Ambient Noise Measurements near the Proposed Knik Arm Crossing Site during May and July 2010

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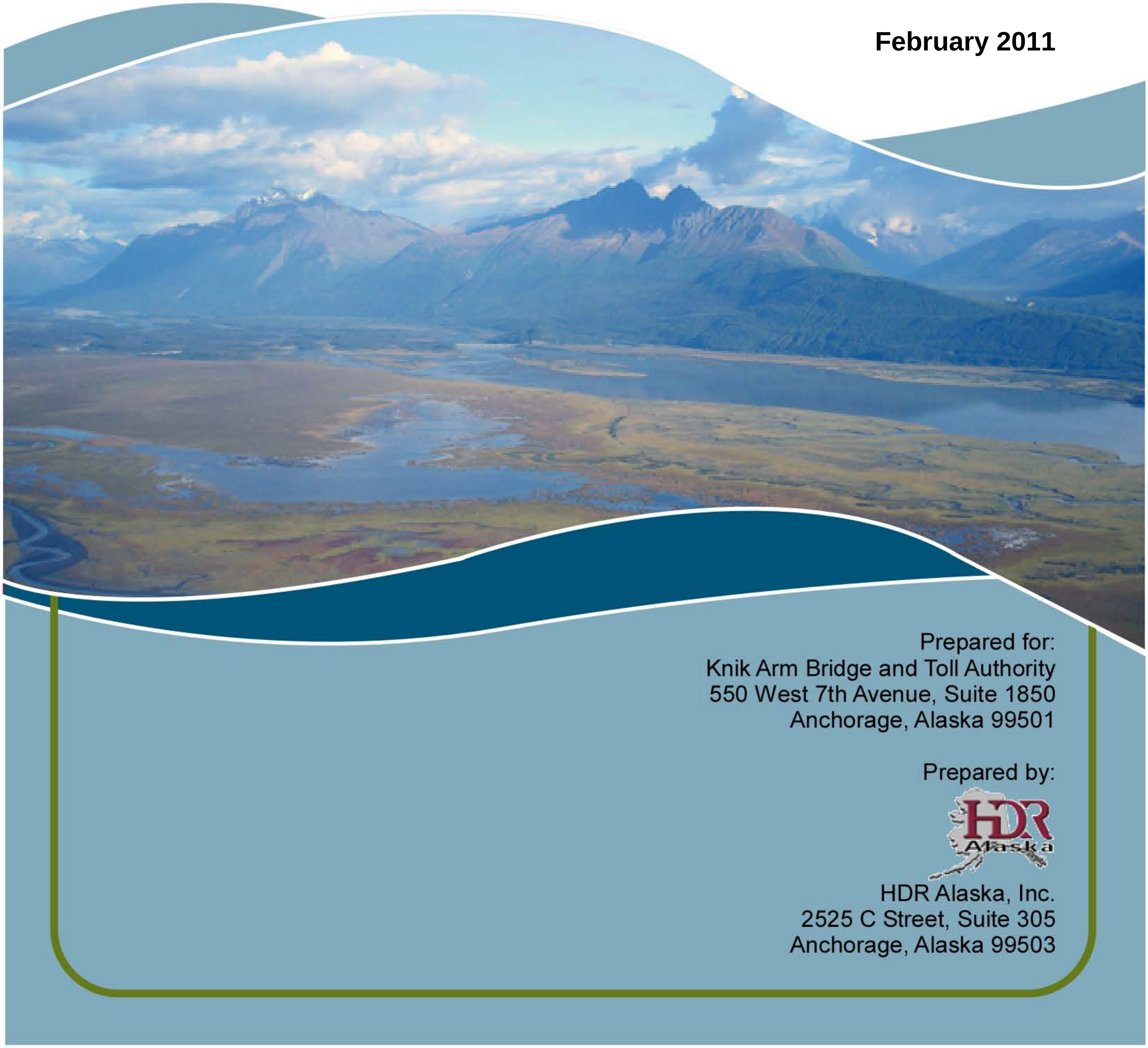

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ACRONYMS AND ABBREVIATIONS

°	degree(s)
ABR	auditory brainstem response
AEP	auditory evoked potential
AWAC	Airborne Warning and Control
dB	decibel(s)
dB re 1 μPa	decibel referenced to 1 micropascal
DTAG	digital acoustic tag
FFT	Fast Fourier Transform
FHWA	Federal Highway Administration
FR	Federal Register
GPS	global positioning system
Hz	hertz
ICI	interclick interval
KABATA	Knik Arm Bridge and Toll Authority
KAC	Knik Arm Crossing
kHz	kilohertz
kg	kilogram(s)
km	kilometer(s)
KW test	Kruskal-Wallis test
m	meter(s)
Mat-Su	Matanuska-Susitna Borough
MLLW	mean lower low water
MRTF	modulation rate transfer function
NMFS	National Marine Fisheries Service
Pa	pascal
POA	Port of Anchorage
Q_{ER}	equivalent rectangular quality
RHIB	rigid-hull inflatable boat
rms	root mean square
s.d.	standard deviation
SPL	sound pressure level
SFS	Scientific Fishery System
TTS	temporary threshold shift

TABLE OF CONTENTS

FIGURES

TABLES

EXECUTIVE SUMMARY

The Alaska Division of the Federal Highway Administration (FHWA) and the Knik Arm Bridge and Toll Authority (KABATA) plan to construct the Knik Arm Crossing (KAC project). The project will further the development of transportation systems in the upper Cook Inlet region by providing improved vehicular access and surface transportation connectivity between Anchorage and the Matanuska-Susitna Borough (Mat-Su) through the Port MacKenzie District. To assess potential impacts on belugas (*Delphinapterus leucas*) (and other marine mammals) from noise produced by the proposed KAC project, it is important to know the baseline ambient noise conditions in the project area.

This study was designed to measure the magnitude and variability of ambient noise in the proposed KAC project area. The intent was to characterize ambient noise both spatially and temporally by replicating acoustic measurements at three sites across the width of the Knik Arm in the area of the proposed KAC construction site, and by sampling the noise field during each tidal cycle (high, ebb, low, and flood tide) during May and July 2010.

Additionally, recordings were made opportunistically in nonindustrial locations and in the vicinity of anthropogenic noise sources (e.g, military aircraft flyovers; dredging operations at the Port of Anchorage [POA]). Throughout the recording sessions, in both May and July, the amplitude and frequency of the recorded noise often sounded like a machine, with accelerations and metallic knocks, which were attributable to dredge operations. The maximum sound levels for concurrently operating suction and clamshell dredges was 148 decibels referenced to 1 micropascal (dB re 1 μPa). High noise levels (maximum of 133 dB re 1 μPa) were recorded at the mouth of the Eagle River, a nonindustrial location, and known beluga whale feeding hotspot.

Overall, ambient noise was highly variable between months, and noise levels in May were more variable than in July. Whether comparing sampling sites or tidal cycles, however, ambient noise levels were much higher in July than in May.

Forty-five noise recordings were made during May and ambient noise levels ranged from 105 to 148 dB re 1 μPa, with a mean of 124 dB re 1 μPa. The 5th and 95th percentiles (i.e., ambient noise level equated to the “quiet” and “loud” conditions) were 109 and 145 dB re 1 μPa, respectively. Thirty-eight percent of ambient noise measurements were above 125 dB re 1 μPa.

During July, 49 noise recording were made and ambient noise levels ranged from 116 to 147 dB re 1 μPa, with a mean of 136 dB re 1 μPa. The 5th and 95th percentile ambient noise levels were 119 and 146 dB re 1 μPa, respectively. Eighty-eight percent of ambient noise measurements were above 125 dB re 1 μPa.

Mean ambient noise levels were significantly different between May and July for all sampling sites and tidal cycles except low tide. Monthly comparisons by sampling site and tidal cycle were made and no significant differences in the mean ambient noise level across the three sampling sites or among tidal cycles were found within either month.

In summary, the collected ambient noise recordings—noise levels measured—demonstrate that Knik Arm is a very loud environment. The results from this study are comparable to other noise studies conducted in the area.

1 INTRODUCTION

The Alaska Division of the Federal Highway Administration (FHWA) and the Knik Arm Bridge and Toll Authority (KABATA) plan to construct the Knik Arm Crossing (KAC project). This involves constructing a new bridge spanning Knik Arm (the Crossing) and approaches from the Matanuska-Susitna Borough (the Mat-Su) side of Knik Arm (the Mat-Su Approach) and the Municipality of Anchorage (Anchorage) side of the Arm (the Anchorage Approach). The Mat-Su and Anchorage approaches will connect the Crossing to existing transportation infrastructure. The project will further the development of transportation systems in the upper Cook Inlet region by providing improved vehicular access and surface transportation connectivity between Anchorage and the Mat-Su through the Port MacKenzie District.

The National Marine Fisheries Service (NMFS) has proposed designating critical habitat for the Cook Inlet beluga whale (*Delphinapterus leucas*), in portions of Cook Inlet, including Knik Arm and the site of the proposed KAC project. As the NMFS noted in its proposed critical habitat rule (74 Federal Register [FR] 63080–63095), anthropogenic noise above ambient levels may cause behavioral reactions in beluga whales (harassment) or mask communication between individuals. The NMFS also expressed concerns that the effects of harassment may include habitat abandonment by belugas.

To assess potential impacts on belugas (and other marine mammals) from noise produced by the proposed KAC project, it is important to know the baseline ambient noise conditions in the project area. Knowledge of the magnitude, variability and predictability of the ambient levels is important for understanding the natural environmental constraints on an animal's ability to communicate, or detect anthropogenic sounds and other relevant sounds.

1.1 Project Objectives

This study was designed to measure the magnitude and variability of ambient noise in the proposed Crossing area. The intent was to characterize ambient noise both spatially and temporally by replicating acoustic measurements at three sites across the width of the Knik Arm in the area of the proposed KAC, and by sampling the noise field during each tidal cycle (high, ebb, low, and flood tide). This sampling design would allow for a synoptic description of the ambient noise in the proposed construction site and provide a snapshot of the impact of tidal cycles on ambient noise for each location. Furthermore, this study would allow for a description of the variability in ambient noise levels due to the tides—valuable knowledge that may be used when mitigating noise effects. The goals of this study were to:

- Collect underwater acoustic recordings of ambient noise in the vicinity of the proposed Crossing at three sites and during the four tidal cycles

- Describe the magnitude and variability of ambient noise in the vicinity of the proposed Crossing using the measurements.

1.2 Applicable Acoustic Exposure Criteria

The NMFS uses generic sound exposure thresholds to determine when an anthropogenic activity produces sound that might result in a take of a marine mammal. A “take,” in the case of acoustic exposure, occurs when an animal is exposed to a sound of a particular duration that is greater than a specified sound level.

The NMFS' "do-not-exceed" criteria currently applicable for exposure of marine mammals to various underwater sound sources are identified below:

- **Level A Harassment: injury by impulse** (e.g., impact pile driving) **and continuous** (i.e., vibratory pile driving) **sounds**: NMFS has a "do-not-exceed" exposure criterion set at a sound pressure level (SPL) value of 180 decibels (dB) referenced to 1 micropascal (dB re 1 μPa) for cetaceans and 190 dB re 1 μPa root mean square (rms) for pinnipeds
- **Level B Harassment: harassment by impulse sounds**: (e.g., impact pile driving) is set at an SPL value of 160 dB re 1 μPa
- **Level B Harassment: harassment by continuous noise**: (e.g., vibratory pile driving) is set at an SPL value of 120 dB re 1 μPa rms. Background noise levels in Knik Arm are consistently at or above 125 dB re 1 μPa. Attempts to measure and identify the distance to the 120 dB isopleth from various sources were unsuccessful given the higher background ambient levels (USDOT and POA 2008). Therefore, calculations for continuous noise exposure for the proposed KAC project use 125 dB re 1 μPa instead of the 120 dB re 1 μPa.

1.3 A Primer to Underwater Sound

Marine bioacoustics is the study of the interaction between marine life and sound in water. It focuses on relating in-water natural and anthropogenic noise (marine acoustics) to biology—in this case the influence/impacts of in-water noise on the beluga whale. This brief background on acoustics will permit the reader to understand the data and discussions relating to ambient noise in the Knik Arm, Alaska, that follow and the noise belugas hear. The terms "noise" and "sound" are often used interchangeably. Although, technically, there is no difference between the two terms, noise is a class of sounds that is considered unwanted, and in some situations can adversely affect the health and well-being of individuals.

Amplitude is the magnitude of the sound pressure wave and is perceived as the "loudness" of a sound. The sound pressure SPL is typically measured using the dB scale. A dB is the ratio between a measured pressure of sound and a reference pressure. It is a logarithmic unit that accounts for the large variations in amplitude that human ears can accommodate; therefore, relatively small changes in dB values correspond to large changes in pressure. Amplitude is typically referenced to a standard pressure measured in pascals (Pa). The underwater sound reference pressure is 1 μPa, while in-air sound is referenced to 20 μPa. Caution must be exercised when comparing source levels for the two media because of the difference in the physical properties between air and water (e.g., Chapman and Ellis 1998). The signal waveform is a representation, on a computer screen or printout, of the signal pressure wave over time. For further information on fundamental acoustic principles, the reader is referred to *Underwater Sound and the Marine Mammal Acoustic Environment: A Guide to Fundamental Principles* (Bradley and Stern 2008).

The ambient sound level of a region is defined by the total acoustical energy being generated by known and unknown sources including sounds from both natural and man-made sources (Greene 1995). The magnitude and frequency of environmental sound levels can vary considerably over the day, season, and larger time frames, which in turn are influenced by changing weather conditions (Urick 1984). For example, ambient noise is affected by the roughness of the sea surface, which is connected to sea state or wind force (i.e., breaking whitecaps), rainfall; flow noise produced by wind blowing over a rough sea surface; collapse of air bubbles formed by turbulent wave action; and current fluctuations associated with the tidal cycle (Wenz 1962; Urick 1983). Variability in ambient noise is also influenced by sound transmission properties of the environment—water temperature; salinity; current speed; and bottom conditions, such as bathymetry and sediment composition.

“Self noise” (also referred to as *pseudosound*) is the noise usually caused by the method in which sounds are being measured. Hydrophones that are extended overboard from a moving boat will often detect the noise caused by water flow around the vessel and airborne sounds produced on the vessel that is coupled into the water. Dragging a hydrophone in the water can also produce self noise as the hydrophone moves through the water; this noise is much like the wind rushing past a microphone. Noise produced by the hydrophone cable as the hydrophone is dragged in the water or is “stationary” in waters with high fluctuating currents—strumming—is another common source of unwanted self noise.

Ambient noise sources can be continuous and persistent or transient and intermittent. In open oceans, primary persistent noise sources tend to be commercial vessels and wind and wave action on the sea surface. Persistent ambient noise sources may also include marine mammals, crustaceans, or fish. Intermittent ambient noise could be produced by seismic geophysical surveying, construction and operation of offshore structures, helicopter and service-vessel traffic, and the explosive removal of structures. In nearshore waters, on-shore industrial activities can also be heard underwater (Greene and Moore 1995). To assess potential impacts on marine mammals from noise produced by the proposed KAC project, it is important to know the baseline ambient noise conditions in the project area including the magnitude, variability, and predictability of ambient noise in the vicinity. The intent of this study, therefore, was to collect ambient noise data that allows prediction of the variability in ambient noise in the proposed KAC project area.

1.4 Beluga Whale Auditory Capabilities

Introduction

Similar to all mammals, odontocetes (toothed whales) interact with their environment using a variety of sensory modalities. The water environment imposes new challenges for any animal to navigate and communicate. The density of salt water is about 770 to 890 times the density of air at sea level (Denny 1993), sound travels five times faster in water than in air and light dissipates almost completely within the first 200 meters (m) of the water column. In this environment, scent and vision are often limited and depend greatly on oceanographic conditions. Because most of the sensory systems used by terrestrial mammals have limited use in the ocean, marine mammals rely extensively on sound to obtain information from their environment because acoustic energy propagates much better in the aquatic environment than any other type of energy (electromagnetic, light, or thermal) (Au 1993). Odontocetes use echolocation to navigate, find prey and avoid predators and obstacles. Marine mammal echolocation – or the assessment of the environment by emitting sounds and listening to echoes as the sound waves reflect off different objects in the environment (Au 1993) – was first evidenced by Schevill and McBride (1956).

Understanding how sounds are likely to affect an animal requires not only knowing the acoustic characteristics of that specific sound and the environment, but also understanding how the animal is likely to perceive or hear these sounds. Because the beluga whale has been kept successfully in captivity, extensive research has been conducted with this species. Several studies have looked at the hearing capabilities of the beluga whale including hearing sensitivity, critical ratio, time constant, directional hearing and temporary threshold shift. The following section summarizes these findings.

Hearing measurements: audiograms

The most common auditory test investigates hearing sensitivity as a function of frequency or pitch. The results are usually plotted as an audiogram with the stimulus frequency on the x-axis and the threshold or minimum audible intensity on the y-axis (**Figure 1**). Similar to other mammals, odontocetes have a typical U-shaped audiogram, with the area of best hearing – or the bottom of the U – in frequencies ranging from 20 to 100 kHz (i.e., bottlenose dolphin *Tursiops truncatus*: Johnson 1966). Two main techniques exist to obtain an audiogram: behavioral audiogram and auditory brainstem response (ABR).

The behavioral audiogram approach is to behaviorally train the subject to respond to the presence or absence of a specific sound. A threshold - or the minimum audible intensity level at which the animal can still detect a sound - can then be determined for a variety of frequencies. Behavioral audiograms yield reliable data but present major limitations. First, training an animal to accomplish such a task takes an important effort and can require several months or years to be fully trained (Nachtigall et al. 2007). Secondly, one needs to account for important factors such as applying proper controls (ensuring the animal only responds when sound is actually playing), the motivation level of the subject, and the reinforcement contingency.

Another technique called the ABR has been used to collect hearing measurements. This non-invasive physiological test looks at the electrical neural activity in response to a sound stimulus. Electrodes are usually positioned directly on the surface of the skin to record evoked potentials generated by the brain. This technique provides results that are comparable to behavioral audiograms with behavioral thresholds usually slightly lower than ABR ones (Yuen et al. 2005; Finneran and Houser 2006). One of the major advantages of this technique is that a complete audiogram can be obtained in 1 to 2 hours, with limited or no training of the animal. While the auditory evoked potential (AEP) technique presents many advantages, it is also important to note that absolute thresholds cannot be obtained due to the inherent biological noise generated by the animal. In addition, differences between behavioral and ABR audiograms may arise from different factors such as the dB level measured (peak to peak vs. root mean square [RMS]) or the type of acoustic signal used (Nachtigall et al. 2007).

Several behavioral audiograms have been obtained with captive beluga whales. White et al. (1978) tested the hearing of two adult beluga whales at Hubbs-Sea World using the staircase method where the session started with a sound intensity 30 to 40 dB above the expected threshold, and was then decreased until the animal could not detect the sound anymore, this switch (from detecting to not detecting) is commonly referred to as a *reversal*. A threshold can be calculated by averaging the SPL where these reversals occur. White et al. (1978) tested frequencies from 1 kHz to 123 kHz and found that the best sensitivity occurred at 30 kHz for both individuals. The overall range of best hearing was estimated between 20 and 80 kHz, with variations between individuals.

Awbrey et al. (1988) tested the low-frequency hearing of three captive beluga whales using an ascending form of the methods of limit, where the sound stimulus was gradually increased until the animal reported hearing it. Thresholds were defined as the midway point between the lowest level the animal reported and the previous lower level. Hearing measurements were conducted with frequencies ranging from 125 Hz to 8 kHz. Best hearing was found at 8 kHz, with an average threshold of 65 dB. Lower frequencies yielded thresholds as high as 121 dB for 125 Hz.

Additional audiograms using the ABR were collected for beluga whales. Klishin et al. (2000) collected thresholds for frequencies between 8 to 128 kHz in quarter-octave intervals. The best hearing or lowest threshold was found at 54 kHz (54.6 dB). Overall, the area of best hearing was between 32 and 108 kHz with thresholds below 75 dB. Mooney et al. (2008) also collected a complete audiogram with an adult beluga whale and found that the range of best hearing was between 11.2 and 90 kHz with thresholds below 75 dB. The frequency with the best sensitivity was found at 32 kHz with a 43.9 dB threshold.

Based on the available data, it appears that beluga whale hearing follows the typical odontocete hearing range, with best hearing from 11.2 kHz to 90 kHz. One should keep in mind that similar to humans, variations between individuals are likely to arise due to age, sex, and physical condition (Houser et al. 2006; Finneran et al. 2005). Presbycusis, or the deterioration of hearing with age, tends to have an earlier onset in male subjects than females. In the case of captive animals, certain antibiotics might also impair the hearing abilities of the subject especially in the high-frequency domain. Finneran et al. (2005) reported the case of an adult beluga whale with a history of ototoxic drug (drugs like antibiotics that can cause hearing loss) administration with significant high-frequency hearing loss above 37 kHz. Variations in results might also occur due to differences in methodology, such as behavioral measurements versus in-air contact jawphone or free-field stimulation. Finally, estimated hearing thresholds vary with ambient noise and will tend to be higher in acoustically-loud environments.

Other auditory measurements

While audiograms provide the baseline data about the hearing of an animal, other tests can provide additional information on how an animal is likely to detect, discriminate and identify specific sounds. The following summarizes findings on directionality; masked hearing; TTS; and behavioral response to sounds.

Directionality

Directional sensitivity is defined as the variations in hearing sensitivity with sound source direction. Because beluga whales rely on echolocation, their directional hearing is of primary interest as it will affect how efficient they are at localizing objects in their environment.

Directionality is usually tested by either obtaining absolute hearing sensitivity with varying sound source azimuths (or the angle between the subject head and the sound source) and frequencies or by relying on a fixed masking noise and a sound source with varying azimuth (Au and Moore 1984).

Klishin et al. (2000) first investigated directional hearing in the beluga whale with auditory evoked potentials. For all the frequencies tested (from 16 to 90 kHz), they observed an increase in threshold (or a decrease in hearing sensitivity) as the sound source was moved from 0 degrees (˚) to 90˚. However, there was no significant difference in this threshold change with frequency. These results differ from Popov and Supin (2009) who investigated the hearing directionality of a beluga whale in comparison to the bottlenose dolphin using auditory evoked potential (AEP) techniques. They measured thresholds for amplitude modulated tone pips with frequencies between 8 and 128 kHz in ¼ octave increments and with the sound source moving from 0 to ± 90˚ around the animal's head. The results indicated that for both the bottlenose dolphin and the beluga whale, the hearing was more directional for higher frequencies although it was not as pronounced in the beluga whale. Unlike the bottlenose dolphin, the best sensitivity direction remained at 0˚ (right in front of the animal) regardless of the sound stimulus frequency. In the bottlenose dolphin, it has been demonstrated that as the frequency decreases, the best sensitivity is found close to 15˚. Directionality is often expressed as the width of the -3 or -6 dB levels. As demonstrated with other species (Au and Moore 1984), the receiving beam width decreases with frequency, which means that as the frequency increases the receiving beam becomes narrower. For the beluga whale, with a frequency range of 8 to 128 kHz, the -3 dB beam width decreased from ±33.5˚ to ±14.3˚ (±14.9˚and from ±6.3˚ for the bottlenose dolphin) and the -6 dB beam width from ±56.9˚ to ± 18.9˚ (±33.1˚ to ±8.4˚ for the bottlenose dolphin). Finally, Popov and Supin (2009) showed that while in the bottlenose dolphin, the best hearing frequency was dependent on the azimuth, this feature was not as prominent, which could indicate inter-species differences, where the beluga whale's hearing is less spatially selective than the bottlenose dolphin's hearing.

Klishin et al. (2000) also investigated how hearing directionality varied for short click stimulus and found an increase in threshold of over 20 dB when the sound source was moved from 0˚ to 90˚. Mooney et al. (2008) observed similar results. Using AEP techniques, they tested the hearing sensitivity to 100 µs clicks centered at 80 kHz at 0˚ (in front of the animal's head), 90˚ and 180˚ (directly behind the animal). The authors found that the thresholds increased from 85 dB in front of the animal to 105 dB at 90˚and 114 dB at 180˚ indicating that the beluga whale hearing is indeed very directional.

While some of the results are conflicting, it appears that the beluga whale's directional hearing is very similar to other odontocetes - as the receiving beam becomes narrower for higher frequencies - although not as extreme as the bottlenose dolphin. This hearing feature has been hypothesized to have evolved with echolocation as it allows the animal to better discriminate a target in front of it.

Critical ratio, critical bandwidth and frequency tuning

Fletcher (1940) first introduced the idea of critical ratio and bandwidth in humans. While testing the hearing of humans to pure tones in the presence of different bandwidth noises, he observed that the masked threshold increased with the noise bandwidth up to a certain value, which he defined as the 'critical bandwidth.' When the noise bandwidth was over this value, the masked threshold remained constant. The critical ratio can then be calculated as the ratio of the tone power to the noise power spectral density.

Both critical ratio and critical bandwidth relate to the detection of a signal in noise. Fletcher (1940) hypothesized that the detection of a signal of a given frequency will depend on the noise energy found in the band of frequency close to the frequency of the signal. In other words, frequencies different from the signal will have limited or no effect in the detection of the specific signal. Critical ratios are defined by "measuring detection thresholds in broadband white noise and dividing the energy of the signal at threshold by the noise energy per hertz in the noise spectrum". To quantify these values, masked thresholds are usually measured behaviorally with noise varying in bandwidth. Johnson et al. (1989) measured critical ratio in the beluga whale using masked hearing threshold. For low frequencies (40 Hz to 8 kHz) the tone had to be 17 to 20 dB above the noise level to be detected. Above 10 kHz, the critical ratios increased up to 40 dB for 100 kHz. Overall, the authors found that the critical ratios – although not calculated in ideal conditions – were 3 dB less than those calculated for the bottlenose dolphin.

Critical bandwidth relates to the shape of the auditory filter, in other words the critical band or bandwidth of a filter - in this case, the auditory system of an animal - is defined by the range or band of frequencies that would mask a specific tone. Klishin et al. (2000) measured the Q_{ER} and Q_{10dB} values for a beluga whale for frequencies between 32 and 108 kHz. The Q_{ER} or equivalent rectangular quality is defined as the center frequency divided by the equivalent rectangular bandwidth or ERB and the Q_{10dB} is defined as the quality factor and can be calculated by the center frequency divided by the bandwidth at a level of -10 dB. Therefore the higher the Q_{ER} and Q_{10dB} value, the sharper the tuning. Klishin et al. found a strong tuning dependence on the probe frequency with Q_{er}= 22.7 (Q_{10dB} = 14.0) at 32 kHz to Q_{ER} = 49.7 (Q_{10dB} = 25.5) at 108 kHz. Similarly, Finneran et al. (2002) obtained ERBs of 9.1 and 15.3% of the center frequency at 20 and 30 kHz for the beluga whale. Erbe (1999) calculated the critical bandwidth of a beluga whale and found that critical bands were approximately 1/12 of an octave wide in the frequency range tested. Although these studies do not necessarily present their results in directly comparable ways, they all indicate that *Delphinapterus leucas* – similar to other odontocetes – rely extensively on frequency discrimination. Klishin et al. (2000) indicated that the beluga whale frequency tuning was even more acute than for the bottlenose dolphin and might explain why this species performs better in detection experiments.

Temporal resolution

Klishin et al. (2000) investigated the temporal resolution of the beluga whale using both amplitude modulated tones (with modulation rates ranging from 125 Hz to 2000 Hz) and with broadband click trains presented at rate ranging from 125 to 2000/second. This test is often referred to as the modulation rate transfer function (MRTF) where the ability of the animal to follow discrete sounds is tested. Both techniques yielded a cut-off of 1400 Hz above which the animal was not capable of discriminating individual sounds. This value is very similar to the one obtained with the bottlenose dolphin and the common dolphin (Supin and Popov 1995; Popov and Klishin 1998) and the killer whale (Szymanski et al. 1998). If a sound is ‘changed’ at a rate up to 1250 Hz or 1250 modulations per second, the animal is consistently capable of following these individual changes, however if a sound is modulated at a rate higher than 1400 Hz, the beluga whale will not be capable of discerning individual modulations and will detect the sound as a continuous tone rather than a modulated one. The results obtained by Klishin et al. (2000) on the MRTF of the beluga whale are in accordance with MRTF obtained with other odontocetes, and this high temporal resolution is believed to have evolved with echolocation.

Sound pathways

Odontocetes have evolved acoustic fats to channel sounds – and more importantly echolocation echoes – back to the inner ear. It was commonly believed that all odontocetes were listening through their fat filled lower jaw, a region often referred to as the panbone (Norris 1966). While the role and function of these fats are still being explored, several projects have looked at their role in hearing in various species. Sound pathways in the beluga whale were investigated by Mooney et al. (2008) where they tested the AEP response to click stimuli presented via a contact hydrophone. The results indicated that the tip of the lower jaw (76 dB) was as sensitive to clicks as the panbone region (78 dB). These findings indicate that the beluga whale might use a different strategy to investigate its environment – which is supposedly more complex than the open ocean.

Masking/noise exposure experiments

One of the major concerns stakeholders face is the impact of anthropogenic noise on marine life. While audiograms provide basic information on hearing sensitivity, additional experiments looking at how specific sounds are likely to affect animals provide both behavioral and physiological information about the animals’ potential response.

Anthropogenic noise might trigger a change in the behavior of belugas. Finley et al. (1990) monitored the behavioral response of beluga whales and narwhals to ice breaking ships in the Canadian High Arctic. While narwhals did not display any aversive response, beluga whales consistently displayed a ‘flee’ response which included swimming away from the ship, undertaking prolonged and asynchronous dives and breaking from the group. This response was elicited when the ice-breaking ship was as far as 80 kilometers (km; 50 miles) away from the whales. Patenaude et al. (2002) opportunistically observed the reactions of beluga whales and bowhead whales to aircraft and helicopter sounds in the Alaskan Beaufort Sea, and found that the beluga whales reacted significantly more than bowhead whales. Observed reactions or changes in behaviors included surfacing, quick turn or dives, rapid swimming or breaching. Changes in behavior were observed as far as 320 m (350 yards) away from the sound source. The authors also indicated that while the acoustic component of the aircraft was likely to trigger a change in behavior, the visual component could not be completely excluded as well. Carter and Nielsen (2011) combined information collected through survey amongst Alaska Native hunters and commercial fishermen. Their survey indicated that Cook Inlet beluga whales can be observed avoiding areas of shipping, sport boating, oil and gas production, and seismic surveys.

Beluga reactions to vessels depend on whale activities and experience, habitat, boat type, and boat behavior (Richardson 1995; NRC 2003). Beluga whales also show the full range of types of behavioral response, including altered headings; fast swimming; changes in dive, surfacing, and respiration patterns; and changes in vocalizations (NRC 2003). For example, belugas in the MacKenzie River estuary appeared to react less to a stationary dredge as opposed to a moving one, even though there was no difference in the vessel noise (Fraker 1977). Cook Inlet beluga whales are familiar with, and likely habituated to, the presence of large and small vessels. Belugas are frequently sighted in and around the POA, the Port MacKenzie Dock, and the small boat launch adjacent to the outlet of Ship Creek (Blackwell and Greene 2002; NMFS 2008; Markowitz, Funk, et al., “Seasonal Patterns,” 2005; Funk, Markowitz, et al. 2005; Ireland, McKendrick, et al. 2005). For example, Cook Inlet beluga whales did not appear to be bothered by the sounds from a passing cargo freight ship (Blackwell and Greene 2002). Despite increased shipping traffic and upkeep operations (e.g., dredging) beluga whales continue to utilize waters within and surrounding the port area, interacting with tugboats and cargo freight ships (Markowitz and McGuire 2007; NMFS 2008). During the POA monitoring studies, animals were consistently found in higher densities in the nearshore area (6 km^2) around the port area throughout the April-to-October period each year where vessel presence was highest (POA et al. 2009).

The masking effects on marine mammals can have a wide range of impacts on the animals. First, it can mask acoustic cues the animals use to communicate, navigate, or forage. Erbe (2008) looked at the masking of beluga vocalizations by natural and anthropogenic noise and found that, when detecting the calls, the animal was likely cueing on the low frequency component (800 Hz) rather than the higher frequency (1600 Hz). This study provides information about what potential effects anthropogenic noise can have on these species. As parts or the entire call get masked by noise, the animal may have to use a different strategy to convey information to conspecifics. In the presence of shipping noise, St. Lawrence beluga whales have been observed to increase the repetition of their calls and the production of falling tonal calls and pulsed calls, as well as to shift the frequencies of their calls (Lesage et al. 1999). Au et al. (1984) measured the echolocation signals of the same beluga whale in San Diego Bay (California) and Kane’ohe Bay (Hawaii). The latter had background noise levels 12 to 17 dB greater than San Diego Bay. The echolocation signals of the beluga whale were 18 dB louder in Kane’ohe Bay and shifted to higher peak frequencies (from 40-60 kHz to 100-120 kHz) and bandwidths (from 15-25 kHz to 20-40 kHz). Additionally, beluga whales in the St. Lawrence Estuary have been observed to increase their call level or loudness to compensate for the noise level (Scheifele et al. 2005), this type of behavior is often referred to as a Lombard vocal response. While it is difficult to quantify what the potential effects of such masking might have at the species level, it is important to note that noise can have detrimental effects on acoustic communication between individuals.

Loud sounds can temporarily impair an animal’s hearing; this phenomenon is referred to as TTS, where the hearing threshold is elevated post sound-exposure, but returns to baseline after minutes or hours. Schlundt et al. (2000) compared TTS in the bottlenose dolphin and the beluga whale after exposure to intense 1-second tones at frequencies ranging from 0.4 to 75 kHz. A shift of 6 dB or more in threshold was observed at probe levels between 192 and 201 dB. For the 0.4 kHz tones, no TTS was observed for any individual even at level as high as 193 dB re 1µPa. This indicates that TTS was more likely to be induced at frequencies above the frequency of the probe tones.

The authors also noted that the sound exposure altered the animals’ behavior. Out of the 195 test sequences, behavioral changes were observed during 129 of them. Even when the tones were below the level inducing TTS, the authors noted that the subjects were disoriented, broke station prematurely, exhibited abrupt and quick departure from station, vocalized, swam around the enclosure or did not respond to the acoustic cues. Additionally, the authors noted a significant increase in travel time (from 14 to 28 seconds) between the sound exposure station and the hearing test station. The results provided evidence of negative TTS where the hearing of the animal is better right after a sound exposure, this hypersensitivity to sound was evidenced by the animals breaking from the hearing test station prematurely. Overall, this study indicates that high frequency sounds are more likely to induce behavioral change and TTS at louder levels.

Finneran et al. (2000) investigated TTS and behavioral response of a beluga whale and two bottlenose dolphins to impulsive sounds resembling underwater explosion. The authors did not find significant TTS at the end of this experiment (defined as a minimum of 6 dB shift in threshold). It should be noted that the authors only tested hearing at low frequencies (1.2, 1.8 and 2.4 kHz) and that no TTS was observed, but could have occurred at higher frequencies. Similar to Schlundt (2000), Finneran and colleagues noted behavioral changes as the level of the sound exposure increased. The beluga whale subject started displaying behavioral alterations at level 9 (charge weight of 500 kilograms [kg] at 1.9 km) which is higher than the levels for the bottlenose dolphin (levels 4 and 5, 5 kg at 9.3 km and 5 kg at 1.5 km). Both behavioral and TTS data indicated that the beluga whale was more tolerant of intense sounds than bottlenose dolphins.

Acoustics and beluga whales

Beluga whales are known to be very acoustically-active. This species is often referred to as the ‘canary of the sea.’ Like other toothed whales, the sounds produced by the beluga whale can be separated into two categories: broadband pulsed sounds or trains of pulsed sounds including echolocation clicks, and other social sounds and narrow-band frequency modulated sounds, often referred to as whistles (Vergara and Barrett-Lennard, 2008). The following section summarizes the sound produced by the beluga whale.

Echolocation

Echolocation signals of beluga whales have been recorded both in the wild and in captivity. Gurevich and Evans (1976) recorded the echolocation click of a beluga whale during a discrimination experiment and found that the peak frequency of the clicks was around 40 kHz with secondary peaks at 80 and 120 kHz. Recorded echolocation signals of three captive beluga whales showed that the animals produced clicks in pairs, with the first signal having a high frequency component (peak frequency of 60 kHz) and the second longer click having a low peak frequency (1.6 kHz) (Kamminga and Wiersma 1981)

Turl and Penner (1989) recorded the clicks of a beluga whale and a bottlenose dolphin during a detection experiment and found that the two species might use different echolocation strategies. The bottlenose dolphin consistently emitted clicks with interclick intervals (ICI) greater than the two way travel time of sound. The beluga whale produced three different patterns of echolocation clicks. The first one started with low frequency clicks and was followed by distinct series of clicks with ICI shorter than the two way travel time. The second pattern consisted of series of individual clicks with varying ICI and the third type was a series of individual clicks with ICI greater than the two-way travel time. Turl and Penner (1989) hypothesized that unlike the bottlenose dolphin that listens to the echo of individual clicks before emitting another click, the beluga whale might listen to the combined echoes of the click series of pattern I rather than listening to individual echoes. This trend was only visible when the target was less than 40 m (131 feet) away from the animal. Lammers and Castellote (2009) recorded emitted echolocation clicks at different azimuths around the head of a beluga whale and showed that off-axis two clicks were present and hypothesized that this species – and perhaps other odontocetes – rely on two sound sources to create an echolocation click in front of the animal’s head. This feature might help beluga whales to adjust and steer their echolocation beam and also how they are capable of producing both whistles and clicks simultaneously.

Because beluga whales live in a constantly changing environment, and have to navigate through ice packs, one should expect their echolocation abilities to adjust to such environmental constraints. Turl et al. (1987) tested the target detection abilities, in the presence of masking noise, of a bottlenose dolphin and a beluga whale, and found that the beluga whale's performance was better than the bottlenose dolphin's. The 75 percent correct response threshold was obtained at noise levels of 55 to 72 dB for the bottlenose dolphin and 63 to 85 dB for the beluga whale. These results indicated that the beluga whale could detect a target even when loud masking noise was present. Additional work using the same paradigm indicated that the beluga whale used an indirect path of sound to detect the target. By blocking surface reflection, the performance of the animal varied significantly in its ability to detect the target. These results indicate that the animal used surface reflected path to minimize the signal to noise ratio. Such strategy was not observed with the bottlenose dolphin (Penner et al. 1986).

Turl et al. (1990) tested how efficient a beluga was at detecting targets in cluttered environments. A screen of cork spheres, located behind the target, was used as clutter. Both the size of the actual stainless steel targets and the distance between the target and the clutter screen were varied. The results indicated that as the distance between the screen and the target increased, the animal's performance to detect the target increased. Similarly, as the target size increased, the animal was better at reporting the presence of the target. Compared to the bottlenose dolphin, Turl et al. (1990) argued that the beluga whale was capable of detecting targets in 3.6 to 5.3 dB more reverberation (more clutter noise) than the bottlenose dolphin. This performance might be related to the fact that beluga whales reside in Arctic sea ice with strong acoustic backscatter and reverberation levels.

Whistles and social sounds

Schevill and Lawrence (1949) first reported on the underwater vocalizations of beluga whales in the St. Lawrence River and noted "Particularly striking is the great variety of *Delphinapterus* sounds and their rapid and apparently continuous succession." Social sounds usually include frequency modulated and narrow band signals as well as broadband pulses similar to echolocation clicks. The vocal repertoire of the bottlenose dolphin is often referred to as 'graded' (Sjare and Smith 1986a; Karlsen et al. 2002; Vergara and Barrett-Lennard 2008) where there is no clear distinction between the two types of vocalizations and both pulses and tonal sounds often merge into one another. The vocal repertoire of this species has been studied and classified in various regions of the world -- St. Lawrence River Estuary (Faucher 1988); Norway (Karlsen et al. 2002); Russia (Bel'kovich and Sh'ekotov 1993); Alaska (Angiel 1997); and Canadian Arctic (Sjare and Smith 1986a,b). All of these studies noted that the vocalizations of the animals varied greatly with behavioral context and group size. All of the authors hypothesized that vocal variations may exist amongst these different geographically separated populations. A total of 22 to 24 call types have been identified for all the previously mentioned populations. Most of the narrow-band mean call frequencies ranged from 3 to7 kHz, and unmodulated whistles are found to be the most prominent in all of the populations studied to this date (Karlsen et al. 2002). The unique characteristics of the sounds used by the beluga whale, makes this species easily identified using passive acoustic monitoring (Simard et al. 2010).

1.5 Previous Ambient Noise Studies in the Knik Arm

A number of previous studies have measured ambient noise levels in and near the proposed KAC project area (**Table 1**). The studies reported that background sound levels can be variable and high (Blackwell and Greene 2002; Blackwell 2005; URS 2007; Scientific Fishery System [SFS] 2009). These acoustic studies, which were conducted in Knik Arm south of the proposed KAC project, found that the lower range of the average broadband ambient noise levels were near or above 120 dB re 1 μPa. The higher noise levels in that area ranged between 150 dB re 1 μPa in industrial areas and 95 dB to 120 dB re 1 μPa in areas away from industrial activity (Blackwell and Greene 2002; Blackwell 2005; URS 2007; SFS 2009). The most recent ambient noise study by SFS (2009) reported very high ambient noise levels near the Port of Anchorage (POA) ranging from 120 to 150 dB re 1 μPa, with a mean of 133 dB re 1 μPa.

2 METHODS

2.1 Study Area

Cook Inlet is a subarctic estuary that extends about 155 miles from the Gulf of Alaska in the south to the city of Anchorage in the northeast. Upper Cook Inlet branches into two shallower extensions: the Knik Arm north of Anchorage and the Turnagain Arm southeast of Anchorage. The Knik Arm is 31 miles long by 5 miles wide. Lined by high bluffs, it is characterized by narrow channels and large tidal flats.

The proposed Crossing will extend from the western shoreline on the Mat-Su side of Knik Arm approximately 1,500 feet south of Anderson Dock, across Knik Arm toward Anchorage, reaching the eastern shore approximately 1 mile north of Cairn Point (see **Figure 2**). On the east and west sides of the proposed KAC, there are extensive mud flats with a relatively steep drop off on the west side. A cross section of the bathymetry in the proposed Crossing construction area, with depths at mean lower low water (MLLW; the average of the lower low water height of each tidal day), is shown in **Figure 3**. Tidal fluctuations of nearly 40 feet cause currents to exceed 11 feet per second (Smith et al. 2005). Ebb flows are stronger than flood flows in the vicinity of the proposed Crossing alignment and current speeds of over 7 knots are common (Smith 2004). Research on the impacts of tidal movements on ambient noise in Narragansett Bay suggests that tides at velocities considerably less than those found in Knik Arm may contribute significantly to background noise levels (Willis and Dietz 1965). Large diurnal tides expose extensive mud flats throughout the upper inlet during the ebb period, leaving approximately 60 percent of Knik Arm exposed at MLLW. Current speeds are slower on the shallower benches on each side of Knik Arm than in the deeper main channel. Current speeds are consistently faster near the surface and tend to show a steady decrease in speed downward to the bed (Smith 2004). The strong currents suspend large volumes of sediment from the Matanuska and Knik rivers, resulting in a highly turbid marine environment.

2.2 Spatial and Temporal Sampling

This study investigated spatial variation in ambient noise by collecting recordings made at three sampling locations (Sites 1–3 shown in **Figure 2**) across the width of the proposed Crossing construction site. Site 1 was located on the west side of Knik Arm near the proposed Mat-Su Approach for the KAC in waters with a MLLW depth of approximately 25 feet depending on tidal cycle. Site 2 was located near the middle of the width of Knik Arm in the deepest water of the proposed Crossing (approximately 75 to 105 feet deep depending on tidal cycle). Site 3 was located on the east side of Knik Arm near the proposed Anchorage Approach for the KAC in waters with a MLLW depth of approximately 25 feet depending on tidal cycle.

Temporal variation in ambient noise was measured by collecting recordings in different months (May and July) and tidal cycles within these months (ebb, flood, high, and low). The periods of high and low tide were determined using tide tables published for the POA (Mobile Geographics 2010); maximum velocities of the ebb and flood tides were assumed to occur midway between high and low tides. The timing of a particular set of recordings was determined according to when the tidal cycle of interest would occur at Site 2—the middle and deepest part of the proposed Crossing construction site. Sequential recordings were then made at Sites 1 and 3 during the time period +/-15 minutes prior to the specific tidal cycle time determined for Site 2 (**Table 2**). Some variation to this recording protocol occurred, for example, when too much noise at a sampling site caused recording overload, and another recording at a lower amplification needed to be made.

2.3 Equipment

2.3.1 Boat

All recordings were made from a 27-foot aluminum hull Harborcraft (*Jakyty*) boat that was allowed to drift with the flow of the current during recording sessions to prevent one aspect of self noise. The scientific team included the captain, one person to deploy the hydrophone, one to operate recording equipment, and an assistant.

2.3.2 Recording System

The recording system was a Cetacean Research Technology C55 hydrophone capable of recording sounds—measuring noise signals—from16 hertz (Hz) to 44 kilohertz (kHz) in conjunction with a Cetacean Research Technology amplifier. The hydrophone was weighted with a 3-pound lead weight and isolated from movement using a shock cord system. "Strumming," or vibration of the hydrophone cable (a source of self noise), was minimized by wrapping the cable with unbraided polypropylene line.

Sampling rates for all recordings were 50 kHz, resulting in a 25-kHz bandwidth recording of the ambient noise signal. The analog waveform of the recorded signal was saved to a laptop computer and digitized with 16 bit precision using DaqView software to obtain a greater than 80 dB dynamic range.

2.4 Field Procedures

Ambient noise recording were made at the sampling sites for five consecutive days in May and July 2010, during the days of the month with the greatest tidal variation. Recording were made during the four tidal cycles: high, ebb, low, and flood when daylight was adequate to work safely.

Prior to recording, using the system described in **Section 2.2**, all noise-producing equipment was turned off including the depth sounder and vessel engines to avoid introducing self noise. In addition, the scientific team on the vessel refrained from moving and talking during recording sessions. Once on station, the hydrophone system was deployed to a depth of 13 feet and recordings of approximately one minute were made. Immediately after each recording session, the following information was documented: the vessel's location (from a Garmin 2010C global positioning system [GPS]), the time, the tidal cycle and speed at which the boat was drifting (based on the GPS reading), water depth, and visible sources of audible sound. After each recording, the signal was checked to verify quality. If the recording was poor quality (e.g., cable strumming or signal overloading) a new recording was made. To ensure that the breadth of the proposed Crossing was sampled for ambient noise during each specific tidal cycle, recordings were made at each sampling site in quick succession.

Opportunistic recordings were made when a unique noise source was encountered or a novel site was visited (e.g., clamshell and suction dredges at the POA; construction at Port MacKenzie; and the ambient noise condition at the mouth of the Eagle River). The same procedures described above were followed with some exceptions (short-duration events [e.g., overflights of U.S. Air Force F-22 jets], which warranted short recordings of 10 to 15 seconds).

2.5 Signal Analysis

Each waveform recording made in the field was then examined and a one-minute segment saved for analysis. One-minute segments were chosen so that waveform —ambient noise measurement—from each recording would be of standard length. The audio signal analyses were done using SpectraPLUS Version 5.0, a spectral analysis program that permits compensation for hydrophone responses. Values from the recording hydrophone's frequency response curve, provided by the manufacturer, were used by the analysis software to compensate for variance in the hydrophone's sensitivity. Due to this compensation, the final spectral output is a flat measure of frequency and amplitude of the ambient noise signal. The following settings were used in the SpectraPLUS program:

- Unweighted 1/3 octave spectra with 50 percent overlap using a 32,768 point Fast Fourier Transform (FFT), which produced 1.526 Hz spectral line resolution. The FFT translates the time-domain characteristics of a signal into its frequency-domain equivalents.
- A Hanning frequency smoothing window.
- Each spectra characterized as a SPL in dB re 1 μPa using the total rms power for the entire unweighted spectrum.

2.6 Statistical Analysis

The mean ambient noise measurements calculated from the recordings collected during each month were compared to determine if these data could be combined and analyzed. Comparisons made included the ambient noise measurements for each sampling site and during each tidal cycle (i.e.., all ambient noise measurements at Site 1 in May were compared to those made at Site 1 in July). In each case, the assumption was that there were no significant differences between sampling site or time of recording (month or tidal cycle). Significance was tested for by using a Kruskal-Wallis test (KW test) (low sample size) at each sampling site during each month. The KW test is a non-parametric procedure to test equality of population medians among groups. Similar analyses between sampling sites and tidal cycles within each time period were also conducted using a KW test to identify significant variation in measurements due to site and tidal cycle. If no significant differences between May and July recordings were detected, mean ambient noise levels would be combined and further analyses among sampling sites and/or tidal cycles would be conducted. However, if significant differences were detected for sampling sites and/or tidal cycles, the May and July data would not be combined. Subsequent analyses would, therefore, be restricted to within the single month and would measure any difference in ambient noise measurements among sampling sites and/or tidal cycles.

Acousticians commonly use the 5th and 95th percentile noise levels to represent an ambient noise field as either “quiet” or “loud,” respectively. The 125 dB noise exposure criteria is currently the NMFS threshold used for the POA in Knik Arm. The 5th, 50th, and 95th percentiles were calculated using the percentile-order statistics in SPSS 17 to represent the percentage of ambient noise level measurements that exceed 125 dB.

3 RESULTS

3.1 Month Comparison

May

Forty-five ambient noise recordings were made during May 10–14, 2010. Ambient noise levels ranged from 105 to 148 dB re 1 µPa ($\bar{x}$ = 124 dB re 1 µPa (standard deviation [s.d.]=10.0 dB). The 5th and 95th percentiles (i.e., ambient noise level equated to the “quiet” and “loud” conditions) were 109 and 145 dB re 1 µPa, respectively. The 50th percentile ambient noise level value was 124 dB re 1 µPa (**Figure 4a**). Thirty-eight percent of ambient noise measurements were above 125 dB re 1 µPa (**Figure 5a**).

July

Forty-nine noise recordings were made during July 12-16, 2010. Ambient noise levels ranged from 116 to 147 dB re 1 µPa ($\bar{x}$ =136 dB re 1 µPa; s.d.=0.9 dB). The 5th and 95th percentile ambient noise levels were 119 and 146 dB re 1 µPa, respectively. The 50th percentile ambient noise level value was 131 dB re 1 µPa **(Figure 4b).** In July, 88 percent of ambient noise measurements were above 125 dB re 1 µPa (**Figure 5b**).

Comparison of May and July

Mean ambient noise levels were significantly different between May and July for all sampling sites and tidal cycles, except low tide (KW test; p < 0.005; **Table 3**). Therefore, data for the May and July sampling periods were not combined. Measurement comparisons by sampling sites and tidal cycles for May and July are reported in **Sections 3.2** and **3.3**.

3.2 Sampling Sites Comparison

May

Regardless of tidal cycle the mean ambient noise level for May across all three sampling sites was 124 dB re 1 µPa (s.d.=10.0) with individual recordings ranging from 105 to 148 dB (**Table 4; Figure 6**). Ambient noise levels were highest for Site 2 ($\bar{x}$ =26 dB re 1 µPa; s.d,=10.8 dB), and ranged from 113 to 148 dB re 1 µPa. Ambient noise levels for Sites 1 and 3 were the same at 122 dB re 1 µPa, but with different s.d. values of 10.2 and 9.1 dB respectively. Noise levels for Site 1 ranged from 108 to 145 dB re 1 µPa. Noise levels for Site 3 ranged from 105 to 134 dB re 1 µPa. There was no significant difference in the mean ambient noise level across the three sampling sites (p=0.580, KW test, *n*=45, df=2, X^2 =10.875; **Table 3**).

July

The mean ambient noise for July across all sampling sites was 136 dB re 1 µPa (s.d.=7.9 dB) with individual levels ranging from 116 to 147 dB (**Table 4; Figure 6**). Site 3 had the highest mean ambient noise level of 138 dB re 1 µPa (s.d.=7.3 dB) with individual levels ranging from 122 to 147 dB re 1 µPa.

Sites 1 and 2 had identical mean ambient noise levels with differing standard deviations of 8.7 and 7.4 dB, respectively. Individual recording levels varied between Sites 1 and 3 (116–144 and 118–142 dB re 1 μPa, respectively; **Table 4**). There was no significant difference in the mean ambient noise levels across the three sampling sites (p=0.580, KW test, *n*=45, df=2, X^2 =10.875; **Table 3**).

Overall, ambient noise was highly variable between May and July regardless of sampling site location, with noise levels in May being more variable than July.

3.3 Tidal Cycles Comparison

May

Ambient noise was highly variable in May where there was a 25 dB variability in ambient noise levels across all tidal cycles at Site 2 (**Figures 7 and 8**).The magnitude of the variability was greatest for flood and low tides (25 dB and 24 dB, respectively), while high tide variability at Site 2 was 18 dB. In May, there were only two ebb tide measurements, both measured at 120 dB.

Highest noise levels were recorded during low tide ($\bar{x}$ =132 dB re 1 μPa; s.d.=9.0 dB) and individual recorded levels ranged from 122 to 148 dB re 1 μPa (**Table 5**). Mean ambient noise levels for the flood and high tides were similar. Mean levels for flood tide were 124 dB re 1 μPa (s.d.=8.0 dB) with recorded levels ranging from 113 to 142 dB re 1 μPa. Mean ambient noise at high tide was 122 dB re 1 μPa (s.d.=11.0 dB) with recorded levels ranging from 105 to 145 dB re 1 μPa. Ebb tide had the lowest mean noise levels ($\bar{x}$ =115 dB re 1 μPa; s.d.=5.1 dB), with recorded levels ranging from 108 to 120 dB re 1 μPa.

There was a significant difference in mean ambient noise level between tidal cycles indicating that at least one tidal cycle was significantly different from the others (p=0.012, KW test, *n*=45, df=3, X^2 =1.089; **Table 3**).

July

Variability in July was almost as pronounced as during May (**Figures 7 and 9**). Low tide was, again, the most variable, with a 26 dB difference between maximum and minimum ambient noise levels at Site 2. During July, however, there was less variability at flood tide where the magnitude was 15 dB. Ebb tide noise levels in July at Site 2 varied by 11 dB. In July, at high tide there were only 2 dB of variability in noise levels at Site 2 compared to 18 dB in May.

During July, the highest noise levels were recorded during high tide ($\bar{x}$ =139 dB re 1 μPa; s.d.=11.0 dB); individual levels ranging 119 to 147 dB re 1 μPa. Mean ambient noise levels for low, flood, and ebb tide were quite similar. Mean ambient noise at low tide was 136 dB re 1 μPa (s.d.=9.0 dB) with recorded levels ranging from 118 to 146 dB re 1 μPa (**Figure 7; Table 5**). Mean ambient noise at flood tide was 135 dB re 1 μPa (s.d.=8.0 dB); individual recorded levels ranged from 121 to 144 dB re 1 μPa. There was no significant difference in the mean ambient noise level across the four tidal cycles (p=0.239, KW test, *n*=49, df=2, X^2 =4.212) (**Table 3**).

Seven additional recordings were made during July at slack tide; four during slack high tide and three during slack low tide. Slack tide occurs when the water flow is lowest between tidal phases. Ambient noise levels recorded at slack high tide ranged from 126 to144 dB re 1 μPa ($\bar{x}$ =136 dB re 1 μPa;

s.d.=7.50 dB). During slack low tide, ambient noise levels ranged from 124 to 139 dB re 1 μPa ($\bar{x}$ =129 dB re 1 μPa; s.d.=8.37 dB). There was no significant difference between mean ambient noise levels at slack high tide and slack low tide (p=0.289, KW test, n=7, df=1, X^2=1.125). Overall, the mean ambient noise level from these slack tide measurements was 133 dB re 1 μPa (s.d.=8.07 dB), which was slightly lower than the overall mean ambient noise level for the July sampling period.

3.4 Opportunistic Recordings

Opportunistic recordings were made of a number of noise sources during both months and included instances of U.S. Air Force F-22 jets, Airborne Warning and Control (AWAC) aircraft, U.S. Coast Guard rigid-hull inflatable boats (RHIB), dredge, land-based construction noise, and a single recording at the mouth of the Eagle River. Sample sound spectrums from F-22 overflights, RHIBs, and dredges are shown in **Figures 10-12**. Photographs of the various noise producing factors (natural and anthropogenic) in Knik Arm are pictured in **Figures 13-16**. Although these opportunistic recordings were not included in the calculations of the ambient noise levels, they are presented in **Table 6** and add to the discussion of anthropogenic contributions to ambient noise.

4 DISCUSSION

4.1 Temporal and Spatial Variability in Ambient Noise Levels

Knik Arm is a noisy environment. Perhaps the best evidence of this is an examination of both the “quiet” and “loud” conditions (i.e., 5th and 95th percentiles, respectively). The “quiet” condition is loud, and the “loud” condition is very loud. The “quiet” conditions recorded during this study (overall mean ambient noise levels of 109 dB in May and 119 dB in July) were slightly less than the current Level B harassment threshold used by the NMFS for continuous noise (e.g., vibratory pile driving) of 120 dB. The “loud” conditions (overall mean ambient noise levels of 145 dB in May and 146 dB in July) are approximately 15 dB less than the current Level B harassment threshold used by the NMFS for impact noise (e.g., impact pile driving). The ambient noise measurements recorded during this study are comparable to those measured by previous investigators (**Table 1**).

Some of the high ambient noise levels in Knik Arm can be explained by strong tidal currents (i.e., noise from the turbulent flow of the water); sediment noise generated by current flow (this study recorded sounds of rolling gravel, most likely cobbles and pebbles, as noted by Blackwell and Greene 2002 for this area); and self noise (e.g., Blackwell and Greene 2002; Sirovic and Kendall 2009; Small 2010). Work in other regions also suggests that the source of observed increases in ambient noise attributable to tidal current velocity is, in fact, flow noise at the receiver (e.g., Narragansett Bay: Willis and Dietz 1961; Puget Sound: Bassett et al. 2010). While the methods of this study attempted to reduce flow noise at the hydrophone by drifting during sampling and reducing strumming (see **Section 2.4**), the issue of flow noise was not completely removed.

Anthropogenic sources also contribute to the high ambient noise levels of the area. Whether comparing sampling sites or tidal cycles, ambient noise levels were much higher in July than in May. The most likely explanation for these findings is that the type and number of noise-producing sources was greater in July than in May. The purpose of this study, however, was to collect data on the overall ambient noise condition in the proposed Crossing footprint and not to investigate the contributors (natural or anthropogenic) to those noise levels.

As noted in **Section 3.4**, opportunistic recordings were made of a number of man-made noise sources, as well as at a nonindustrial area for comparative purposes.

Port of Anchorage

Throughout the recording sessions in May and July, the amplitude and frequency of the recorded noise often sounded like a machine, with accelerations and metallic knocks. This matches the descriptions of dredges by Green and Moore (1995). It is important to note that typically there were no other large vessels or potential noise sources visible in addition to the dredges working at the POA. In most cases, the predominant sound source was in all likelihood a suction dredge working near the POA marine terminal expansion site (**Figure 13**). The suction dredge produces primarily low-frequency noise in contrast to the clamshell dredge, which may emit higher-frequency noise depending on the stage of operation (Dickerson et al. 2001). A maximum sound level of 148 dB re 1 μPa was recorded when suction and clamshell dredges were operating concurrently (**Table 6**). Sample sound spectrums for dredges recorded at Sites 1 and 3 are shown as **Figures 12a and 12b**.

Port MacKenzie

A variety of earth-moving equipment including front loaders, bulldozers and dump trunks were working at low tide on gravel along a berm near the water at Port MacKenzie during May and July (**Figure 16**). The maximum noise level—133 dB re 1 µPa—was recorded 100 yards offshore of this construction site during July (**Table 6**). This level is the same as the overall mean ambient noise level of 136 dB re 1 µPa recorded in July. Noise produced by that land-bound construction effort, therefore, was not adding any noise to underwater ambient noise levels. These data are important relative to the proposed KAC project because construction of the approach causeways will involve a similar type of construction activity.

Eagle River

Recordings were made at the mouth of the Eagle River during May and July. In May, the sound levels were 116 dB re 1 µPa, while in July they were louder—129 dB re 1 µPa (**Table 6**). This study's recorded ambient noise levels at Eagle River are less than the overall mean ambient noise levels for this study, which were 124 dB re 1 µPa in May and 136 dB re 1 µPa in July. These recorded levels are similar to those measured by Blackwell and Greene (2002) in areas away from industrial noise sources. Small (2010) commented that Eagle River was a noisy area, suggesting that the high noise levels were due to sediment noise generated by current flow.

F-22 Fighter Aircraft

There were numerous flights by U.S. Air Force F-22 jets over the proposed Crossing's construction site. Although the noise levels from these military aircraft were not particularly high (loudest was 129 dB re 1 µPa; **Table 6; Figure 10**) compared to other noise levels recorded during this project, their rapid onset and higher frequency content made them particularly noticeable. These recorded levels are similar to the mean value of 128 dB re 1 µPa recorded by Blackwell and Greene (2002) for military aircraft at Elmendorf Air Force Base.

4.2 Impact on Beluga Whales

The present study provides baseline information of ambient noise in the proposed KAC construction site. The great seasonal and geographical variations between the results indicate that this area is highly dynamic in terms of tides, current flow and anthropogenic activity. Ross (2005) demonstrated that the increase in ambient noise between 20 and 200 Hz originates from anthropogenic activities such as ship propulsion. Above 200 Hz, the ambient noise level is driven primarily by sea state (Urick 1983) and wind speed, and can vary by at least 20 dB.

Based on the auditory information available for the beluga whale (**Section 1.4**), little can be inferred concerning the animal's detection of sounds below 100 Hz as no hearing measurements in that frequency range have been obtained to date. **Figures 4a and 4b** provide the sound spectrum of the ambient noise and most of the energy is found within 10 and 200 Hz, with SPLs varying from 98 dB to over 140 dB in May and 89 dB to 140 dB in July. These levels might be inaudible, or barely audible, by beluga whales based on the audiograms presented in this report with thresholds at 108 dB for a 100 Hz tone and 118 dB for 250 Hz (Awbrey et al. 1988; Johnson et al. 1989).

Above 200 Hz, the noise levels decrease from 110 dB to approximately 80 dB in May and from103 dB to 84 dB in July. While it is difficult to assert the direct and measurable impact of the noise between 200 to

20 kHz, one can assume that the ambient noise above 200 Hz is likely to be detected by the animal as the SPL are above the measured thresholds obtained in controlled conditions. It is, however, difficult to test whether these ambient sounds are likely to provoke some physiological or behavioral responses. Beluga whales are often observed in the studied area and while aversive behaviors have been recorded for transient anthropogenic noise (e.g., boating activities and construction) none have been experimentally quantified for continuous ambient noise (Carter and Nielsen 2011). As noted by Tyack (2008), “It is very difficult to test whether elevated ambient noise is preventing an animal from hearing and reacting to a communication signal.” The ambient noise levels measured at Eagle River were lower than of the KAC construction site, with a maximum SPL of 133 dB re 1 μPa. This area is known to be a feeding area for the Cook Inlet beluga whale. In the absence of anthropogenic activity, one can assume that beluga whales have successfully adapted to such loud ambient noise levels.

Hearing impairment, or TTS, is likely to happen with loud impulse sounds (178 to 193 dB). During TTS experiments, Schlundt et al. (2000) noted behavioral disruption when the 1 second fatiguing sounds were above 180 dB (frequencies between 400 Hz and 75 kHz). Because most of the continuous anthropogenic ambient noise measured in this study was below these values, one can expect to see limited behavioral change. However, intermittent and transient noise such as dredging or overflight can potentially cause behavioral change or TTS, depending on the distance between the animals and the sound source.

Overall measured baseline ambient SPLs are above the 120 dB limit set by the NMFS sound exposure threshold guideline (124 dB in May and 136 dB in July). The 12dB increase from May to July is likely due to increase in transient boat traffic and can potentially cause discrete changes in behavior, such as observed by Finley et al. (1990), in the Canadian High Arctic, and Patenaude et al (2002), in the Alaskan Beaufort Sea. These behaviors include surfacing, quick turns, rapid swimming or breaching. Anthropogenic sounds such as dredging at Sites 1 and 3 (145.20 dB re 1 μPa and 125.30 dB re 1 μPa), the Coast Guard RHIBs (128.48 dB re 1 μPa) and the overflight of a U.S. F-22 fighter (120.14 dB re 1 μPa) are transient and mostly discrete anthropogenic sounds likely to trigger behavioral changes, as observed in previous studies in other locales.

Other marine mammals are known to alter their behavior in response to changes in ambient noise. For example, the relationship between behavioral state and ambient noise levels was investigated in the Florida manatee (*Trichechus manatus latirostris*). The authors found that when the sound levels were the highest, the animals spent more time feeding (‘directed, goal oriented’) and less time milling (‘undirected behavior’) (Miksis-Olds and Wagner 2011). Boat avoidance by humpback whales (*Megaptera novaeangliae*) has been observed both in Hawaii and Alaska (Baker and Herman 1989; Frankel and Clark 1998).

Because most of the energy of the ambient noise is again within a range that is either inaudible or partially audible by the animals (10 to 200 Hz), there is limited opportunity for masking of social (1 to 7 kHz) or echolocation signals. Masking will primarily occur when the masking noise is 1/12 of the octave band around the frequency of a specific sound (Erbe 1999).

Marine mammals are known to adapt to loud ambient environment. Au et al. (1984) measured the properties of the echolocation signal of a beluga whale housed in San Diego Harbor (California) and

Kane’ohe Bay (Hawaii) and found that the animal changed its echolocation click to higher frequencies and intensities in Kane’ohe Bay as the ambient noise is 12 to 17 dB greater than in San Diego Harbor. These results indicate that the beluga whale has a very adaptive echolocation system and can compensate for changes in ambient noise.

However, as mentioned earlier, beluga whales have been observed to increase the production of pulsed calls and falling tonal calls, the repetition of the calls and to shift their call frequencies in the presence of boat noise (Lesage et al. 1999). The Lombard vocal response observed by Scheifele et al. (2005) is also believed to be an adaptation to masking effects.

Other species have been observed to adapt to varying ambient noise. To compensate for boat noise, bottlenose dolphins have been observed to increase the repetition rate of their calls (Buckstaff 2004). Morisaka and colleagues (2005) compared the acoustic characteristics of three populations of Indo-Pacific bottlenose dolphins (*Tursiops aduncus*) and the acoustic characteristics of their respective ambient noise conditions and found that in louder ambient noise, the animals produced lower frequency calls with fewer frequency modulations.

Mysticetes (baleen whales) also have been observed to modify their calls with changes in ambient noise. Because mysticete acoustic communication is primarily in the low-frequency domain, North Atlantic right whales (*Eubalaena glacialis*) have been observed increasing the amplitude of their calls in response to an increase in ambient noise. This adaptation allows the animals to maintain the range of acoustic communication between individual constant (Parks et al. 2007, 2010). However, there is no empirical data addressing the potential cost and the detrimental effect of such change on the animals.

Physiological changes that are non behavioral or auditory related can occur with loud sound exposure. Hormones levels can change in response to stress. Thomas et al. (1990) measured catecholamine levels in captive beluga whales before and after noise exposure to oil drilling platform sounds. The results indicated no difference in these stress hormones. Additionally, Romano et al. (2004) found significant differences in dopamine, nor-epinephrine and epinephrine levels in a captive beluga whale after sound exposures louder than 183 dB re 1 μPa^2s. These results were consistently higher than for sound exposures lower than 183 dB re 1 μPa^2s or no sound exposure sessions. The bottlenose dolphin had higher aldosterone levels and a significant decrease in monocytes counts after sound exposure sessions (Romano et al. 2004). Based on these results, it appears that loud sounds can trigger changes in immune and hormonal systems and that these effects might vary between species.

While it has been shown that marine mammals are capable of adapting to changes in ambient noise levels, it remains difficult to assert when these changes in behavior and communication will start being detrimental for the fitness or survival of the species.

4.3 Conclusions

This study was designed to sample ambient noise levels across three sampling sites during all four tidal cycles in an attempt to explain any spatial or temporal variation in noise levels. Based on research findings from Cook Inlet, as well as other locales, it was anticipated that the greatest tidal currents (i.e., during flood and ebb tides) would produce the highest ambient noise levels. For example, Willis and

Dietz (1965) working in Narragansett Bay, where tidal velocities are 25 percent of those found in the Knik Arm, determined that tidal action increased ambient noise by over 20 dB.

This did not appear to be the situation in Knik Arm. This study’s results indicate that ambient noise levels for the four tidal cycles were not significantly different in July, and only one tidal cycle was significantly different (low tide) in May. One potential reason for the lack of statistical significance amongst the combined tidal cycles of both months (without the low tide recordings made in May) is that the timing of recordings relative to those cycles may not in sync with the actual reduction in tidal flow during slack tides. The slack tide results are indicative of the influence of water movements. Slack tides represent the times each day when there is minimal tidal motion. Ambient noise levels recorded during this period of minimum water turbulence should be relatively low.

However, the overall mean ambient noise during slack tide at Site 2 was133 dB re 1 μPa. These results suggest that the natural flow of water (i.e., current) is not the cause of the high ambient noise recordings, but instead more likely due to anthropogenic noise contributors. Yet, high noise recordings at the mouth of Eagle River, a non-industrial area, suggest further investigation is needed.

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5 RECOMMENDATIONS FOR FUTURE WORK

In completing this “snapshot” investigation of ambient noise in Knik Arm, as well as upon reviewing previously conducted noise studies in the region and in the available literature, the following is a list of recommended studies and measurement/monitoring activities to further elucidate the role of environmental and anthropogenic factors on ambient noise levels in the Knik Arm.

- Year-round, continuous fine-scale temporal in-water measurements of ambient noise across all tidal cycles for an extended period from numerous locations within Knik Arm. These data will allow a predictive model of the true measure of tidal action relative to ambient noise within the area.
- Detailed studies of the influence of bathymetric relief on variation in ambient noise levels across all tidal cycles to provide valuable information relative to the observed variability in ambient noise levels within the region
- Detailed studies to determine the influence of current speed (i.e., flow) on ambient noise using Acoustic Doppler Current Profile technologies within the KAC area (at similar spatial and temporal scales as other studies mentioned above)
- Simultaneous “real-time” passive acoustic monitoring and visual observation for beluga whales within specified regions to provide needed information with regards to movement relative to ambient noise along the footprint of the KAC
- Behavior studies using non-invasive, digital acoustic tags (DTAGs) attached to beluga whales. Use these archival sound and behavior recording tags to collect information on sound levels received by belugas in Knik Arm and their behavioral responses (e.g., body motion and dive depth) to those sounds.
- Measure source/received levels from anthropogenic activities (e.g., pile-driving, dredging, ship traffic, aircraft flyovers, etc.) to help evaluate the dominant contribution of these activities to increased noise levels at the proposed KAC construction site

LITERATURE CITED

Angiel, N.M. 1997. *The vocal repertoire of the beluga whale in Bristol Bay, Alaska*. Master's thesis, University of Washington.

Au, W.W.L. 1993. *The sonar of dolphins*. New York: Springer-Verlag.

Au, W.W.L., and P.W.B. Moore. 1984. Receiving beam patterns and directivity indices of the Atlantic bottlenose dolphin *Tursiops truncatus*. *Journal of the Acoustical Society of America* 75(1):255-262.

Au, W.W.L., D.A. Carder, R.H. Penner, and B.L. Scronce. 1984. Demonstration of adaptation in beluga whale echolocation signals. *Journal of the Acoustical Society of America* 77(2):726-730.

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

Baker, C.S., and L.M. Herman. 1989. *The behavioral responses of summering humpback whales to vessel traffic: Experimental and opportunistic observations*. Kewalo Basin Marine Mammal Laboratory. Technical Report No. NPS-NR-TRS-89-01. Final report from Kewalo Basin Marine Mammal Laboratory to the National Park Service, Alaska Regional Office, Anchorage, Alaska.

Bassett, C., J. Thomson, and B. Polagye. 2010. Characteristics of underwater ambient noise at a proposed tidal energy site in Puget Sound. *Proceedings, Oceans '10 MTS/IEEE, September 20-23, 2010, Seattle, Washington*. http://depts.washington.edu/nnmrec/docs/20100920_BassettC_conf_UnderwaterNoise.pdf>, accessed October 2010.

Bel'kovich, V.M., and M.N. Sh'ekotov. 1993. *The belukha whale: Natural behavior and bioacoustics*. Union of Soviet Socialist Republics Academy of Science, Moscow, translated by Woods Hole Oceanographic Institution.

Blackwell, S.B. 2005. *Underwater measurements of pile-driving sounds during the Port MacKenzie dock modifications, August 13–16, 2004*. Prepared for Knik Arm Bridge and Toll Authority, Anchorage; Alaska Department of Transportation and Public Facilities, Anchorage, Alaska; and Federal Highway Administration, Juneau, Alaska. Prepared by Greeneridge Sciences, Inc., Goleta, Calif.; and LGL Alaska Research Associates, Inc., Anchorage; in association with HDR Alaska, Inc., Anchorage.

Blackwell, S.B., and C.R. Greene. 2002. *Acoustic measurements in Cook Inlet, Alaska, during August 2001*. Greeneridge Sciences, Inc. Report 271-1. Prepared by Greeneridge Sciences, Inc., for National Marine Fisheries Service.

Bradley, D.L., and R. Stern. 2008. *Underwater sound and the marine mammal acoustic environment: A guide to fundamental principles*. Marine Mammal Commission, Bethesda, Maryland. <http://www.mmc.gov/reports/workshop/pdf/sound_bklet.pdf>, accessed October 2010.

Buckstaff, K.C. 2004. Effects of watercraft noise on the acoustic behavior of bottlenose dolphins, *Tursiops truncatus*, in Sarasota Bay, Florida. *Marine Mammal Science* 20(4):709-725.

Carter, B.T.G., and E.A. Nielsen. 2011. Exploring ecological changes in Cook Inlet beluga whale habitat though [sic] traditional and local ecological knowledge of contributing factors for population decline. *Marine Policy* 35:299-308.

Chapman, D.M. F., and D.D. Ellis. 1998. The elusive decibel: Thoughts on sonars and marine mammals. *Canadian Acoustics* 26**:** 29-31.

Denny, M.W. 1993. *Air and water: The biology and physics of life's media*. Princeton, New Jersey: Princeton University Press.

Dickerson, C., K.J. Reine, and D.G. Clarke. 2001. *Characterization of underwater sounds produced by bucket dredging operations*. ERDC TN-DOER-E14. U.S. Army Engineer Research and Development Center, Vicksburg, Miss. <www.wes.army.mil/el/dots/doer>.

Erbe, C. 2008. Critical ratios of beluga whales (*Delphinapterus leucas*) and masked signal duration. *Journal of the Acoustical Society of America* 124(4):2216-2223.

Erbe, C., A.R. King, M. Yedlin, and D.M. Farmer. 1999. Computer models for masked hearing experiments with beluga whales (*Delphinapterus leucas). Journal of the Acoustical Society of America* 105(5):2967-2978.

Finneran, F.J., and D.S. Houser. 2006. Comparison of in-air evoked potential and underwater behavioral hearing thresholds in four bottlenose dolphins (*Tursiops truncatus*). *Journal of the Acoustical Society of America* 119(5):3181-3192.

Faucher, A. 1988. *The vocal repertoire of the St. Lawrence Estuary population of beluga whale (*Delphinapterus leucas*) and its behavioral, social and environmental contexts*. Master's thesis, Dalhousie University.

Finley, K.J., G.W. Miller, R.A. Davis, and C.R. Greene. 1990. Reactions of belugas, *Delphinapterus leucas* and narwhals, *Monodon monoceros*, to ice-breaking ships in the Canadian high Arctic. *Canadian Bulletin of Fisheries and Aquatic Sciences* 224:97-117.

Finneran, J.J., C.E. Schlundt, D.A. Carder, J.A. Clark, J.A. Young, J.B. Gaspin, and SH. Ridgway. 2000. Auditory and behavioral responses of bottlenose dolphins (*Tursiops truncatus*) and a beluga whale (*Delphinapterus leucas*) to impulsive sounds resembling distant signatures of underwater explosions. *Journal of the Acoustical Society of America* 108(1):417-431.

Finneran, J.J., C.E. Schlundt, R. Dear, D.A. Carder, and S.H. Ridgway. 2002. Temporary shift in masked hearing thresholds in odontocetes after exposure to single underwater impulses from a seismic watergun. *Journal of the Acoustical Society of America* 111(6):2929-2940.

Finneran, J.J., D.A. Carder, R. Dear, T. Belting, J. McBain, L. Dalton, and S.H. Ridgway. 2005. Pure tone audiograms and possible aminoglycoside-induced hearing loss in belugas (*Delphinapterus leucas*). *Journal of the Acoustical Society of America* 117(6):3936-3943.

Fletcher, H.L. 1940. Auditory patterns. *Reviews of Modern Physics* 12:47-65.

Fraker, M. A. 1977. *The 1976 white whale monitoring program, Mackenzie Estuary, N.W.T.* Rep. prepared for Imperial Oil Ltd., Calgary, Alberta. F.F. Slaney & Co., Ltd., Vancouver, British Columbia.

Frankel, A.S., and C.W. Clark. 1998. Results of low-frequency playback of M-sequence noise to humpback whales, *Megaptera novaeangliae*, in Hawaii. *Canadian Journal of Zoology* 76(3):521-535.

Funk, D. W., T. M. Markowitz, R. Rodrigues, M. W. Demarchi, and M. R. Link. 2005. "The Influence of Tide on the Habitat Use and Movements of Beluga Whales in Knik Arm." In *Baseline studies of beluga whale habitat use in Knik Arm, Upper Cook Inlet, Alaska, July 2004– July 2005*, edited by D. W. Funk, T. M. Markowitz, and R. Rodrigues, 6-1–6-27. LGL Report P826. Prepared by LGL Alaska Research Associates, Inc., Anchorage, in association with HDR Alaska, Inc., Anchorage, for Knik Arm Bridge and Toll Authority, Anchorage; Department of Transportation and Public Facilities, Anchorage; and Federal Highway Administration, Juneau.

Greene, C.R. 1995. "Ambient Noise." In *Marine mammals and noise*, eds. W.J. Richardson, C.R. Greene, Jr., C.I. Malme, and D.H. Thomson. San Diego, Calif.: Academic Press, pp. 87–100.

Greene, C.R., and S.E Moore. 1995. "Man-Made Noise." In *Marine mammals and noise*, eds. W.J. Richardson, C.R. Greene, Jr., C.I. Malme, and D.H. Thomson. San Diego, Calif.: Academic Press, pp. 101-158.

Gurevich, V.S., and W.E. Evans. 1976. Echolocation discrimination of complex planar targets by the Beluga whale (*Delphinapterus leucas*). *Journal of the Acoustical Society of America* 60 (Supplement 1):S5-S6.

Houser, D.S., A. Gomez-Rubio, and J.J. Finneran. 2008. Evoked potential audiometry of 13 Pacific bottlenose dolphins (*Tursiops truncatus gilli*). *Marine Mammal Science* 24(1):28-41.

Ireland, D. S., S. McKendrick, Funk D. W., T. M. Markowitz, A. Prevel-Ramos, M. R. Link, and M. W. Demarchi. 2005. "Spatial Analysis of Beluga Whale Distribution in Knik Arm." In *Baseline studies of beluga whale habitat use in Knik Arm, upper Cook Inlet, Alaska, July 2004–July 2005*, edited by D. W. Funk, T. M. Markowitz, and R. Rodrigues, 7-1–7-22. Anchorage: LGL Alaska Research Associates, Inc., in association with HDR Alaska, Inc., Anchorage, for the Knik Arm Bridge and Toll Authority, Anchorage; Alaska Department of Transportation and Public Facilities, Anchorage; and the Federal Highway Administration, Juneau.

Johnson, C.S. 1966. Auditory thresholds of the bottlenosed porpoise (*Tursiops truncatus*, Montagu). NOTSTP Report No. 4178. U.S. Naval Ordinance Test Station, China Lake, California.

Johnson, C.S., M.W. McManus, and D. Skaar. 1989. Masked tonal hearing thresholds in the beluga whale. *Journal of the Acoustical Society of America* 85(6):2651-2654.

Kamminga, C., and H. Wiersma. 1981. Investigations of cetacean sonar. II. Acoustical similarities and differences in odontocete sonar signals. *Aquatic Mammals* 8(2):41-62.

Karlsen, J. D., A. Bisther, C. Lydersen, T. Haug, and K.M. Kovacs. 2002. Summer vocalisations of adult male white whales (*Delphinapterus leucas*) in Svalbard, Norway. *Polar Biology* 25(11):808-817.

Klishin, V.O., V.V. Popov, and A.Y. Supin. 2000. Hearing capabilities of a beluga whale, *Delphinapterus leucas*. *Aquatic Mammals* 26(3):212-228.

Lammers, M.O., and M. Castellote. 2009. The beluga whale produces two pulses to form its sonar signal. *Biology Letters* 5(3):297-301.

Lesage, V., C. Barrette, M.C.S. Kingsley, and B. Sjare. 1999. The effect of vessel noise on the vocal behavior of belugas in the St. Lawrence Estuary, Canada. *Marine Mammal Science* 15(1):65-84.

Markowitz, T.M., and T. L. McGuire*. 2007. Temporal-spatial distribution, movements and behavior of beluga whales near the Port of Anchorage, Alaska*. Anchorage: LGL Alaska Research Associates, Inc., for Integrated Concepts and Research Corporation and the U.S. Department of Transportation Maritime Administration.

Markowitz, T. M., D. W. Funk, R. Rodrigues, M. R. Link, A. M. Prevel-Ramos, and M. K. Blees. 2005. "Seasonal Patterns in Beluga Whale Use of Knik Arm." In *Baseline studies of beluga whale habitat use in Knik Arm, upper Cook Inlet, Alaska, July 2004–July 2005*, edited by D. W. Funk, T. M. Markowitz, and R. Rodrigues, 5-1–5-49. Anchorage: LGL Alaska Research Associates, Inc., in association with HDR Alaska, Inc., Anchorage, for the Knik Arm Bridge and Toll Authority, Anchorage; Alaska Department of Transportation and Public Facilities, Anchorage; and the Federal Highway Administration, Juneau.

Miksis-Olds, J.L., and T. Wagner. 2011. Behavioral response of manatees to variations in environmental sound levels. *Marine Mammal Science* 27(1):130-148.

Mobile Geographics. 2010. XTide Tide Prediction Server: Anchorage (Knik Arm), Alaska. <http://www.mobilegeographics.com:81/>, accessed May 2010.

Mooney, T.A., P.E. Nachtigall, M. Castellote, K.A. Taylor, A.F. Pacini, and J.-A. Esteban. 2008. Hearing pathways and directional sensitivity of the beluga whale, *Delphinapterus leucas*. *Journal of Experimental Marine Biology and Ecology* 362:108-116.

Morisaka, T., M. Shinohara, F. Nakahara, and T. Akamatsu. 2005. Effects of ambient noise on the whistles of Indo-Pacific bottlenose dolphin populations. *Journal of Mammalogy* 86(3):541-546.

Nachtigall, P.E., T.A. Mooney, K.A. Taylor, and M.M.L. Yuen. 2007. Hearing and auditory evoked potential methods applied to odontocete cetaceans. *Aquatic Mammals* 33(1):6-13.

National Marine Fisheries Service (NMFS). 2008. *Conservation plan for the Cook Inlet beluga whale* (*Delphinapterus leucas*). Juneau: National Marine Fisheries Service.

Norris, K.S. 1967. “The Evolution of Acoustic Mechanisms in Odontocete Cetaceans.” Pp. 297-324. *In Evolution and Environment*, ed. E. Drake. New Haven, Connecticut: Yale University Press, pp. 297-324.

National Research Council (NRC). 2003. *Ocean noise and marine mammals*. Washington, D.C.:National Academies Press.

Parks, S.E., C.W. Clark, and P.L. Tyack. 2007. Short- and long-term changes in right whale calling behavior: The potential effects of noise on acoustic communication. *Journal of the Acoustical Society of America* 122(6):3725-3731.

Parks, S.E., M. Johnson, D. Nowacek, and P.L. Tyack. 2011. Individual right whales call louder in increased environmental noise. *Biology Letters* 7:33-35.

Patenaude, N.J., W.J. Richardson, M.A. Smultea, W.R. Koski, G.W. Miller, B. Würsig, and C R. Greene, Jr. 2002. Aircraft sound and disturbance to bowhead and beluga whales during spring migration in the Alaskan Beaufort Sea. *Marine Mammal Science* 18(2):309-335.

Penner R., H., C.W. Turl, and W.W.L. Au. 1986. Target detection by the beluga using a surface-reflected path. *Journal of the Acoustical Society of America* 80(6):1482-1483.

Port of Anchorage (POA), U.S. Department of Transportation (USDOT), and U.S. Army Corps of Engineers (USACE). 2009. *Biological assessment of the beluga whale* Delphinapterus leucas *in Cook Inlet for Port of Anchorage Expansion Project and associated dredging at the Port of Anchorage, Alaska*. Prepared for the National Marine Fisheries Service, Juneau, Alaska by Port of Anchorage, Anchorage, and U.S. Department of Transportation, Maritime Administration, Washington, D.C. and U.S. Army Corps of Engineers, Alaska District, Elmendorf AFB, Alaska.

Popov, V.V., and V.O. Klishin. 1998. EEG study of hearing in the common dolphin, *Delphinus delphis*. *Aquatic Mammals* 24(1):13-20.

Popov, V.V., and A. Y. Supin. 2009. Comparison of directional selectivity of hearing in a beluga whale and a bottlenose dolphin. *Journal of the Acoustical Society of America* 126(3):1581-1587.

Richardson, W. J. 1995b. “Documented Disturbance Reactions.” In *Marine mammals and noise*, eds. W. J. Richardson, C. R. Greene, Jr., C. I. Malme, and D. H. Thomson, 241–324. San Diego: Academic Press

Romano, T.A., M.J. Keogh, C. Kelly, P. Feng, I. Berk, C.E. Schlundt, D.A. Carder, and J.J. Finneran. 2004. Anthropogenic sound and marine mammal health: Measures of the nervous and immune systems before and after intense sound exposure. *Canadian Journal of Fisheries and Aquatic Sciences* 61:1124-1134.

Ross, D. 2005. Ship sources of ambient noise. *IEEE Journal of Oceanic Engineering* 30(2):257-261.

Scheifele, P.M., S. Andrew, R.A. Cooper, M. Darre, F.E. Musiek, and L. Max. 2005. Indication of a Lombard vocal response in the St. Lawrence River beluga. *Journal of the Acoustical Society of America* 117(3, Part 1):1486-1492.

Schevill W.E., and B. Lawrence. 1949. Underwater listening to the white porpoise (*Delphinapterus leucas*). *Science* 109:143-144.

Schevill, W.F., and A.F. McBride. 1956. Evidence for echolocation by cetaceans. *Deep-Sea Research* 3(2):153-154.

Schlundt, C.E., J.J. Finneran, D.A. Carder, and S.H. Ridgway. 2000. Temporary shift in masked hearing thresholds of bottlenose dolphins, *Tursiops truncatus*, and white whales, *Delphinapterus leucas*, after exposure to intense tones. *Journal of the Acoustical Society of America* 107(6):3496-3508.

Scientific Fishery Systems, Inc. (SFS). 2009. *2008 underwater noise survey during construction pile driving, Port of Anchorage Marine Terminal Development Project, in support of Alaska Native Technologies, LLC*. Prepared for U.S. Department of Transportation Maritime Administration, Port of Anchorage, and Integrated Concepts and Research Corporation.

Simard, Y., N. Roy, S. Giard, C. Gervaise, M. Conversano, and N. Menard. 2010. Estimating whale density from their whistling activity: Example with St. Lawrence beluga. *Applied Acoustics* 71(11):1081-1086.

Širović, A., and L. Saxon Kendall. 2009. *Passive acoustic monitoring of Cook Inlet beluga whales: Analysis report, Port of Anchorage Marine Terminal Redevelopment Project*. Prepared for U.S. Department of Transportation, Maritime Administration, Washington, D.C.; Port of Anchorage, Anchorage; and Integrated Concepts and Research Corporation, Anchorage.

Sjare, B.L., and T.G. Smith. 1986a. The vocal repertoire of white whales, *Delphinapterus leucas*, summering in Cunningham Inlet, Northwest Territories. *Canadian Journal of Zoology* 64(2):407-415.

Sjare, B.L., and T.G. Smith. 1986b. The relationship between behavioral activity and underwater vocalizations of the white whale, *Delphinapterus leucas. Canadian Journal of Zoology* 64(12):2824-2831.

Small, R.J. 2010. *Acoustic monitoring of beluga whales and noise in Cook Inlet. 1 October 2009 through 31 March 2010*. Semi-annual performance report to Alaska Department of Fish and Game. <www.fakr.noaa.gov/protectedresources/whales/beluga/acoustics/cib_acoustics-1009-0310_adfg.pdf>, accessed June 25, 2010.

Smith, O.P. 2004. Knik *Arm Bridge conceptual engineering, Knik Arm current, sediment transport, and ice studies*. Prepared for Knik Arm Bridge and Toll Authority, Anchorage, AK.

Smith, O., A. Khokhlov, and M. Zieserl. 2005. *Water property, sediment, tide and current measurements and analyses in the vicinity of the proposed Knik Arm Bridge*. A report prepared for URS and HDR.

Supin, A.Ya., and V.V. Popov. 1995. Envelope-following response and modulation transfer function in the dolphin's auditory system. *Hearing Research* 92:38-46.

Szymanski, M.D., A.Y. Supin, D.E. Bain, and K.R. Henry. 1998. Killer whale (Orcinus orca) auditory evoked potentials to rhythmic clicks. *Marine Mammal Science* 14(4):676-691.

Thomas, J.A., R.A. Kastelein, and F.T. Awbrey. 1990. Behavior and blood catecholamines of captive belugas during playbacks of noise from an oil drilling platform. *Zoo Biology* 9:393-402.

Turl, C.W., R.H. Penner, and W.W.L. Au. 1987. Comparison of target detection capabilities of the beluga and bottlenose dolphin. *Journal of the Acoustical Society of America* 82(5):1487-1491.

Turl, C.W., and R.H. Penner. 1989. Differences in echolocation click patterns of the beluga (*Delphinapterus leucas*) and the bottlenose dolphin (*Tursiops truncatus*). *Journal of the Acoustical Society of America* 86(2):497-502.

Turl, C.W., D.J. Skaar, and W.W.L. Au. 1990. The echolocation ability of the beluga *(Delphinapterus leucas*) to detect targets in clutter. *Journal of the Acoustical Society of America* 89(2):895-901.

Tyack, P.L. 2008. Implications for marine mammals of large-scale changes in the marine acoustic environment. *Journal of Mammalogy* 89(3):549-558.

Urick, R.J. 1983. *Principles of underwater sound. Third edition*. Peninsula Publishing, Los Altos, California.

———. 1984. *Ambient noise in the sea*. Undersea Warfare Technology Office, Naval Systems Command, Department of the Navy.

URS. 2005. *Historical bathymetry of Knik Arm*. Prepared for HDR Alaska, Inc.

———. 2007. *Port of Anchorage Marine Terminal Development Project underwater noise survey test pile driving program, Anchorage, Alaska*. Final underwater noise report. Prepared for Integrated Concepts and Research Corp. Infrastructure Support Services.

U.S. Department of Transportation (USDOT) and Port of Anchorage (POA). 2008. *Rulemaking and Letters of Authorization Application for construction activities associated with the Port of Anchorage Marine Terminal Redevelopment Project, July 15, 2009 – July 15, 2014*. Prepared by Integrated Concepts and Research Corporation (ICRC), Anchorage, with assistance from URS Corporation (URS).

Vergara, V., and L.G. Barrett-Lennard. 2008. Vocal development in a beluga calf (*Delphinapterus leucas*). *Aquatic Mammals* 34(1):123-143.

Warner, G., and D. Hannay. 2009. *Underwater noise levels from vehicles crossing the Knik River Bridge, Version 1*. Prepared by JASCO for LGL Alaska Research Associates, Inc., Anchorage.

Wenz, G.M. 1962. Acoustic ambient noise in the ocean: Spectra and sources. *Journal of the Acoustical Society of America* 34(12):1936-1956.

White, M.J., Jr., J. Norris, D. Ljungblad, K. Baron, and G. Di Sciara. 1978. Auditory thresholds of two beluga whales (*Delphinapterus leucas*). HSWRI Technical Report 78-109. Prepared by Hubbs SeaWorld Research Institute, San Diego, for Naval Ocean Systems Center, San Diego.

Willis, J., and F.T. Dietz. 1965. Some characteristics of 25-cps shallow-water ambient noise. *Journal of the Acoustical Society of America* 37(1): 125-130.

Yuen, M.E., P.E. Nachtigall, and A. Ya. Supin, and M. Breese. 2005. Behavioral and auditory evoked potential audiograms of a false killer whale (*Pseudorca crassidens*). *Journal of the Acoustical Society of America* 118(4):2688-2695.

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Table 1. Summary of broadband ambient noise levels recorded in Knik Arm, Upper Cook Inlet during various acoustic monitoring studies.

Date	Sound level (dB re 1 µPa)	Location	Notes	Source
Aug 2001	95 (mean)	Birchwood	high tide	Blackwell and Greene (2002)
Aug 2001	118 (mean)	Eagle River	high tide	Blackwell and Greene (2002)
Aug 2001	119 (mean)	Elmendorf AFB	incoming tide	Blackwell and Greene (2002)
Aug 2001	120 (mean)	north of Point Possession	incoming tide	Blackwell and Greene (2002)
Aug 2004	115–133	Port MacKenzie	background levels; large contribution of flow noise	Blackwell (2005)
April 2007	97.5–111.9	Knik River Bridge	max. recorded during drift	Warner and Hannay (2009)
Oct 2007	105–120	Port of Anchorage	no industrial sounds	URS (2007)
Oct 2007	120–140	Port of Anchorage	operating vessels & dredges	URS (2007)
Sept–Oct 2008	120–150 (mean=133)	Port of Anchorage	background levels, strongly correlated with wind, less so w/ tide	SFS (2009)
Aug–Sept 2009	117.9 ±10.5	Port of Anchorage	without construction	Širović and Saxon Kendall (2009)
Aug–Sept 2009	129.4 ±5.4	Port of Anchorage	with construction	Širović and Saxon Kendall (2009)

Note: No published ambient noise data are currently available from ADF&G work (Small et al.); bucket dredging studies off Point Woronzof (Dickerson et al. 2001), or in Eagle River by the U.S. Army.

Table 2. Sampling schedule followed during the ambient noise study in Knik Arm during May and July 2010.

	May Recording Schedule (hhmm) (24-hour clock)														
	High tide			Ebb tide			Low tide			Flood tide			High tide		
Date	Site 1	Site 2	Site 3	Site 1	Site 2	Site 3	Site 1	Site 2	Site 3	Site 1	Site 2	Site 3	Site 1	Site 2	Site 3
5/10/2010								1154		1435	1445	1506	1732	1740	1745
5/11/2010								1223		1510	1546	1556	1812	1841	1850
5/12/2010								1317		1620	1632	1640	1858	1919	1927
5/13/2010	0656	0708	0727	1034	1047	1056	1355	1404	1412	1651	1709	1716			
5/14/2010	0714	0743	0802	1050	1108	1119	1420	1438	1448	1750	1802	1813			

	July Recording Schedule (hhmm) (24-hour clock)													
	High tide			Slack/High tide	Ebb tide			Low tide			Slack/Low tide	Flood tide		
Date	Site 1	Site 2	Site 3	Site 2	Site 1	Site 2	Site 3	Site 1	Site 2	Site 3	Site 2	Site 1	Site 2	Site 3
7/12/2010												1740	1755	1807
7/13/2010	0832	0843	0854	0935	1215	1228	1239	1541	1604	1612		1824	1840	1852
7/14/2010	0915	0932	0942	1023	1313	1336	1355	1636	1647	1655	1702	1910	1935	1945
7/15/2010	1016	1026	1036	1110	1354	1404	1423	1712	1723	1732	1749	2019	2035	2044
7/16/2010	1100	1109	1120	1155	1440	1451	1504	1803	1808	1817	1837		2110	

Table 3. Comparisons of ambient noise levels recorded at the proposed KAC construction site during May and July 2010 by sampling site and tidal cycle.

	Site 1		**Site 2**		**Site 3**		**Flood tide**		**High tide**		**Ebb tide**		**Low tide**	
	n	**Mean Rank**	***n***	**Mean Rank**	***n***	**Mean Rank**	***n***	**Mean Rank**	***n***	**Mean Rank**	***n***	**Mean Rank**	***n***	**Mean Rank**
July	16	19.75	17	21.65	15	20.93	13	19.54	12	20.08	12	12.25	12	11.92
May	14	10.64	17	13.35	14	8.64	15	10.13	15	9.13	6	4.00	9	9.78
X^2		7.996		5.904		15.091		9.114		12.696		9.563		0.612
df		1		1		1		1		1		1		1
Significance		0.005		0.015		0.000		0.003		0.000		0.002		0.434
Significant Difference		Yes		Yes		Yes		Yes		Yes		Yes		No

Table 4. Ambient noise levels recorded at the proposed KAC construction site during May and July 2010.

May

Sound level	Site 1 (*n*=14) (dB re 1 µPa)	Site 2 (*n*=17) (dB re 1 µPa)	Site 3 (*n*=14) (dB re 1 µPa)	Overall (*n*=45) (dB re 1 µPa)
Mean	122 (s.d.=10.2)	126 (s.d.=10.8)	122 (s.d.=9.1)	124 (s.d.=10.0)
Minimum	108	113	105	105
Maximum	145	148	134	148

July

Sound level	Site 1 (*n*=16) (dB re 1 µPa)	Site 2 (*n*=18) (dB re 1 µPa)	Site 3 (*n*=15) (dB re 1 µPa)	Overall (*n*=49) (dB re 1 µPa)
Mean	134 (s.d.=8.7)	134 (s.d.=7.4)	138 (s.d.=7.3)	136 (s.d.=7.9)
Minimum	116	118	122	116
Maximum	144	142	147	147

Table 5. Ambient noise levels recorded at the proposed KAC construction site during tidal cycles.

May

Sound level	Ebb tide (*n*=6) (dB re 1 μ Pa)	Low tide (*n*=9) (dB re 1 μ Pa)	Flood tide (*n*=15) (dB re 1 μ Pa)	High tide (*n*=15) (dB re 1 μ Pa)
Mean	115 (s.d.=5.1)	132 (s.d.=9.0)	124 (s.d.=8.0)	122 (s.d.=11.0)
Minimum	108	122	113	105
Maximum	120	148	142	145

July

Sound level	Ebb tide (*n*=12) (dB re 1 μ Pa)	Low tide (*n*=12) (dB re 1 μ Pa)	Flood tide (*n*=13) (dB re 1 μ Pa)	High tide (*n*=12) (dB re 1 μ Pa)
Mean	135 (s.d.=7.6)	136 (s.d.=10.2)	135 (s.d.=6.3)	139 (s.d.=7.2)
Minimum	116	118	121	119
Maximum	142	146	144	147

Table 6. Maximum sound pressure levels recorded in Knik Arm for various noise sources (anthropogenic and natural).

Source	Maximum sound pressure level (dB re 1 µPa)
U.S. Coast Guard RHIB	128
Inboard work boat (Terra Surveys, LLC's vessel, *SeaDucer*)	145
U.S. Air Force F-22 fighter jet	129
Mouth of Eagle River	116 (May) 129 (July)
Port MacKenzie rip-rap construction	133
Clamshell and suction dredges at Port of Anchorage	148
Clamshell dredge at Port of Anchorage	136
Clamshell dredge, spoils dumping	140

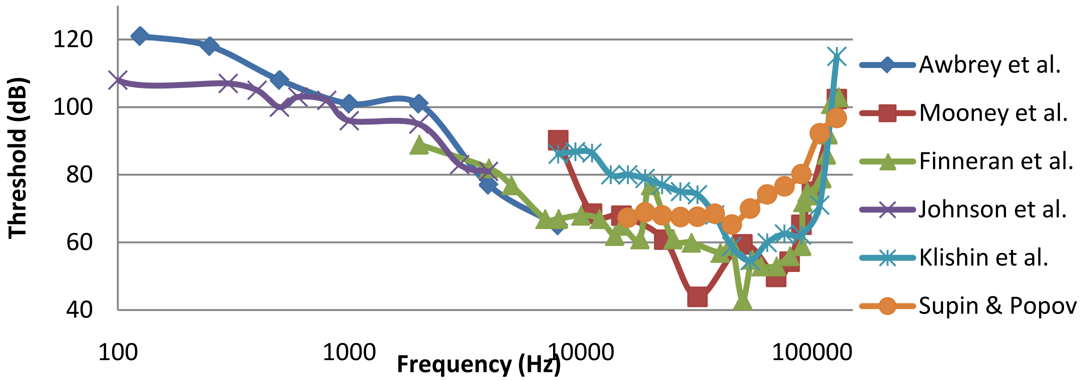


Figure 1. Beluga whale audiograms.

Sources: Johnson (1989), Awbrey et al. (1988) (behavioral), Mooney et al. (2008) (AEP), Klishin et al. (2000), Finneran et al. (2006), and Supin and Popov (2009).

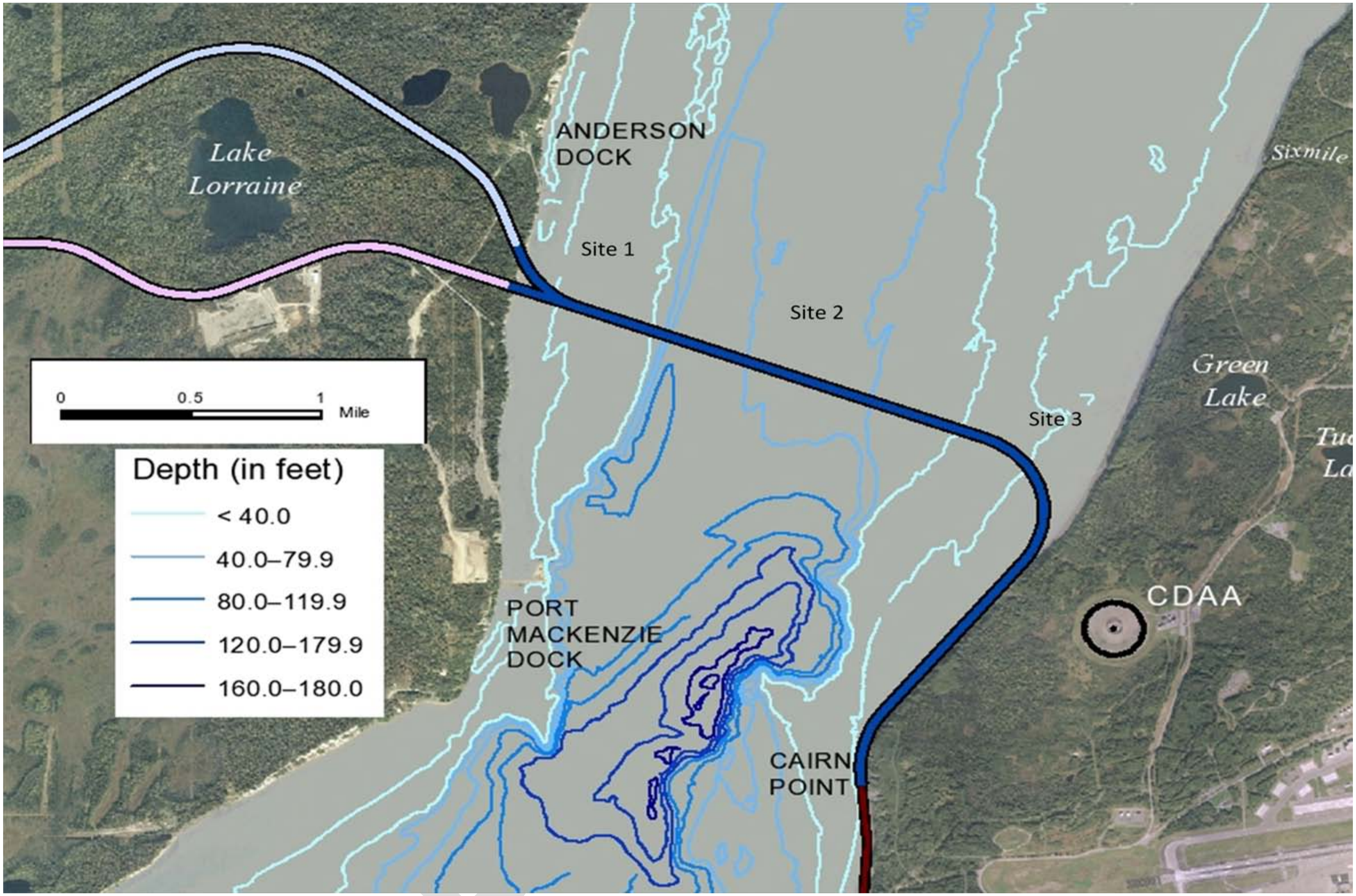


Figure 2. Bathymetry of the proposed KAC construction site.
The wide blue line represents the proposed bridge and approach causeways. Sampling Sites 1-3 are shown.

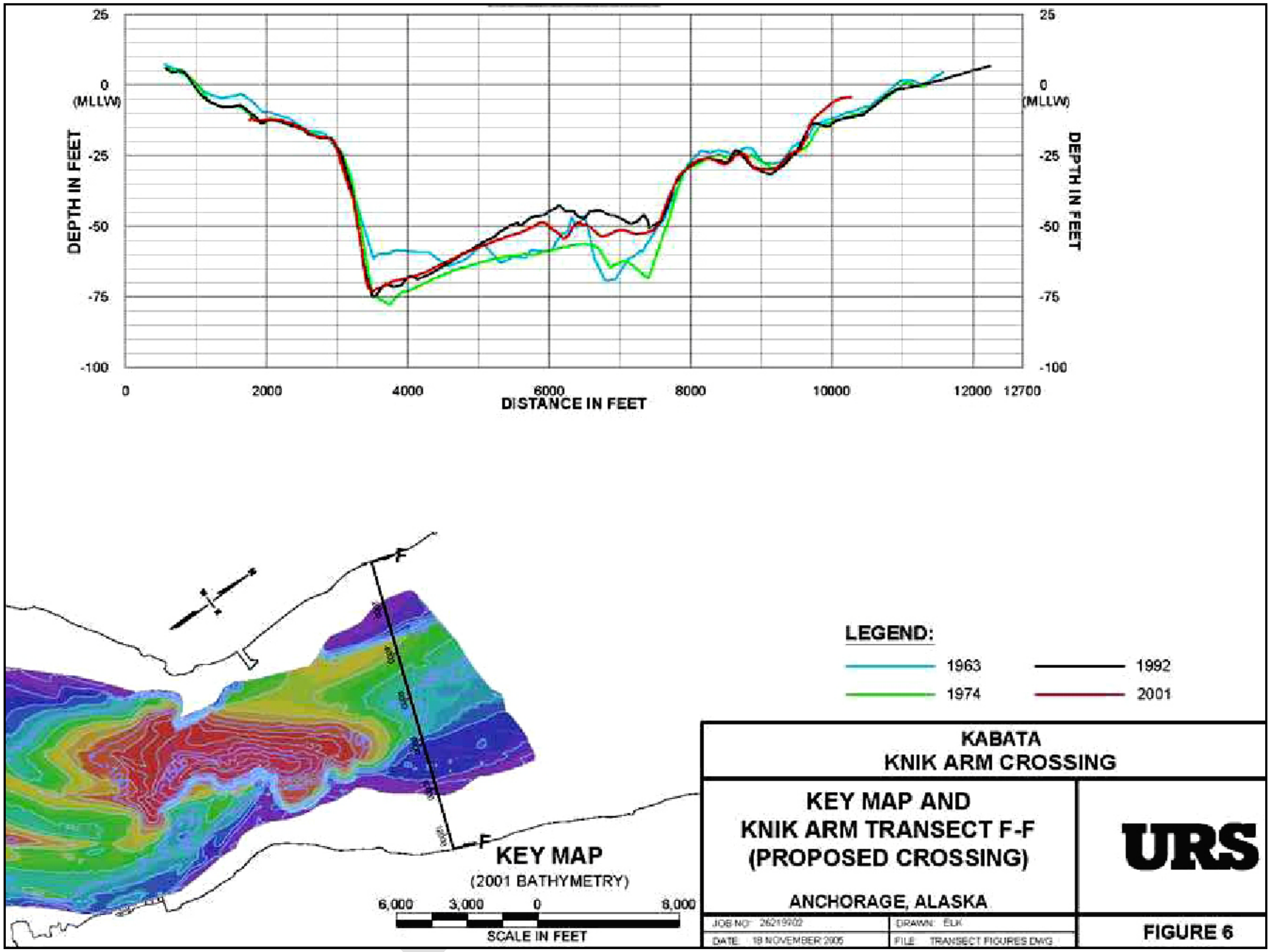


Figure 3. Cross section of the proposed Knik Arm Crossing relative to bathymetry.

Source: URS 2005.

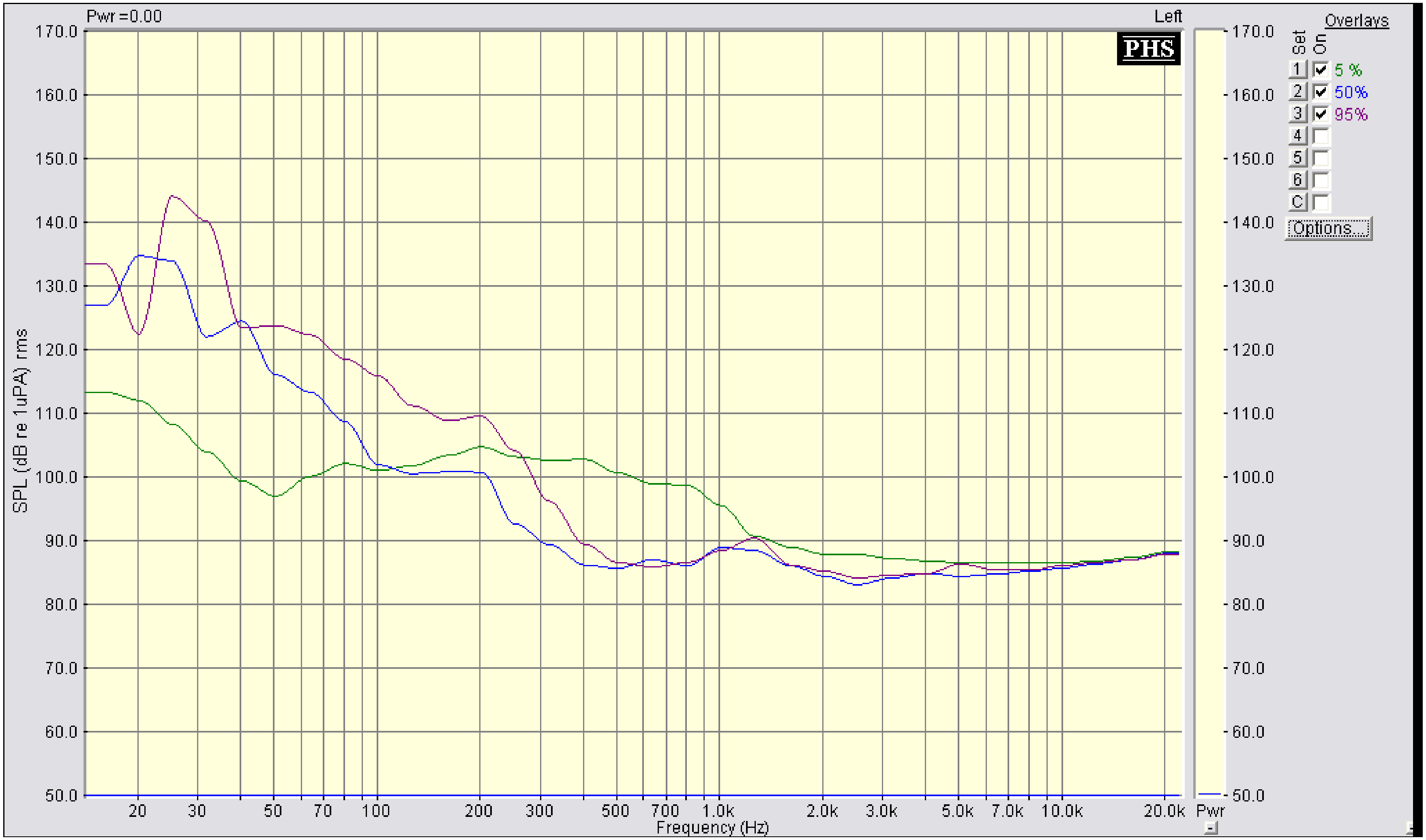
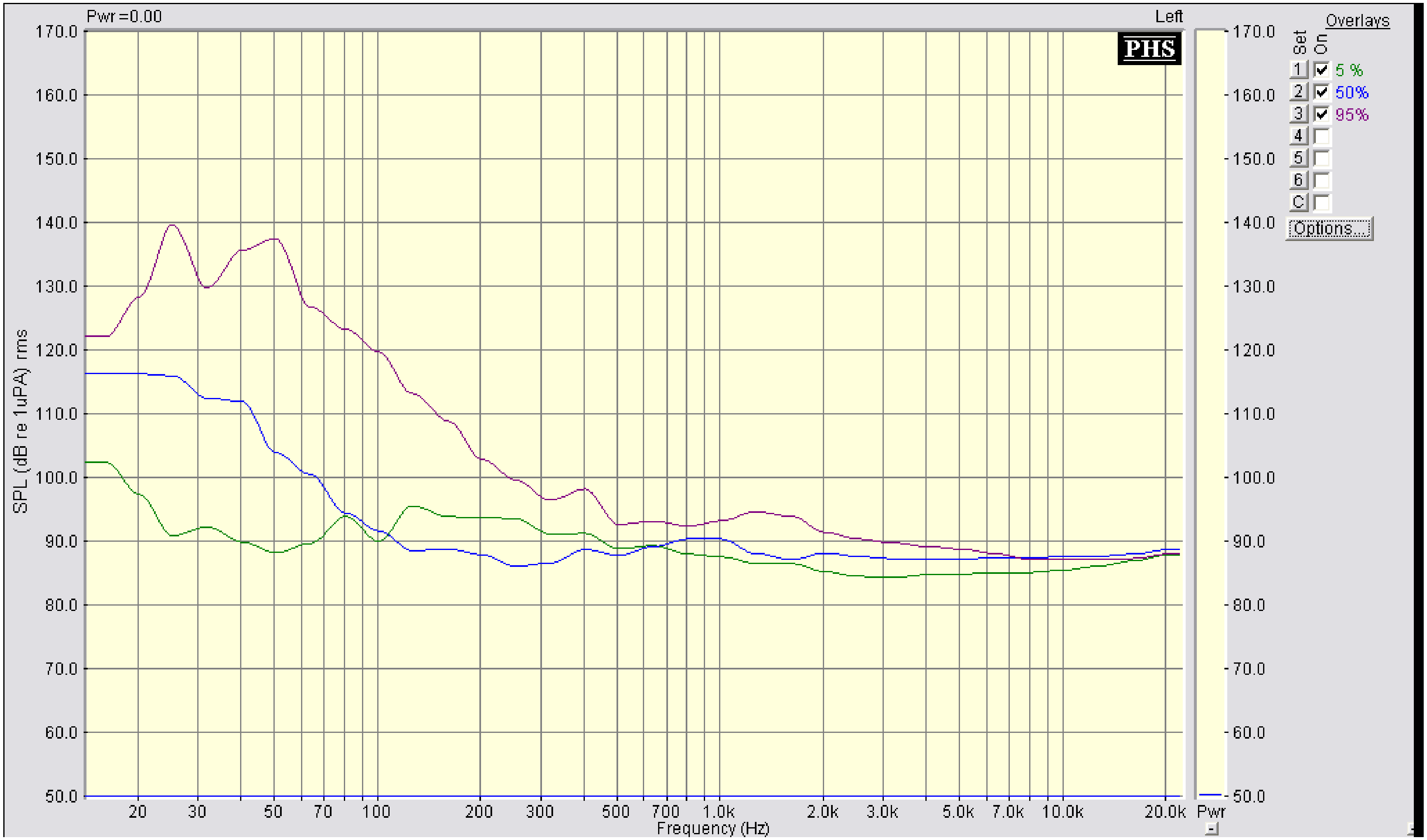


Figure 4a. Sound spectrum of the 5th (green), 50th (blue), and 95th (purple) percentiles for ambient noise recordings made at the proposed KAC construction site during May 2010.



1 ☑ 5 %
2 ☑ 50%
3 ☑ 95%
4 ☐
5 ☐
6 ☐
C ☐

Figure 4b. Sound spectrum of the 5th (green), 50th (blue), and 95th (purple) percentiles for ambient noise recordings made at the proposed KAC construction site during July 2010.

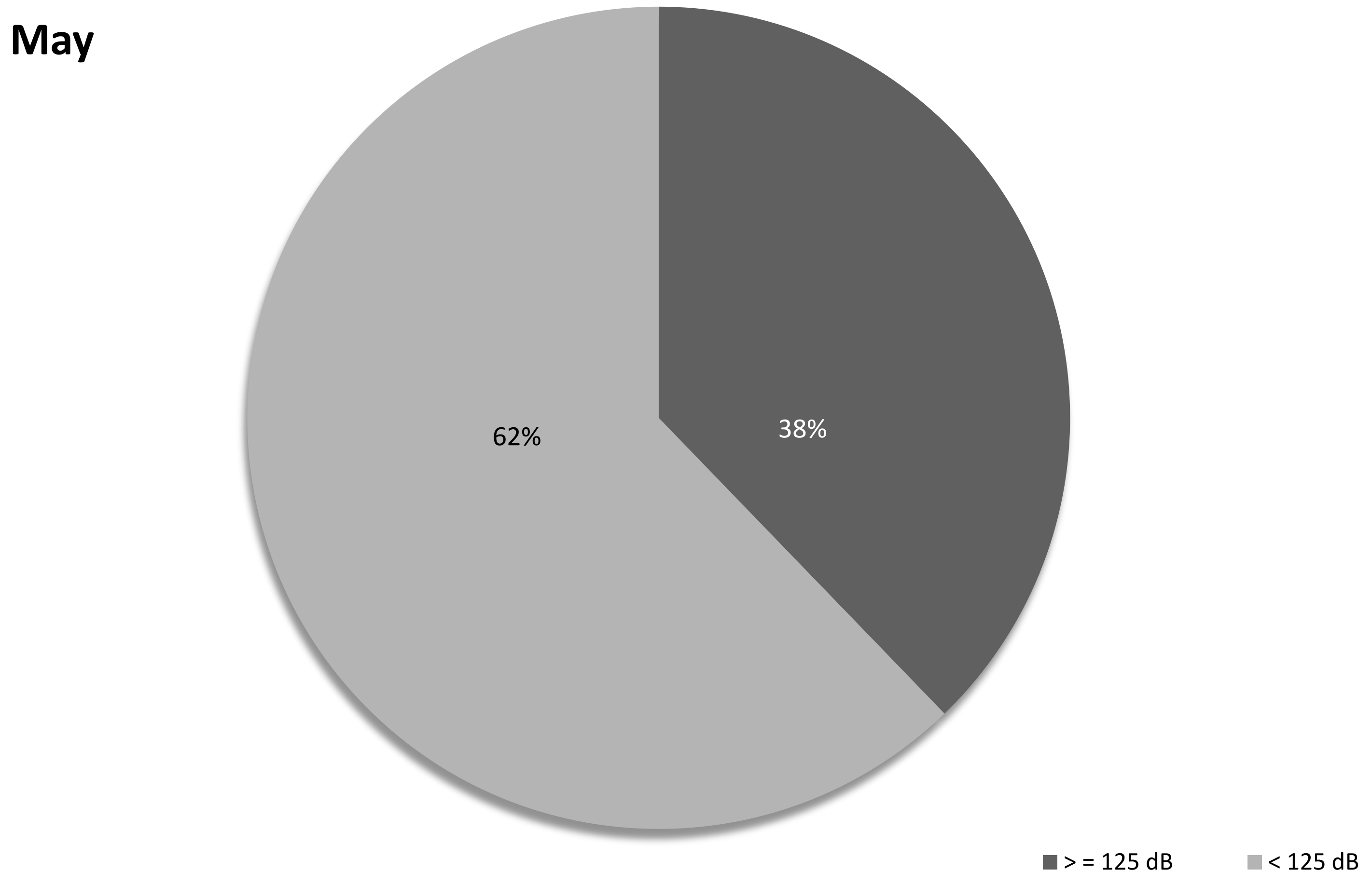


Figure 5a. Percentage of May 2010 recordings made at the proposed KAC construction site (*n*=45) relative to 125 dB.

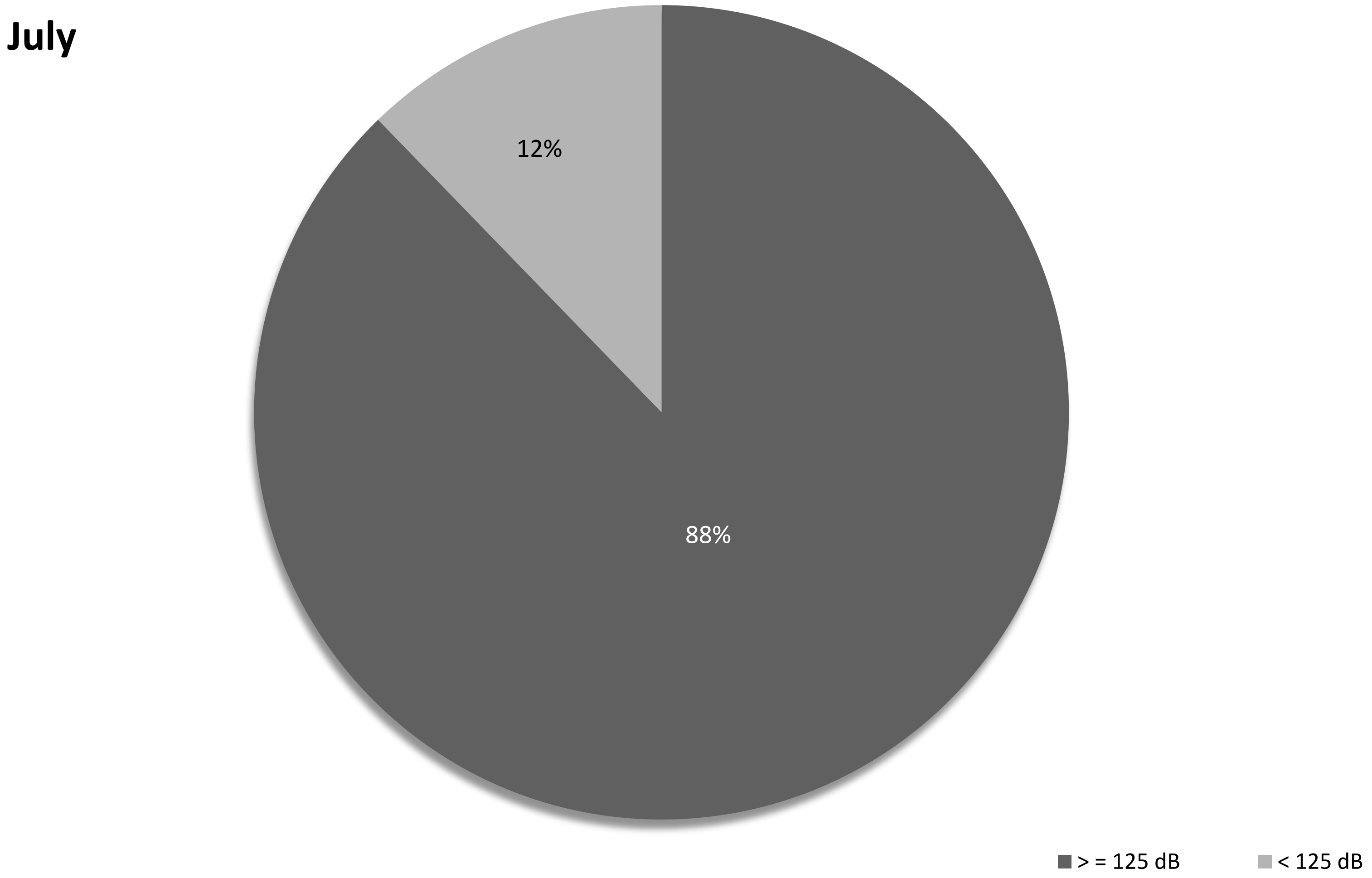


Figure 5b. Percentage of July 2010 recordings made at the proposed KAC construction site (*n*=49) relative to 125 dB.

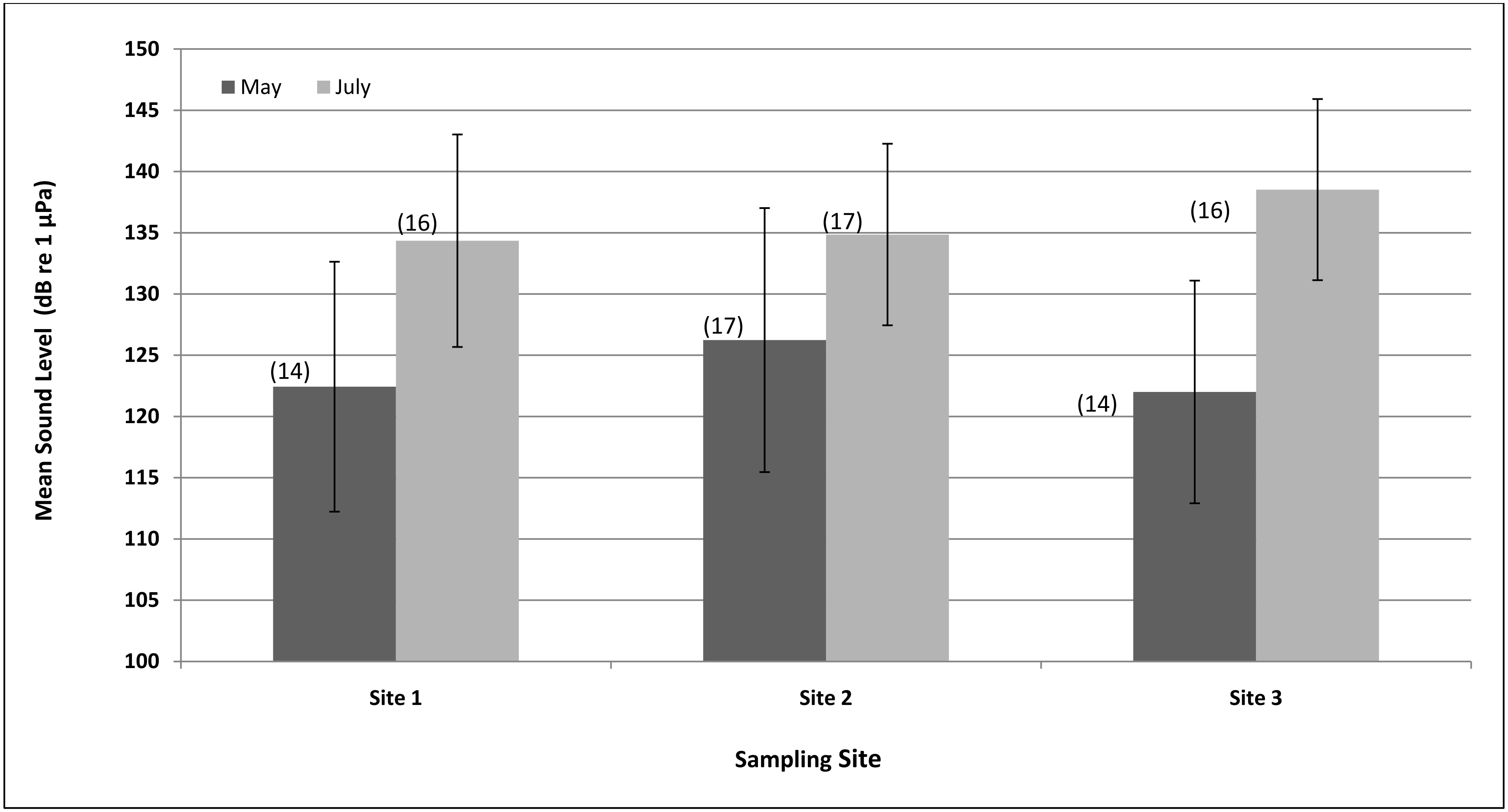


Figure 6. Mean ambient noise levels measured for each sampling site during May (*n*=45) and July (*n*=49) 2010, regardless of tidal cycle. Sample sizes are in parentheses.

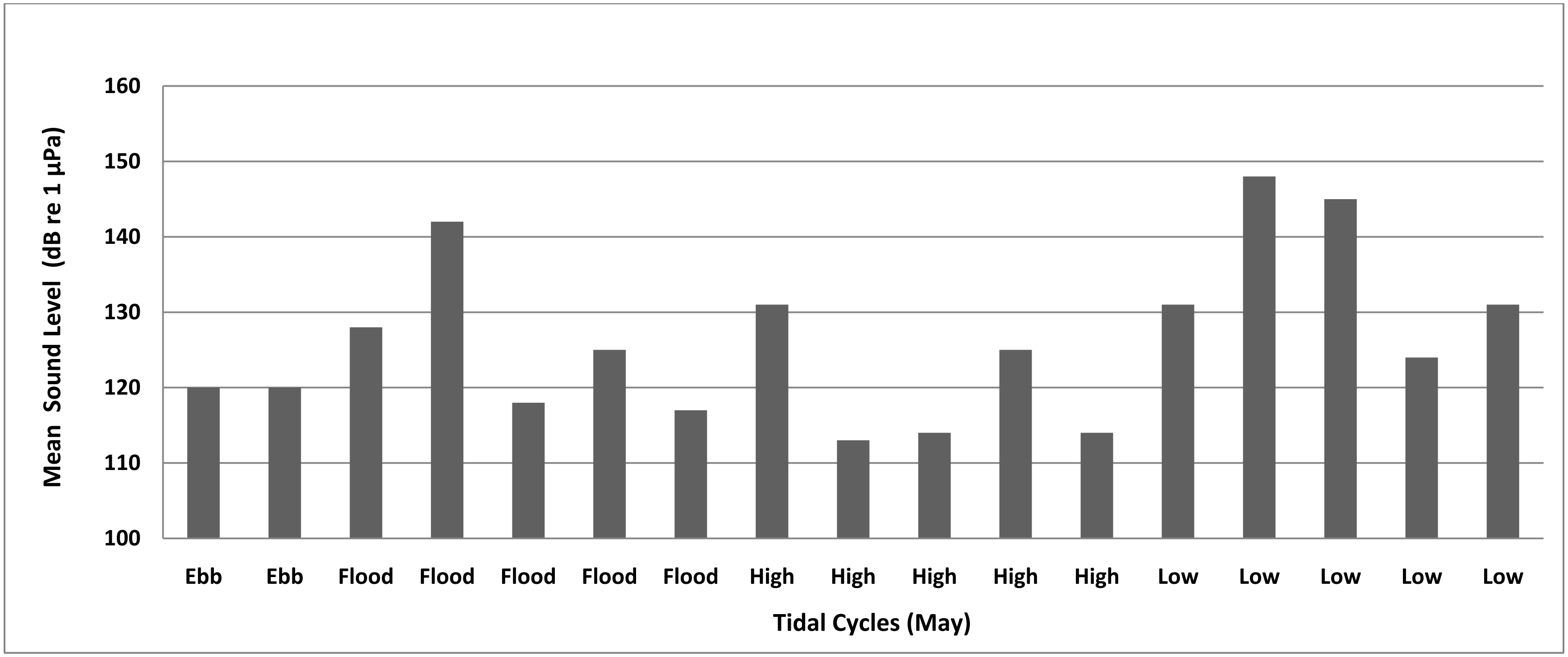


Figure 7. Variability in mean ambient noise levels measured at Site 2 for all tidal cycles during May 2010.

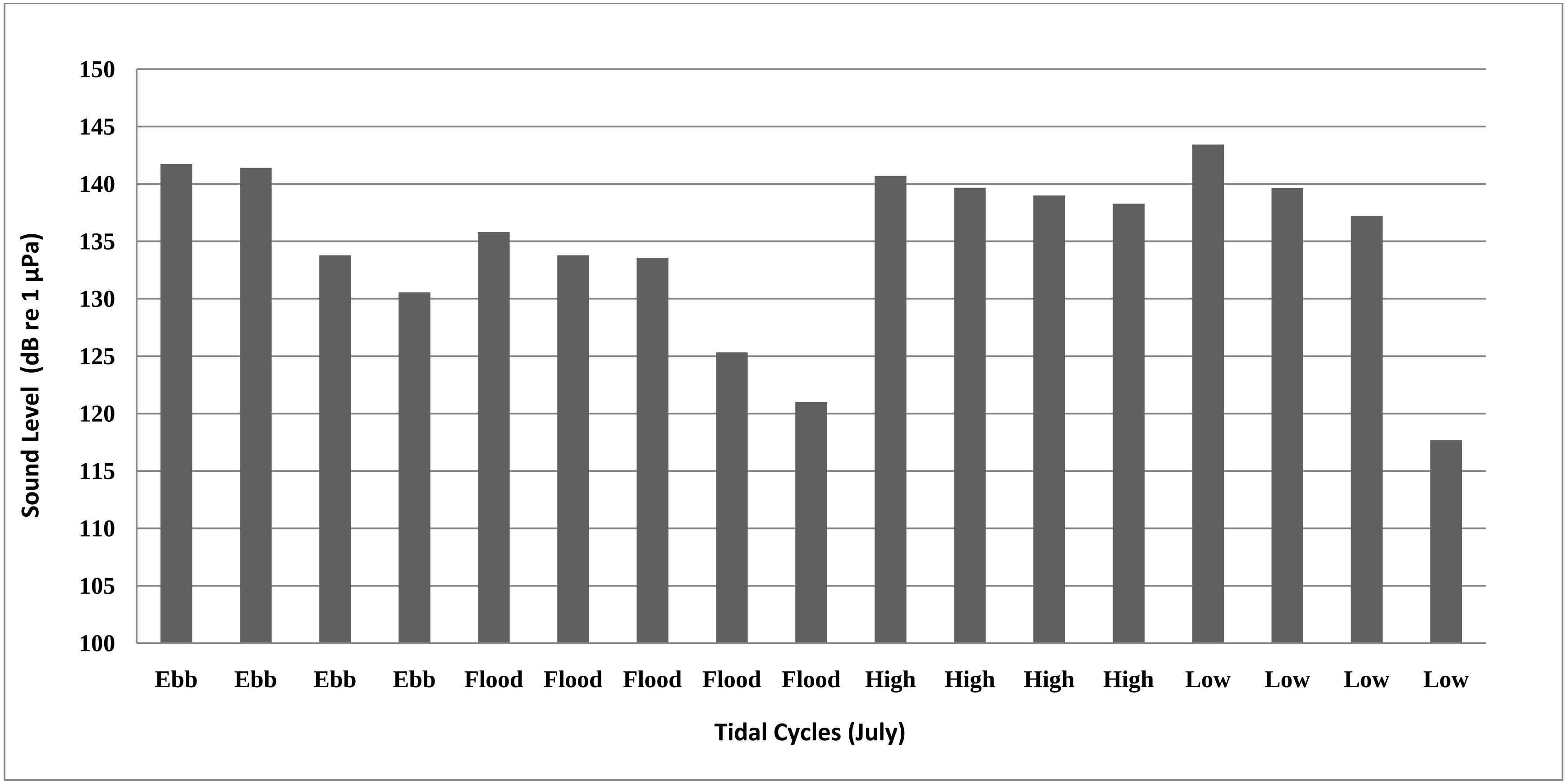


Figure 8. Variability in mean ambient noise levels measured at Site 2 for all tidal cycles during July 2010.

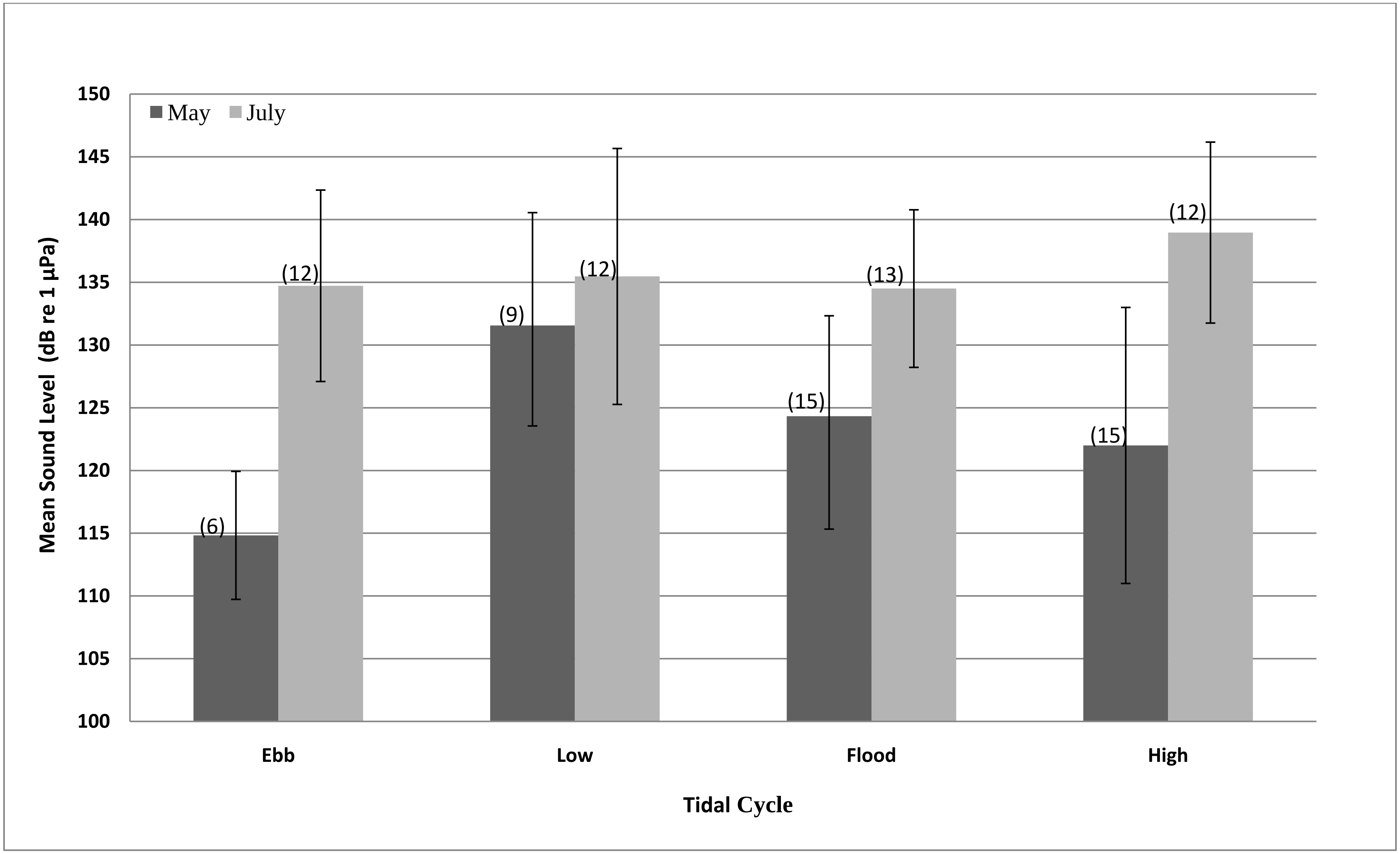


Figure 9. Mean ambient noise levels measured for each tidal cycle during May and July 2010 independent of sampling location. Sample sizes are in parentheses.

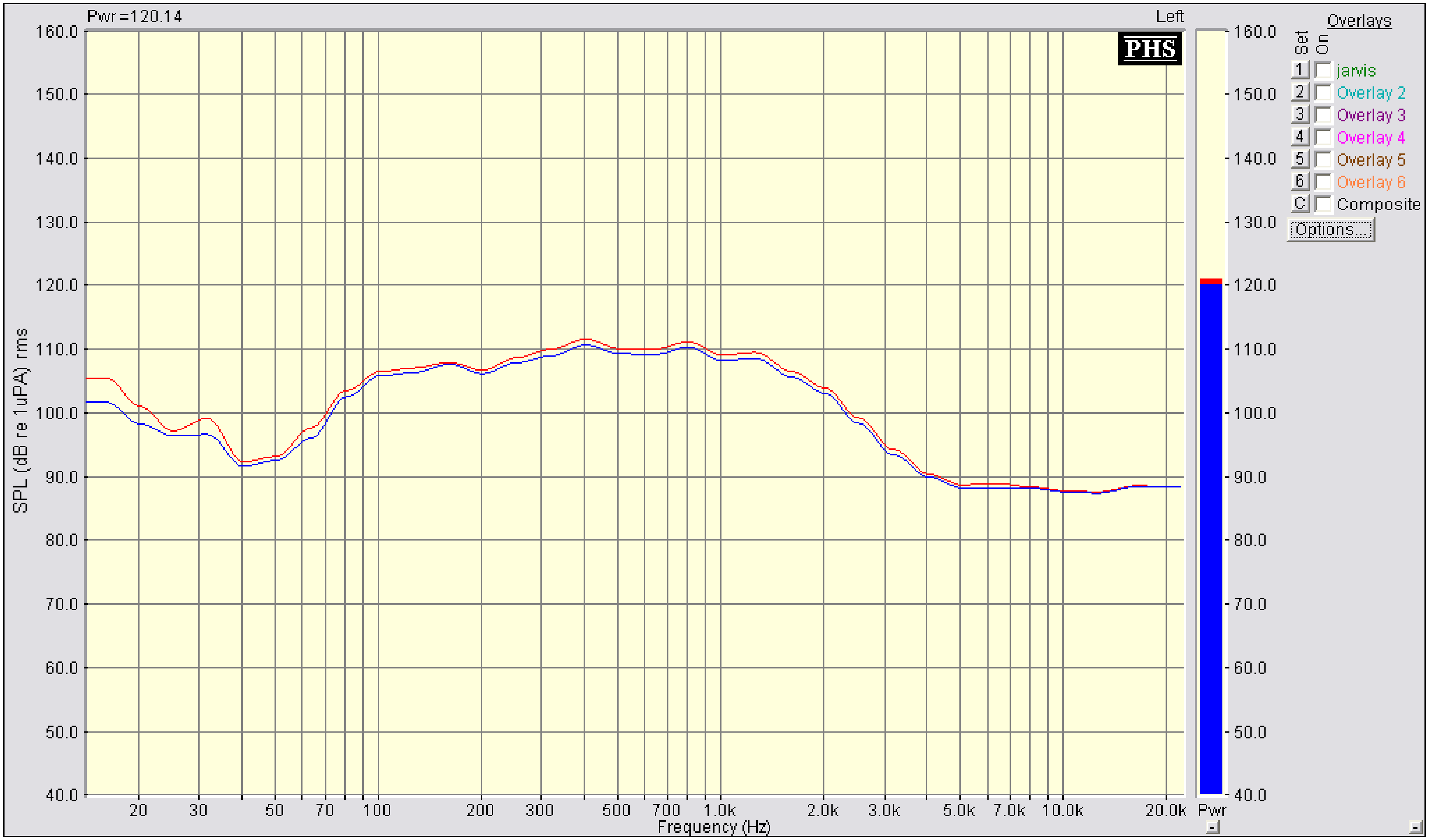


Figure 10. Sound spectrum of in-water noise from an overflight of a U.S. Air Force F-22 fighter near Elmendorf Air Force Base.

This is a 1/3 octave spectrum illustrating amplitude (dB re 1 µPa) as a function of frequency (Hz). The red line indicates the peak hold for that segment of the signal, while the blue line indicates the 1/3 octave level. The overall total power for this segment is 120.14 dB re 1 µPa.

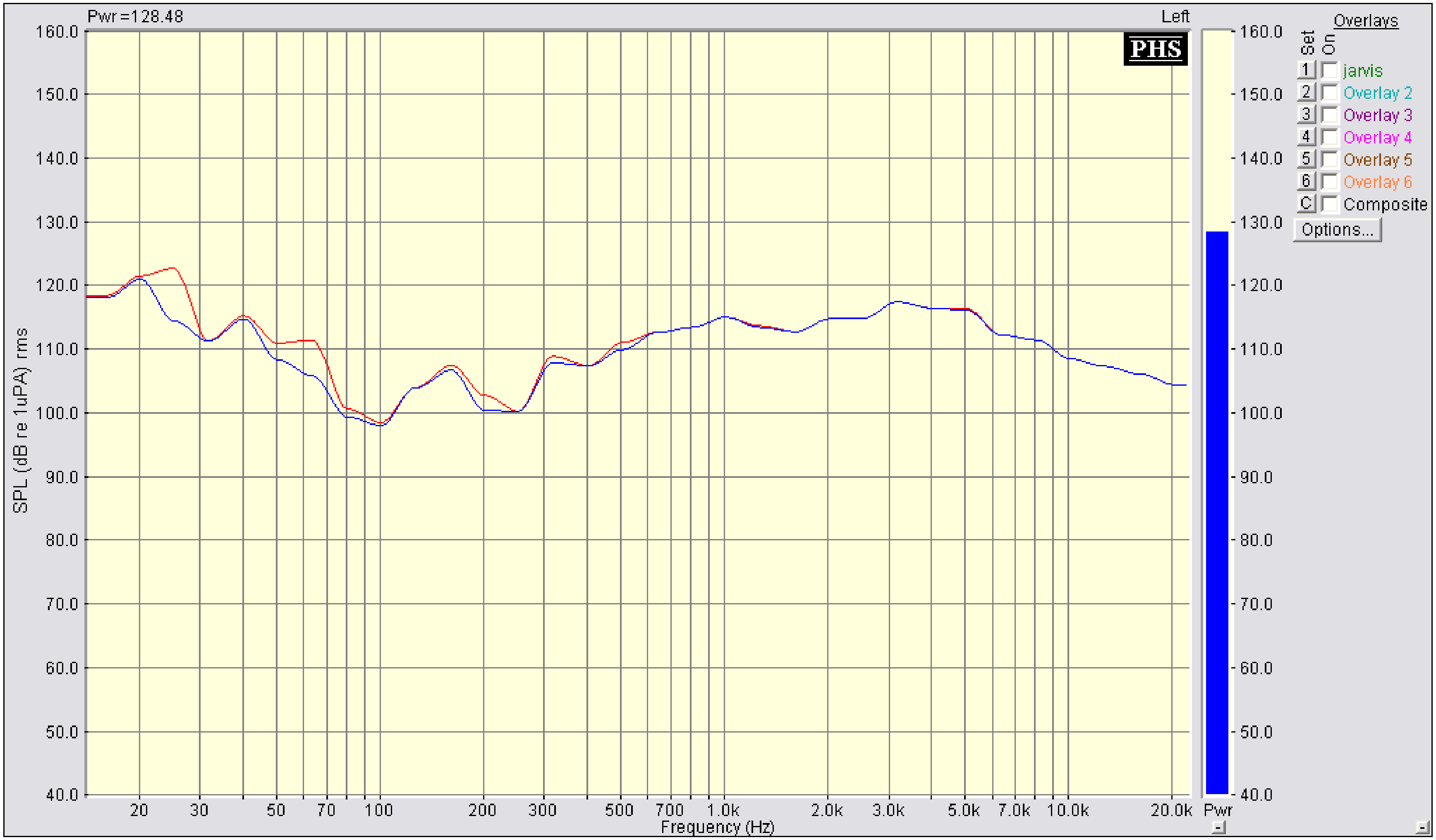


Figure 11. Sound spectrum of a drive-by of two U.S. Coast Guard RHIBs using outboard engines.

This is a 1/3 octave spectrum illustrating amplitude (dB re 1 µPa) as a function of frequency (Hz). The red line indicates the peak hold for that segment of the signal while the blue line indicates the 1/3 octave level. The overall total power for this segment is 128.48 dB re 1 µPa.

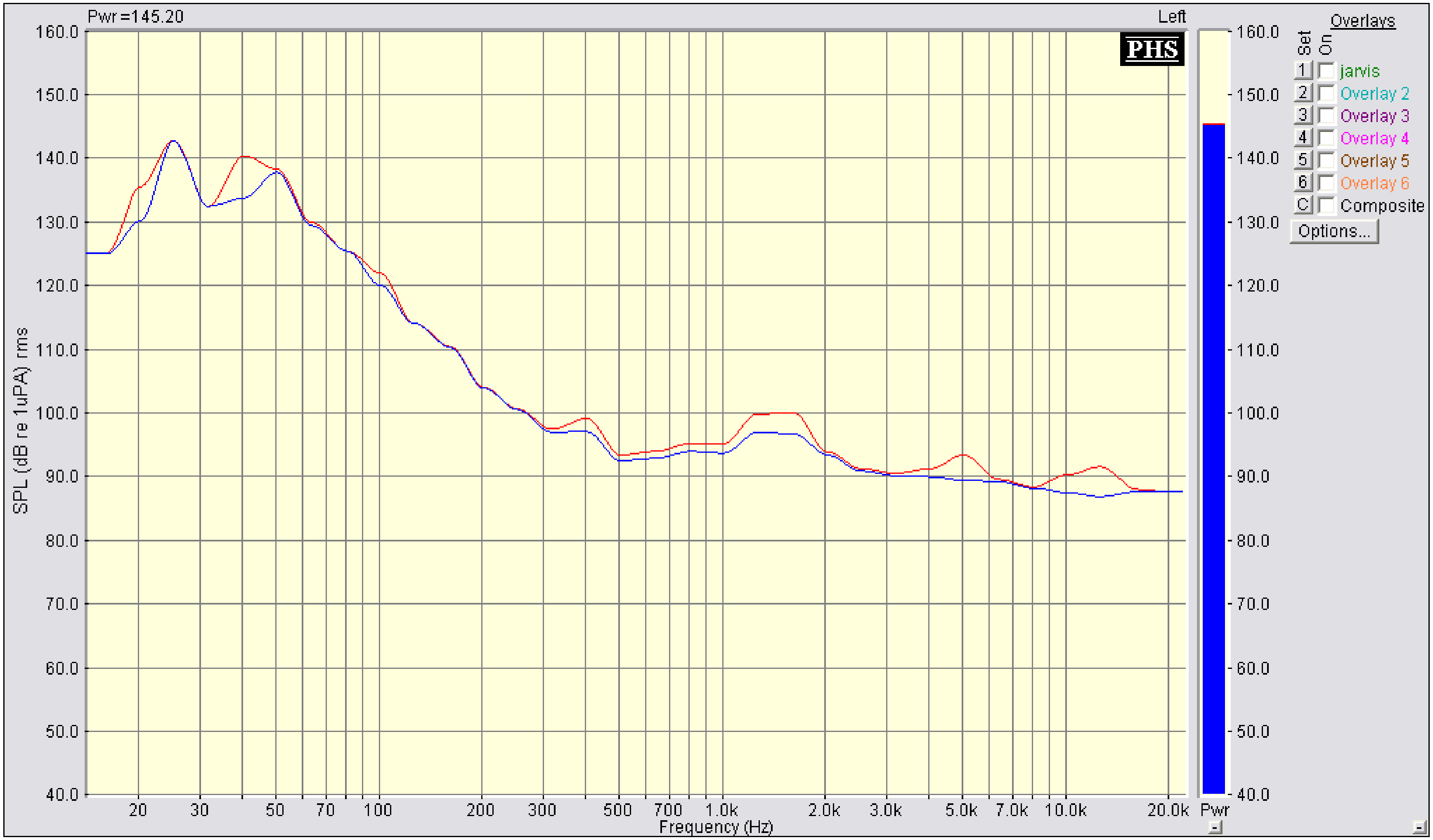


Figure 12a. Sound spectrum of a dredge recorded at Site 1.

This is a 1/3 octave spectrum illustrating amplitude (dB re 1 µPa) as a function of frequency (Hz). The red line indicates the peak hold for that segment of the signal while the blue line indicates the 1/3 octave level. The overall total power for this segment is145.20 dB re 1 µPa. The dredge was recorded from a distance of 3.2 nautical miles.

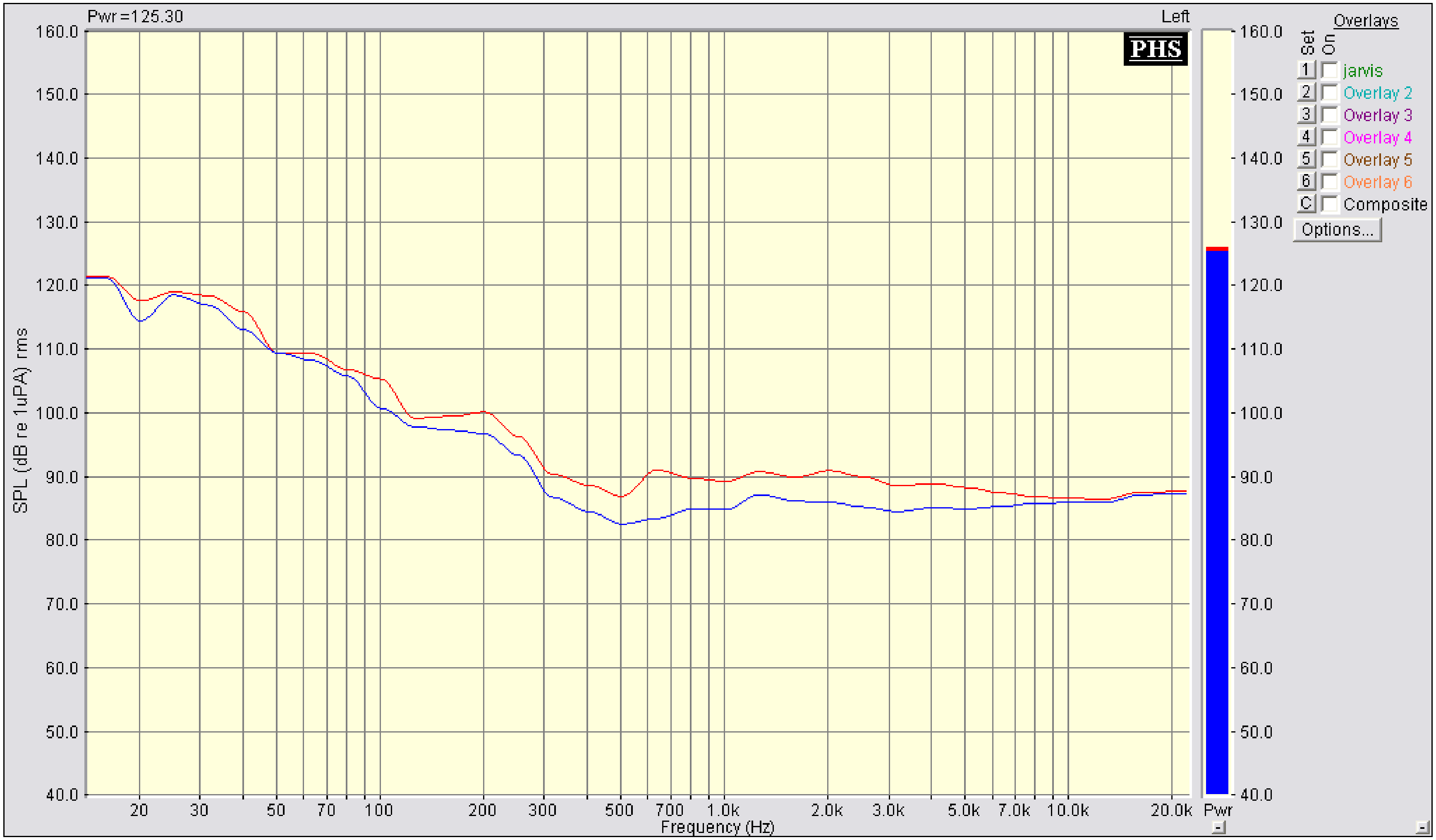


Figure 12 b. Sound spectrum of a dredge recorded at Site 3.
This is a 1/3 octave spectrum illustrating amplitude (dB re 1 µPa) as a function of frequency (Hz). The red line indicates the peak hold for that segment of the signal while the blue line indicates the 1/3 octave level. The overall total power for this segment is 125.30 dB re 1 µPa. The dredge was recorded from a distance of 2.5 nautical miles.

Figure 13. Suction dredge operating at the Port of Anchorage.

Figure 14. Turbulent conditions encountered during tidal cycle changes.

Figure 15. Example of multiple noise sources operating concurrently near the Port of Anchorage, which contribute to ambient noise conditions of Knik Arm.

Figure 16. On-land construction activities at Port MacKenzie during July 2010.

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