackwell and Greene 2002). The hydrophones will be suspended from the boat through PVC pipe to keep the hydrophones as vertical as possible in the current and to reduce flow noise. Signals from each hydrophone will be recorded continuously using an Edirol R-09 digital recorder at a sample rate of 48 kHz. Once the hydrophones are placed in the water, the boat engines will be turned off to reduce the ambient noise and allow the boat to drift with the current. Recordings will take place in approximately 3-km transects during different tidal stages and construction activities (e.g., vibratory hammer pile driving, impact hammer pile driving). GPS positions will be recorded continuously during sampling to document the drift pattern. Sampling will take place on two occasions during the study, for approximately 3 hours each. Transects will aid in determining the transmission loss characteristics by documenting sound levels at a range of distances from the sound source.

---

[7] Sound level from a source can be calculated as a sum of the received sound level at the receiver and the estimated transmission loss between the source and the receiver. Transmission loss (TL) is a function of the range between the source and the receiver, r, and can be expressed as TL = x * log(r), where x is the transmission loss coefficient.

3.6 Sampling Efforts

Acoustic data will be collected for a total of 20 days (~120 hours) spread out throughout the study. To ensure full 8-hour coverage of sonobuoy transmission during daily acoustic monitoring periods, monitoring will be conducted at the Cairn Point station in two shifts, each of approximately 4 hours duration. Recordings will be collected during periods with and without construction activity.

The time of acoustic surveys will be coordinated, to the maximum extent practicable, with the time of marine mammal observations by the Scientific Marine Mammal Monitoring Team, in an effort to ensure concurrent visual and acoustic data collection. However, to ensure independent sampling, the two groups will work independently and will not be aware of any beluga detections by the other group. The two teams will be instructed not to communicate with each other, and the member of the acoustic monitoring team will be wearing headphones and will be unable to hear any conversations of the marine mammal monitoring team. Since only one member of the acoustic monitoring team will be present during each monitoring session, the marine mammal observers will not have an opportunity to overhear conversations from the acoustic study station. To avoid biasing the observations of the marine mammal observers, the acoustic monitoring team will not share their findings with the marine mammal observers during the study.

4.0 DATA ANALYSIS METHODS

Data will be analyzed as it is collected and also during report preparation. All data will be backed up on a hard disk each day. MatLab (MathWorks, Natick, MA) based sound analysis software will be used for preliminary sound analysis, such as characterization of beluga sound frequency and temporal characteristics. To optimize the data analysis process, automatic detectors[8] will be developed and fine-tuned throughout the study. Several automatic detection methods for efficient detection of calls (e.g. spectrogram correlation, acoustic power level, or neural network analysis) will be investigated, and the method with the lowest level of false

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[8] Automatized methods will be used for acoustic data analyses to ensure consistency, reduce human error, and increase the ability to process large quantities of acoustic data (Au and Hasting 2008).

detections will be chosen for subsequent analysis. Automatic detection analysis will provide information on the presence and timing of the beluga whale sounds.

The acoustically detected presence of beluga whales will be compared with the number of beluga whale sightings recorded by the Scientific Marine Mammal observers stationed at the Cairn Point station. Beluga whale sightings and beluga whale acoustic detections will be pooled into 30-minute bins centered at the times of acoustic detections. Since beluga whales mostly pass near the Port area, if visual and acoustic detections are more than 30 minutes apart, it will be assumed that they represent different groups. These two time-series of detections will be correlated and the estimate of the percent of time beluga whales are missed by visual observations alone will be determined. Also, individual beluga whales will be localized to estimate the minimum proportion of beluga whales missed by visual observations alone.

The location of vocalizing beluga whales will be determined using the time of arrival difference (TOAD) method (Cato 1998). All beluga whale sounds <35 kHz that are recorded on all four sonobuoys in the array will be identified. Accurate differences in the time of arrival of these sounds to each instrument will be determined by cross-correlating[9] the sounds between different instruments. Programming code for automatic cross-correlation of the signals from different instruments will be developed and applied to determine accurate time of arrival differences between each instrument pair. Hyperbolic localization[10] method will be used to determine the location of vocalizing beluga whales. For easier comparison within the 30-min time bin, the locations of beluga whales detected by the passive acoustic method will be entered into ArcGIS (ESRI, Redlands, CA) and overlain with a grid showing the locations of the beluga whale sightings recorded by the Scientific Marine Mammal Observers. The proportion of beluga whales detected and localized by the passive acoustic method but not seen by the Scientific Marine Mammal Observers will be estimated. This fine-scale localization and tracking of vocalizing belugas will allow direct measurement of whales' response to the MTR in-water

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[9] Cross-correlation is a measurement of the similarity of two wave-forms as a function of time lag between them. The difference in the time of arrival of the signal between two instruments is determined as the time when cross-correlation function has the maximum value, i.e. when the two signals are the most similar.

[10] Determining the location of a sound source with an array of hydrophones by geometrically and mathematically calculating the location of a sound source using the properties of a hyperbola (Au and Hastings 2008).

construction activities (e.g. change in the amount or loudness of vocalizations; change in the direction of movement; etc.).

APU will characterize sound levels within the study area relating to, and in the absence of, all in-water construction activities within the MTR Project footprint. Ten-second recordings with and without construction activities will be examined. Measurements derived from the recordings of impact hammer pile driving will include three parameters: peak pressure, pulse duration, and received level. The mean of each parameter will be calculated from 15 recordings. To calculate sound pressure levels (SPL), propagation loss will be determined. Empirical data will be used to estimate the propagation loss coefficient (Section 3.6). In order to obtain this estimate, a plot of received levels versus estimated range will be made for all recordings of the sound of interest. The propagation loss coefficient will be calculated as the slope of the best-fit line through the sound received levels versus estimated range plot (Blackwell 2005; Širović *et al.* 2007). Additionally, sound propagation modeling will be used to theoretically verify the empirical result. Also, the mean SPL from vibratory hammer pile driving and general construction activities will be calculated from 15 recordings to better understand the SPL from construction activities within the MTR Project footprint.

5.0 Scheduling

The schedule for the passive acoustic monitoring (PAM) study includes the development of this study plan for approval, implementation of the plan, and completion of an analysis report. Upon receipt of review comments, the draft plan will be revised and submitted to ICRC for final approval. Exact date of submission will depend on the date when ICRC comments are received by APU, but the Final Study Plan submission is planned on or before July 31, 2009. During the week of July 20, 2009, APU will calibrate and test the equipment and make any necessary adjustments to protocols. Field Implementation of the approved study plan will take place from August 1 through September 30. Exact dates of acoustic monitoring during this period will depend on environmental conditions, but will be coordinated to the maximum extent practicable with the schedule of the marine mammal observation team of the Scientific Marine Mammal Monitoring Program and with MTR Project construction activities. APU will submit the Draft PAM Data Analysis Report (Report) to ICRC in accordance with the current contract requirements on November 30, 2009. The Report will include the elements of the Final PAM Study Plan, analysis, and conclusions. The Final PAM Study Plan, Final PAM Analysis Report, and all relevant supporting information and data will be provided electronically on compact disc (Plan and Report) and hard disk (data) in Microsoft Word, Microsoft Excel, Adobe, wav files, and/or other formats as approved by ICRC.

Table 1. Proposed Schedule with Major Tasks

Date	Task
Week of 20 July	Array Calibration and Field Testing
31 July	Submit Final PAM Study Plan
1 August-30 September	Field Implementation
30 November	Submit Draft Analysis Report

6.0 References

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APPENDIX 1: Data Log Sheet

POA PAM Study

Deployment Date:

Obs. Start Time: **Obs. End Time:**

Mooring 1	Mooring 2	Mooring 3	Mooring 4
Time	Time	Time	Time
Lat	Lat	Lat	Lat
Long	Long	Long	Long
Channel	Channel	Channel	Channel

Activity	Start time	End time	Channel	Species	Comment

Environmental

Time	Wind Speed	Precipitation	Sea State (Beaufort Scale)	Swell Height