DOLPHIN PILE RESET

Edmonds – Kingston: Vibratory Driving Monitoring of a Dolphin Pile Reset Operation

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October 2017

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ACRONYMS AND ABBREVIATIONS

dB	decibel
Hz	hertz
μPa	micro-Pascal
NIST	National Institute of Standards and Technology
Pa	Pascal
RMS	root mean squared
s.d.	standard deviation
SEL	Sound Exposure Level
cSEL	Cumulative Sound Exposure Level
SL	sound level, regardless of descriptor
SPL	sound pressure level
SR	State Route
USFWS	U.S. Fish and Wildlife Service
WSF	Washington State Ferries
WSDOT	Washington State Department of Transportation

EXECUTIVE SUMMARY

This technical report describes the results of underwater sound level monitoring conducted during the vibratory resetting/driving of existing 36-inch diameter steel dolphin piles during a pile reset operation at both the Edmonds and Kingston ferry terminals on July 25 and 20, 2017 respectively. The goal of these measurements were to determine if the pile reset operation is quieter than typical vibratory pile driving. All measurements were collected at 10 meters from the pile at midwater depth.

The values measured at Kingston were generally lower than those measured at Edmonds (Table 1). Also, the results from a similar pile vibratory driven at Colman dock were between the values of the two reset piles. Due to the variability in the results it is difficult to say that the pile reset operation is substantially different from typical vibratory pile driving and the variability could be explained by differences in substrate and vibratory hammer operators.

Table 1: Summary of 36-inch Hollow Steel Piles Vibratory Reset Underwater Sound Levels.

Pile #	Terminal	Cutoff Frequency (Hz)	RMS L_{50} (dB)	SEL L_{50} (dB)	Peak L_{50} (dB)	Cumulative SEL (dB)
1	Kingston	Broadband	150	160	159	184
		7	149	159	157	184
		50	145	155	154	183
		60	144	154	153	182
		150	133	143	146	181
		275	131	141	145	181
2	Edmonds	Broadband	184	194	191	216
		7	184	194	190	215
		50	179	189	185	210
		60	174	184	181	205
		150	155	165	168	187
		275	151	161	165	183

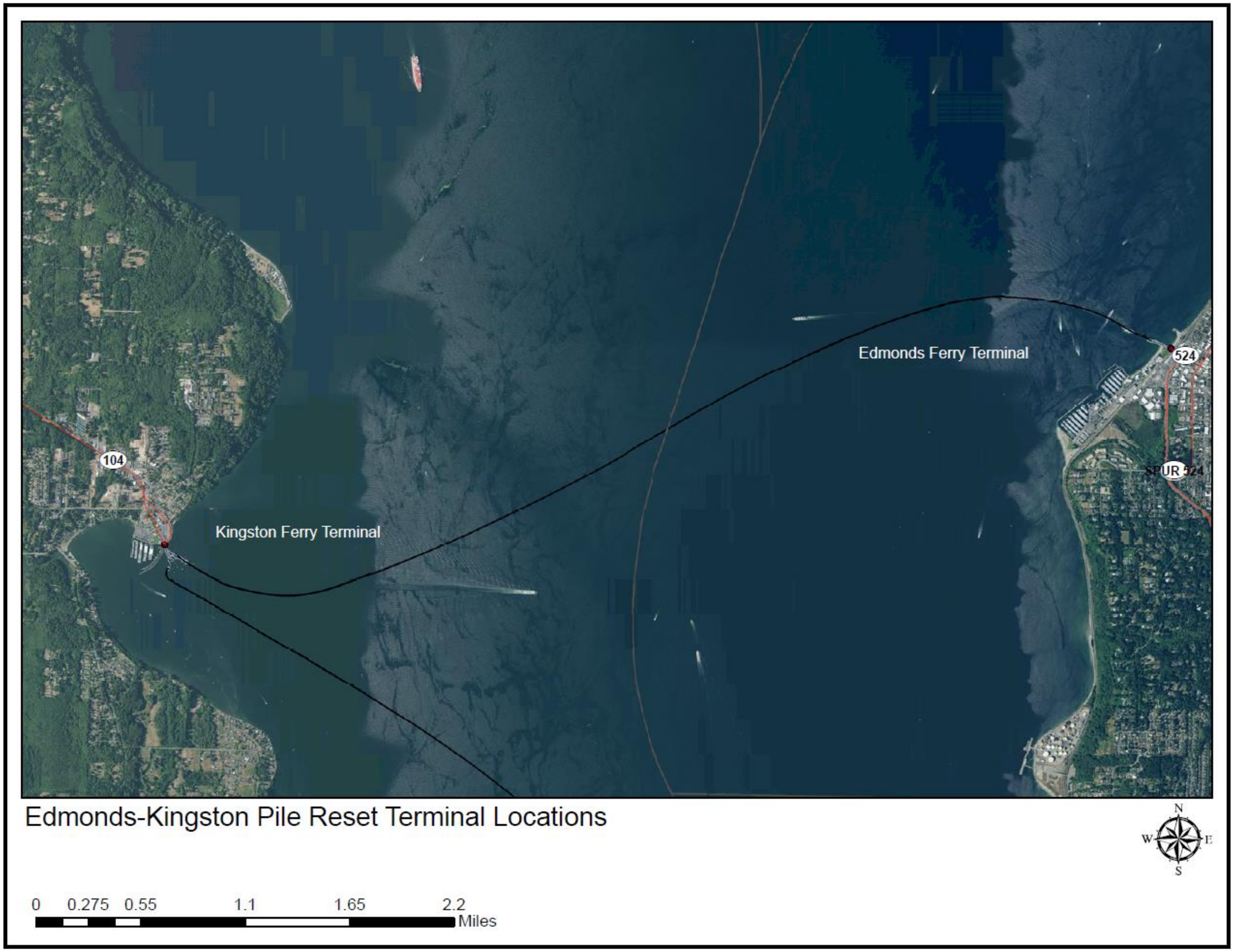
INTRODUCTION

This technical report presents the results of underwater noise monitoring conducted during the resetting of 36-inch diameter hollow steel piles for an existing dolphin structure at both the Edmonds and Kingston ferry terminals on September 25 and 20, 2017 respectively. The piles are part of an existing dolphin that were pushed out of the plumb vertical position by repeated vessel contact. This project pulled the out of plumb pile(s) up a few feet using a vibratory hammer and then reset in the plumb position using the same vibratory hammer. This study was to determine whether this resetting operation is quieter than typical vibratory driving of similar steel piles.

Project Location

The Edmonds ferry terminal is located in the city of Edmonds just north of Seattle (Figure 1). It is the western terminus of State Route 104 (SR 104) before it crosses Puget Sound to Kitsap County via the Washington State Ferry system. The Kingston ferry terminal is located in Kitsap County at the eastern terminus of SR 104 before it crosses Puget Sound back to Edmonds (Figure 1).

Figure 1: Edmonds and Kingston Ferry Terminal Locations



Project Description

Piles driven to support dolphins at ferry terminals on occasion are pushed out of plumb by a ferry vessel pushing against them while at the terminal. As part of regular terminal maintenance these piles must be partially extracted with a vibratory hammer and then reset in a plumb position. In July of 2017, Quick Response Research funding was approved to conduct a quick study to determine whether this pile reset activity is quieter than typical vibratory driving of a steel pile. One pile at the Edmonds ferry terminal and one pile at the Kingston ferry terminal were monitored for underwater noise during the reset activity.

Monitoring Locations

All underwater noise monitoring was conducted on 36-inch steel dolphin piles (Figures 2 and 3).

Figure 2: ***The location of the Edmonds monitored pile***

Figure 3: ***The location of the Kingston monitored pile***

CHARACTERISTICS OF UNDERWATER SOUND

Several descriptors are used to describe underwater noise impacts. Two common descriptors are the instantaneous peak sound pressure level (SPL) and the Root Mean Square (RMS) pressure level during the impulse. The majority of literature uses SPL to evaluate barotrauma injury to fish, whereas Cumulative Sound Exposure Level (cSEL) and RMS is used by the National Marine Fisheries Service (NMFS) in criteria for judging effects to marine mammals from underwater continuous and impulse-type sounds.

The peak SPL is the instantaneous maximum or minimum overpressure observed during each pulse and can be presented in Pascale (Pa) or decibels (dB) referenced to a pressure of 1 micro Pascal (μPa). Since water and air are two distinctly different media, a different sound level reference pressure is used for each. In water, the most commonly used reference pressure is 1 μPa whereas the reference pressure for air is 20 μPa. The equation to calculate the sound pressure level is:

Sound Pressure Level (SPL) = 20 log (p/p_{ref})*, where* p_{ref} *is the reference pressure (i.e., 1 μPa for water)* (eq. 1)

The RMS level is the square root of the energy divided by the impulse duration. This level, presented in dB re: 1 μPa, is the mean square pressure level of the pulse. Except where otherwise noted, sound levels reported in this report are expressed in dB re: 1 μPa.

Sound Exposure Level (SEL) is a measure of the total energy that an individual is exposed to over a given time period. For vibratory pile driving sound levels underwater the SEL is calculated for each individual 10-second interval using the RMS and the pulse duration over which the RMS is calculated (10-seconds). Then the SEL for each 10-second interval is accumulated for each pile drive and for all piles driven during a 24-hour period to determine the Cumulative SEL (cSEL). The injury thresholds for marine mammals, fish and marbeled murrelets are a cSEL threshold.

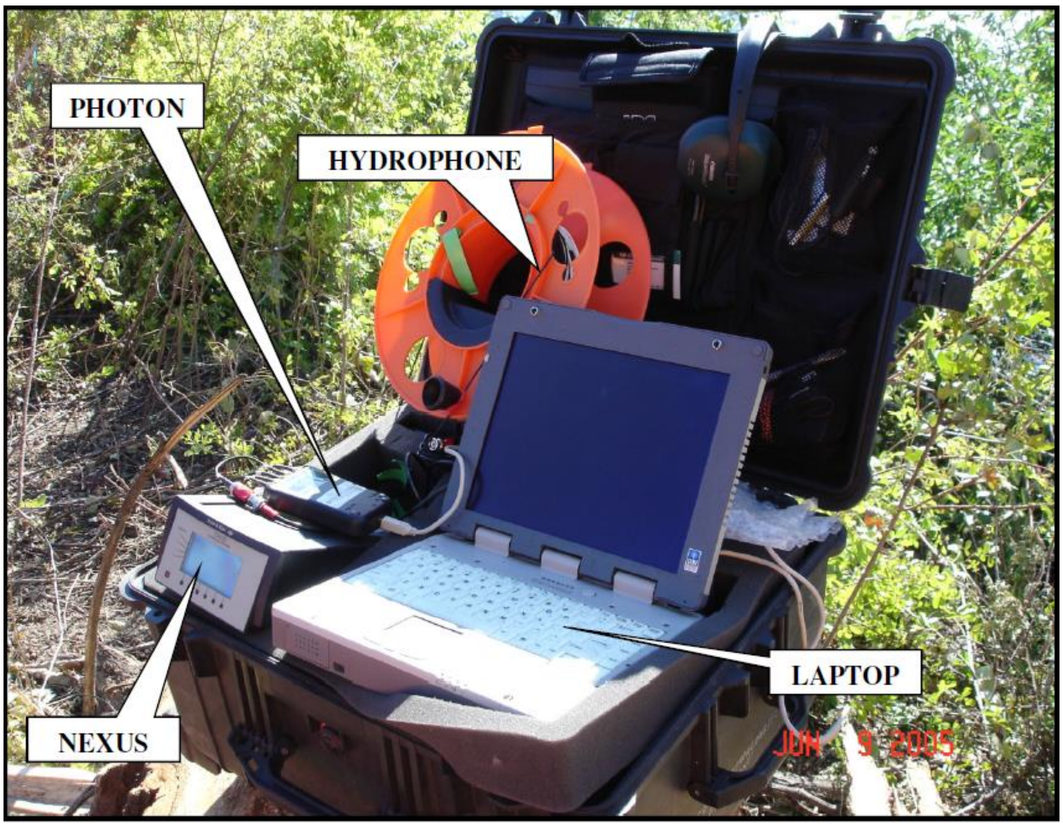
METHODOLOGY

Typical Equipment Deployment

Underwater sound levels were measured near the piles using a Reson TC 4013 hydrophone deployed on a weighted nylon cord from the monitoring location. The hydrophone was deployed from crane barge near the piles being reset and positioned at a distance of 10 meters and at mid-water depth (17 feet at each terminal). The hydrophone was fixed in position with anchors and a surface float. The measurement system also includes a Bruel and Kjaer Nexus type 2692 4-channel signal conditioner, which kept the high underwater sound levels within the dynamic range of the signal analyzer. The output of the Nexus signal conditioner is received by a Bruel and Kjaer Photon 4-channel signal spectrum analyzer that is attached to a Dell ATG laptop computer.

The monitoring equipment is outlined below and shown in Figure 4.

Figure 4*: Near Field Acoustical Monitoring Equipment*



The equipment captures underwater sound levels from the pile driving operations in the format of an RTPro signal file for processing later. The system and software calibration is checked annually against the NIST traceable standard.

Hydroacoustic Data Analysis

The signal received by the Photon signal analyzer is stored as a proprietary digital signal file format. Data for the entire duration of each pile drive is captured and recorded in this manner. The peak sound pressure levels in units of Pascals are displayed on the screen during monitoring.

Signal analysis software provided with the Photon was set at a sampling rate of one sample every 20.8 μs (18,750 Hz). This sampling rate provides sufficient resolution to catch the peaks and other relevant data. The anti-aliasing filter included in the Photon also allows the capture of the true peak.

Due to the variability of the recording, an L_{50} peak and RMS value is computed to give an indication of the median value for each pile. The L_{50} or 50^{th} percentile is a statistical measure of the median value over the measurement period where 50 percent of the measured values are above the L_{50} and 50 percent are below.

Post analysis of the raw recordings were analyzed using Matlab software. The RMS was calculated for each 10-second interval. The SEL was calculated for each 10-second interval using the following equation, where τ is the time interval over which the RMS value is calculated (10 seconds):

$$SEL_{90\%} = RMS + 10\ LOG\ (\tau) \qquad \text{(eq. 3)}$$

From these results the cumulative SEL (cSEL) was calculated by accumulating each of these values for each pile and each day.

In addition, the raw data was filtered using a 6^{th} order high pass Butterworth filter in Matlab with cutoff frequencies of 7 Hz, 50 Hz, 60 Hz, 150 Hz and 275 Hz which correspond to the lower frequencies of the hearing ranges of the different marine mammal functional hearing groups described in NMFS (2016). The above calculations for RMS, SEL and cSEL were then repeated for each filtered dataset.

A Power Spectral Density plot was created using Matlab to show the differences in frequency composition between the different pile locations and operations.

The results are compared to the typical values for vibratory driving a 36-inch steel pile at Colman Dock in 2017.

RESULTS

Underwater Sound Levels

WSDOT monitored a total of 2, 36-inch hollow steel piles for underwater noise. Data from all piles are presented in Table 2 below.

The vibratory resetting of the pile at Kingston was generally quieter than the pile at Edmonds. On average the values were approximately 17 dB to 36 dB quieter for the pile at Kingston. The drive at Edmonds was also approximately 15 minutes longer than at Kingston which in addition to the higher overall sound levels at least in part resulted in higher cSEL values at Edmonds (Table2).

The analysis separated out the initial part of resetting the pile, which was pulling up on or extracting the pile, from the latter part of the drive, which was pushing/resetting the pile into the substrate (Table 2). The data indicates that the extraction phase was the louder of the two phases at Kingston and at Edmonds they were roughly equal with resetting phase being only slightly louder. This could be the result of differences in the substrates at the two locations or differences in how the vibratory hammer was operated at each location.

Table 3 shows a comparison of the two pile reset results with recent measurements of a 36-inch steel pile being driven with a vibratory hammer at Colman Dock. The results indicate that the sound levels from the Colman Dock pile are approximately in between the two piles at Edmonds and Kingston.

Figure 5 is a Power Spectral Density plot of the two piles at Edmonds and Kingston as well as for the pile at Colman Dock. The plot shows that the frequency distribution and associated sound levels for each frequency follow the same general trend for all three piles. The plot for Edmonds shows higher sound levels in general and the plot for Colman Dock is roughly the same with slightly lower sound levels. The plot for Kingston has lower sound levels than the other two.

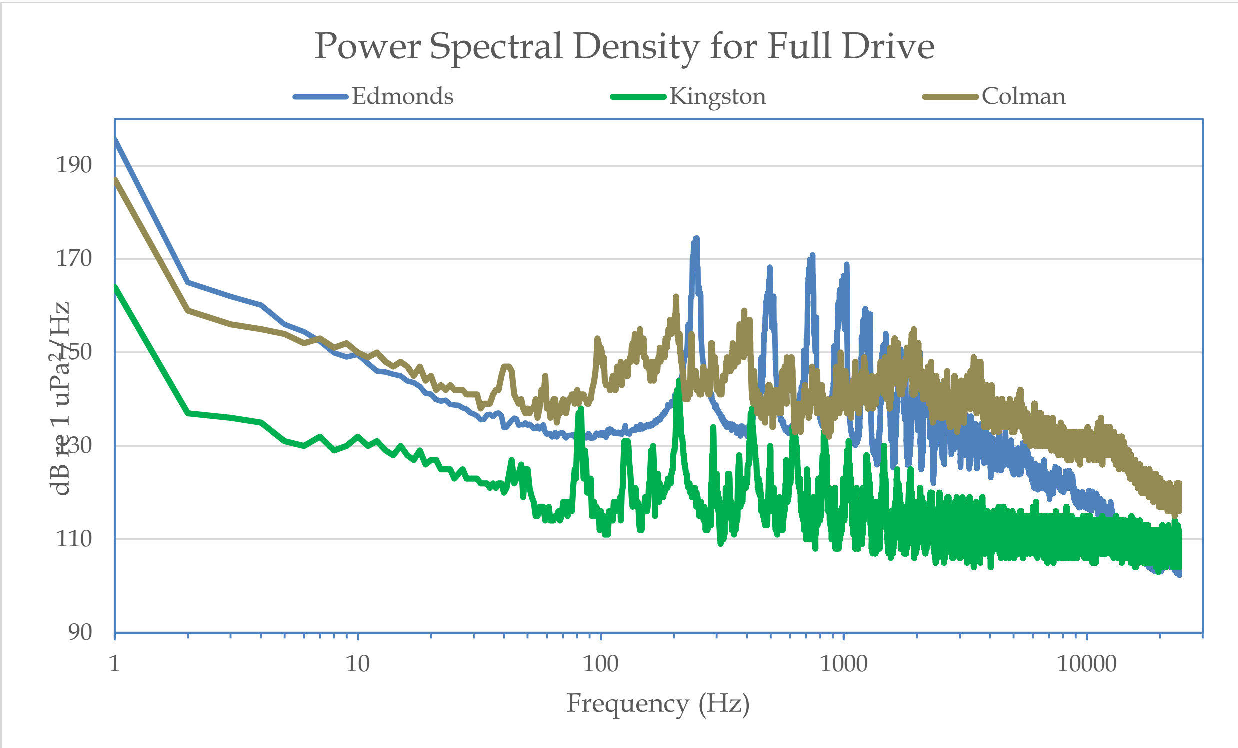
Table 2: Summary of Underwater Sound Levels for the Edmonds and Kingston Pile Reset

			Extraction				Reset				Full			
Pile #	Terminal	Cutoff Frequency	RMS L_{50} (dB)	SEL L_{50} (dB)	Peak L_{50} (dB)	Cumulative SEL (dB)	RMS L_{50} (dB)	SEL L_{50} (dB)	Peak L_{50} (dB)	Cumulative SEL (dB)	RMS L_{50} (dB)	SEL L_{50} (dB)	Peak L_{50} (dB)	Cumulative SEL (dB)
1	Kingston	Broadband	163	173	182	179	149	159	159	182	150	160	159	184
		7	163	173	182	179	149	159	157	182	149	159	157	184
		50	162	172	182	179	145	155	154	180	145	155	154	183
		60	162	172	181	179	143	153	153	179	144	154	153	182
		150	162	172	182	179	133	143	146	177	133	143	146	181
		275	162	172	181	178	131	141	145	177	131	141	145	181
2	Edmonds	Broadband	180	190	186	207	185	195	191	213	184	194	191	216
		7	180	190	185	207	185	195	191	213	184	194	190	215
		50	177	187	183	204	180	190	186	208	179	189	185	210
		60	173	183	180	199	174	184	181	202	174	184	181	205
		150	155	165	167	181	154	164	167	183	155	165	168	187
		275	150	160	164	177	151	161	165	180	151	161	165	183

Table 3: Comparison of Underwater Sound Levels for a Pile Reset and Typical Vibratory Driving 36-inch Steel Piles

	Edmonds				Kingston				Colman			
Cutoff Frequency	RMS L_{50} (dB)	SEL L_{50} (dB)	Peak L_{50} (dB)	Cumulative SEL (dB)	RMS L_{50} (dB)	SEL L_{50} (dB)	Peak L_{50} (dB)	Cumulative SEL (dB)	RMS L_{50} (dB)	SEL L_{50} (dB)	Peak L_{50} (dB)	Cumulative SEL (dB)
Broadband	184	194	191	216	150	160	159	184	176	186	187	202
7	184	194	190	215	149	159	157	184	176	186	186	202
50	179	189	185	210	145	155	154	183	172	182	185	198
60	174	184	181	205	144	154	153	182	172	182	185	198
150	155	165	168	187	133	143	146	181	172	182	184	197
275	151	161	165	183	131	141	145	181	166	176	181	192

Figure 5*: Power Spectral Density Plot for the Entire Pile Reset at Edmonds, Kingston and Colman Terminals*



Daily Cumulative SEL

The daily cSEL's were calculated using an actual individual SEL value calculated for every 10 seconds of each pile for each day and accumulated over that period (Table 4).

Table 4: Summary of daily cumulative SEL's

Day	Cumulative SEL
7/25/2017	216
7/20/2017	184

SUMMARY

A total of 2, 36-inch hollow steel piles were monitored during the pile reset activity at Edmonds and Kingston ferry terminals and were compared to a typical 36-inch vibratory pile drive at Colman Dock. The underwater sound levels analyzed are as follows:

- Peak underwater 50th percentile (L_{50}) sound levels at 10 meters varied in a range between 159 dB and 191 dB for the two reset piles at Kingston and Edmonds.
- The L50 RMS levels ranged between 150 dB_{RMS} and 184 dB_{RMS} for the reset piles.
- Cumulative Sound Exposure Levels (cSEL) for the two reset piles ranged between 216 dB_{cSEL} and 184 dB_{cSEL}.
- The Colman Dock pile, for comparison, had sound levels that were more similar to the Edmonds pile but in general was approximately between the two reset piles.
- While the Kingston pile was generally quieter than the Edmonds or Colman piles it is difficult to say whether this difference is due to substrate conditions or vibratory hammer operator differences.

REFERENCES

National Marine Fisheries Service. 2016. Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing: Underwater Acoustic Thresholds for Onset of Permanent and Temporary Threshold Shifts. U.S. Dept. of Commer., NOAA. NOAA Technical Memorandum NMFS-OPR-55, 178 p.