APPENDIX D

NOISE ANALYSIS

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1.0 INTRODUCTION

Bioacoustics, or the study of how sound affects living organisms, is a complex and interdisciplinary field that includes the physics of sound production and propagation, the source characteristics of sounds, and the perceptual capabilities of receivers. This Appendix is intended to introduce the reader to the basics of sound measurements and sound propagation.

Sound is an oscillation in pressure, particle displacement, or particle velocity, as well as the auditory sensation evoked by these oscillations, although not all sound waves evoke an auditory sensation (i.e., they are outside of an animal's hearing range) (Acoustical Society of America 1994). Sound may be described in terms of both physical and subjective attributes. Physical attributes may be directly measured. Subjective (or sensory) attributes cannot be directly measured and require a listener to make a judgment about the sound. Physical attributes of a sound at a particular point are obtained by measuring pressure changes as sound waves pass. The following material provides a short description of some of the basic parameters of sound.

Sound can be characterized by several factors, including frequency, intensity, and pressure (Richardson et al. 1995). Sound frequency (measured in hertz [Hz]) and intensity (amount of energy in a signal [watts per meter^2]) are physical properties of the sound which are related to the subjective qualities of pitch and loudness (Kinsler et al. 1999). Sound intensity and sound pressure (measured in pascals [Pa]) are also related; of the two, sound pressure is easier to measure directly, and is therefore more commonly used to evaluate the amount of disturbance to the medium caused by a sound ("amplitude").

Because of the wide range of pressures and intensities encountered during measurements of sound, a logarithmic scale known as the decibel (dB) is used to evaluate these properties; in acoustics, "level" indicates a sound measurement in decibels. The dB scale expresses the logarithmic strength of a signal (pressure or intensity) relative to a reference value of the same units. This document reports sound levels with respect to sound pressure only. Each increase of 20 dB reflects a ten-fold increase in signal pressure. In other words, an increase of 20 dB means ten times the pressure, 40 dB means one hundred times the pressure, 60 dB means one thousand times the pressure, and so on.

The sound levels in this document are given as sound pressure levels (SPLs). For measurements of underwater sound, the standard reference pressure is 1 micropascal (µPa, or 10^{-6} pascals), and is expressed as "dB re 1 µPa." For airborne sounds, the reference value is 20 µPa, expressed as "dB re 20 µPa." Sound levels measured in air and water are not directly comparable, and it is important to note which reference value is associated with a given sound level.

Airborne sounds are commonly referenced to human hearing using a method which weights sound frequencies according to measures of human perception, de-emphasizing very low and very high frequencies which are not perceived well by humans. This is called A-weighting, and the decibel level measured is called the A-weighted sound level (dBA). A similar method has been proposed for evaluating underwater sound levels with respect to marine mammal hearing. While preliminary weighting functions for marine mammal hearing have been developed (Southall et al. 2007; National Marine Fisheries Service [NMFS] 2013), they are not yet applied to sound exposure from pile driving activities. Therefore, underwater sound levels given in this document are not weighted and evaluate all frequencies equally.

Table D–1 summarizes common acoustic terminology. Two of the most common descriptors are the instantaneous peak SPL and the root mean square (RMS) SPL. The peak SPL is the instantaneous maximum or minimum over- or under-pressure observed during each sound event and is presented in dB re 1 µPa peak. The root mean square level is the square root of the energy divided by a defined time period, given as dB re 1 µPa RMS.

Table D–1. Definitions of Acoustical Terms

Term	Definition
Decibel [dB]	A unit describing the amplitude of sound, equal to 20 times the logarithm to the base 10 of the ratio of the pressure or intensity of the sound measured to the appropriate standard reference value. This document uses only sound pressure measurements to calculate decibel levels. The reference pressure for water is 1 micropascal (µPa) and for air is 20 µPa (approximate threshold of human audibility).
Sound Pressure Level [SPL]	Sound pressure is the force per unit area, usually expressed in micropascals (or 20 micro Newtons per square meter), where 1 Pascal is the pressure resulting from a force of 1 Newton exerted over an area of 1 square meter. Sound pressure level is the quantity that is directly measured by a sound level meter, and is expressed in decibels referenced to the appropriate air or water standard.
Frequency, Hz	Frequency is expressed in terms of oscillations, or cycles, per second. Cycles per second are commonly referred to as hertz (Hz). Typical human hearing ranges from 20 Hz to 20,000 Hz; hearing ranges in non-humans are widely variable and species specific.
Peak Sound Pressure (unweighted), dB re 1 µPa peak	The maximum absolute value of the instantaneous sound pressure expressed as dB re 1 µPa peak.
Root Mean Square [rms], dB re 1 µPa rms	The rms level is the square root of the pressure divided by a defined time period, expressed in decibels. For impulsive sounds, the rms has been defined as the average of the squared pressures over the time that comprise that portion of waveform containing 90 percent of the sound energy for one impact pile driving impulse. For non-impulsive sounds, rms energy represents the average of the squared pressures over the measurement period and is not limited by the 90 percent energy criterion. Expressed as dB re 1 µPa.
Sound Exposure Level [SEL], dB re 1 μPa^2 sec	Sound exposure level is a measure of energy. Specifically, it is the dB level of the time integral of the squared-instantaneous sound pressure, normalized to a 1-second period. It can be an extremely useful metric for assessing cumulative exposure because it enables sounds of differing duration to be compared in terms of total energy.
Waveforms, µPa over time	A graphical plot illustrating the time history of positive and negative sound pressure of individual pile strikes shown as a plot of µPa over time (i.e., seconds).
Frequency Spectra, dB over frequency range	A graphical plot illustrating the frequency content over a given frequency range. Bandwidth is generally defined as linear (narrowband) or logarithmic (broadband) and is stated in frequency (Hz).
A-Weighted Sound Level, dBA	A frequency-weighted measure used for airborne sounds only. A-weighting de-emphasizes the low and high-frequency components of a given sound in a manner similar to the frequency response of the human ear and correlates well with subjective human reactions to noise. A-weighted levels are referenced to 20 µPa unless otherwise noted.
Ambient Noise Level	The background noise level, which is a composite of sounds from all sources near and far. The normal or existing level of environmental noise at a given location, given in dB referenced to the appropriate pressure standard.

While the body of knowledge on the impacts of pile driving noise on marine and terrestrial species has expanded significantly in the past few years, monitoring and research are still needed to better gauge both the scope and intensity of these impacts. The Navy has enhanced its approach for the selection of appropriate proxy source levels, acoustic propagation modeling, and understanding the potential behavioral and physiological effects on marine mammals, fish, sea turtles, and birds. This progress is facilitated by dedicated acoustic monitoring during active installation and experience removing a wide variety pile sizes and materials. Further, new peer-reviewed and grey literature from monitoring and studies both in the U.S. and internationally is helping to inform the Navy's analysis of environmental effects during infrastructure upgrades. Scientific research and recent biological opinions from regulatory agencies have suggested that current guidelines and criteria for marine species behavioral and physiological impacts may warrant review and revision.

For the assessment of potential impacts associated with the LWI and SPE projects, the Navy has considered previous analyses for pile driving projects in Puget Sound and Hood Canal, as well as standards for similar projects around the country. These analyses and standards were combined with the best available science and literature, real-world requirements for construction activities, and opinions from regulatory agencies. The assessment and resulting conclusions included in this document reflect these factors.

2.0 SOUND VS. NOISE

Sound may be purposely created to convey information, communicate, or obtain information about the environment. Examples of such sounds are sonar pings, marine mammal vocalizations/echolocations, tones used in hearing experiments, and small sonobuoy explosions used for submarine detection.

Noise is undesired sound (Acoustical Society of America 1994). Whether a sound is noise depends on the receiver (i.e., the animal or system that detects the sound). For example, small explosives and sonar used to locate an enemy submarine produce *sound* that is useful to sailors engaged in anti-submarine warfare, but is likely to be considered undesirable *noise* by marine mammals. Sounds produced by military training and construction activities are considered noise because they represent possible energy inefficiency and increased detectability, which are undesirable.

Noise also refers to all sound sources that may interfere with detection of a desired sound and the combination of all of the sounds at a particular location (ambient noise).

3.0 DESCRIPTION OF NOISE SOURCES

3.1. EXISTING NOISE LEVELS

Ambient noise in the vicinity of the Land-Water Interface (LWI) / Service Pier Extension (SPE) project is a composite of sounds from natural sources, and typical recreational and enterprise activities such as boating, commercial and recreational fishing, and military ship traffic. Small powerboats generate peak narrow band SPLs of 150 to 165 dB at 3 feet (0.9 meter) in the 350 to 1,200 Hz region, with mean SPLs of 148 dB at 3 feet (0.9 meter) (Barlett and Wilson 2002).

Fishing vessels can generate peak spectral densities of 140 dB at 3 feet (0.9 meter) in the 250 to 1,000 Hz regime (Hildebrand 2004). Underwater sound from human activities includes ship traffic noise, use of sonar and echo sounders in commercial fishing to locate fish schools, industrial ship noise, and recreational boat use. Ship and small boat noise comes from propellers and other on-board mechanical equipment or fluid systems. Other sources of underwater noise at industrial waterfronts can come from cranes, generators, and electrical distribution facilities, as well as mechanized equipment operating on wharves or the adjacent shoreline.

In a study conducted in Haro Strait, San Juan Islands, data showed that the ambient half-hourly SPL ranged from 95 dB to 130 dB (Veirs and Veirs 2005), demonstrating the range over which localized human-generated noise can vary by specific locations and time periods. Carlson et al. (2005) measured the underwater baseline noise at Hood Canal Bridge and found that broadband (24 kilohertz [kHz] bandwidth) underwater noise levels ranged from 115 to 135 dB re 1 μPa. The Washington State Department of Transportation (WSDOT) summarized underwater broadband (20 Hz to 20 kHz) noise over three consecutive 24-hour periods at ferry terminals in Mukilteo, Port Townsend, Anacortes, Edmonds, and Seattle (Laughlin 2014). Based on WSDOT's recent research, the broadband sound level was 124 dB at Mukilteo, 107 dB at Port Townsend, 133 dB at Anacortes, 123 dB at Edmonds, and 141 dB at Seattle.

3.1.1. LWI Project Sites

Existing noise levels at the LWI project site are expected to be similar to baseline underwater noise levels measured during a 30-day period along the developed portion of the Bangor waterfront (Slater 2009). The average broadband RMS noise level at the LWI project sites is approximately 114 dB re 1 μPa between 100 Hz and 20 kHz; the minimum was 103 dB RMS re 1 μPa and the maximum was 147 dB RMS re 1 μPa (Slater 2009). The primary source of noise was due to industrial activity along the waterfront (e.g., at the Explosives Handling Wharf-1 [EHW-1], Marginal Wharf, and Delta Pier), small boat traffic, and wind-driven wave noise. No substantial precipitation was noted during the study period, although this would undoubtedly contribute to noise during seasonal periods. Peak spectral noise from industrial activity was noted below a frequency of 300 Hz, with maximum levels of 110 dB re 1 μPa noted in the 125 Hz band. In the 300 Hz to 5 kHz range, average levels ranged between 83 and 99 dB re 1 μPa. Wind-driven wave noise dominated the background noise environment at approximately 5 kHz and above, and ambient noise levels flattened above 10 kHz.

Ambient underwater sound in the vicinity of EHW-1, approximately 1,500 feet (450 meters) from the north LWI and 5,900 feet (1,800 meters) from the south LWI, was measured during the Test Pile Program (TPP) in 2011. Average underwater sound levels ranged from 112 dB RMS re 1 μPa at mid-depth between 50 Hz and 20 kHz to 114 dB RMS re 1 μPa at deep depth (Illingworth & Rodkin 2012). For the purposes of noise analyses for the LWI project, the average background underwater noise level at the project area was considered to be 114 dB RMS re 1 μPa between 100 kHz and 20 kHz.

3.1.2. Service Pier Extension Project Site

Some of the baseline underwater noise levels described above for LWI were measured at sample locations in the vicinity of the existing Service Pier (Slater 2009). Therefore, existing underwater noise levels at Service Pier are expected to be similar to those described above for the LWI project sites. For the purposes of noise analyses for the SPE project, the average background underwater noise level at the project area was considered to be 114 dB RMS re 1 µPa between 100 kHz and 20 kHz.

3.2. CONSTRUCTION NOISE SOURCES

In-water construction activities associated with SPE Alternative 2 include impact and vibratory pile driving. The sounds produced by these activities fall into two sound types: impulsive (impact driving) and non-impulsive (vibratory driving). Distinguishing between these two general sound types is important because each sound type may cause different types of physical effects to marine species, particularly with regard to hearing (Ward 1997).

Impulsive sounds (e.g., explosions, seismic airgun pulses, and impact pile driving) are brief, broadband, atonal transient sounds which can occur as isolated events or be repeated in some succession (Southall et al. 2007). Impulsive sounds are characterized by a relatively rapid rise from ambient pressure to a maximal pressure value followed by a decay period that may include a period of diminishing, oscillating maximal and minimal pressures (Southall et al. 2007). Impulsive sounds generally have a greater capacity to induce physical injury compared with sounds that lack these features (Southall et al. 2007).

Non-impulsive sounds can be tonal, broadband, or both. They lack the rapid rise time and can have longer durations than impulsive sounds. Non-impulsive sounds can be either intermittent or continuous sounds. Examples of non-impulsive sounds include vessels, aircraft, and machinery operations such as drilling, dredging, and vibratory pile driving (Southall et al. 2007).

Table D–2 details representative noise levels of anthropogenic activities to provide context for this analysis.

Table D–2. Representative Underwater Noise Levels of Anthropogenic Sources

Noise Source	Source Level	Frequency Range	Reference
Dredging	161 – 186 dB RMS re: 1 µPa @ 1 meter	1 – 500 Hz	Richardson et al. 1995; DEFRA 2003; Reine et al. 2014
Wind Turbine	100 – 120 dB RMS re: 1 µPa @ 100 meters	30 – 200 Hz	Betke 2006; Nedwell et al. 2007
Small Vessel	141 – 175 dB RMS re: 1 µPa @ 1 meter	860 – 8,000 Hz	Galli et al. 2003; Matzner and Jones 2011; Sebastianutto et al. 2011
Large Ship	176 – 186 dB re: 1 $\mu Pa^2 sec$ SEL @ 1 meter	20 – 1,000 Hz	McKenna et al. 2011
Airgun Array	255 – 262 dB peak re: 1 µPa @ 1 meter[1]	10 – 200 Hz	MacGillivray and Chapman 2005; Götz et al. 2009

[1]Measurements = reported in both peak and peak-to-peak units.

4.0 PROXY SOURCE LEVELS

During construction of the LWI and SPE projects, underwater and airborne noise levels in the Action Areas would be elevated due to pile driving, vessel and boat traffic, and operation of heavy construction equipment. The greatest sound levels would be produced by impact driving hollow steel piles (WSDOT 2013). Some noise would be generated with construction support vessels, small boat traffic, and barge-mounted equipment such as cranes and generators, but this noise will typically not exceed existing underwater noise levels resulting from existing routine waterfront operations in the vicinity of the construction sites. Several non-pile driving construction activities would also occur at the project areas. Among them are relocation of mooring anchors; installation of Port Security Barrier [PSB] units, pier decking, and camels; and operation of cranes, power utility booms, and other equipment. While no in situ empirical data exist for these construction activities, they are expected to be significantly lower than those estimated for pile installation using an impact/vibratory pile driver. Although it is possible that sound could be transmitted from these activities along the piles' length and enter the water, underwater acoustic impacts from these construction operations are expected to be minimal.

4.1. UNDERWATER SOURCE LEVELS

Underwater pile driving source levels were chosen from recommendations developed by the Navy for Navy waterfront projects located in Puget Sound (Navy 2015, FEIS Appendix H: *Proxy Source Sound Levels and Potential Bubble Curtain Attenuation for Acoustic Modeling of Nearshore Marine Pile Driving at Navy Installations in Puget Sound*). Values used in the analysis are shown in Table D–3.

4.2. AIRBORNE SOURCE LEVELS

Unweighted airborne impact and vibratory pile driving source levels are reviewed in Appendix H. Recommended unweighted airborne source level values are presented in Table D-4.

The most recent A-weighted data from the 2013 Explosives Handling Wharf (EHW-2) acoustic monitoring report (Illingworth & Rodkin 2013) were reviewed in order to determine the proxy levels for modeling of airborne noise for receptors other than pinnipeds. Based on measurements for 24-inch (60-centimeter) piles, a conservative assumed value of 100 dBA was modeled for all pile sizes.

Table D–3. Underwater Pile Driving Source Levels (unattenuated)

Impact Driving			
Pile Size / Type	**dB RMS re: 1 μPa @ 10 m**	**dB peak re: 1 μPa @ 10 m[1]**	**dB SEL re: 1 μPa^2 sec @ 10 m**
36-inch (90-centimeter) steel pipe	194	211	181
24-inch (60-centimeter) steel pipe	193	210	181
18-inch (45-centimeter) square concrete	170	184	159
Vibratory Driving			
Pile Size / Type	**dB RMS re: 1 μPa @ 10 m**	**dB peak re: 1 μPa @ 10 m**	**dB SEL re: 1 μPa^2 sec @ 10 m**
36-inch steel pipe	166	n/a	n/a
24-inch steel pipe	161		

1. Because 36- and 24-inch steel pipe piles may be installed on any active pile driving day during the first in-water work window under SPE Alternative 2, the more conservative (i.e., higher) source level for 36-inch piles was modeled, yielding the largest potential range to effect.

Table D–4. Airborne Pile Driving Source Levels

Impact Driving		
Pile Size / Type	**dB RMS re: 20 μPa @ 15 m**	
	Unweighted	A-weighted
36-inch (90-centimeter) steel pipe	112	100[1]
30-inch (76-centimeter) steel pipe	---[1]	
24-inch (60-centimeter) steel pipe	110[1]	
18-inch (45-centimeter) square concrete	112	
Vibratory Driving		
Pile Size / Type	**dB RMS re: 20 μPa @ 15 m**	
	Unweighted	A-weighted
36-inch steel pipe	95	96
30-inch steel pipe	95	---
24-inch steel pipe	92[1]	89[1]

1. Because steel pipe piles may be installed on any active pile driving day during the first in-water work window under SPE Alternative 2, the more conservative (i.e., higher) source level for 36-inch piles was modeled, yielding the largest potential range to effect.

4.3. Attenuation

A bubble curtain or other noise attenuating device is assumed to be used to minimize noise levels during impact pile driving operations. Bubble curtain attenuators emit a series of bubbles around a pile to introduce a high-impedance boundary through which pile driving noise is attenuated. A review of bubble curtain performance is presented in FEIS Appendix H. The analysis concluded that 8 to 10 dB was an achievable level of attenuation for 36- and 48-inch (90- and 120-centimeter) steel pipe piles.

These analyses support an 8 dB reduction in sound levels for impact proofing of steel piles with bubble curtains during the first in-water work window. TPP data were inadequate to evaluate attenuation values for 24-inch (60-centimeter) piles, and no recommendation was made for this pile size in the literature review. Therefore, it is assumed that attenuation for 24-inch piles would be similar to attenuation for 36- and 48-inch (90- and 120-centimeter) piles. A bubble curtain will not be deployed during impact driving of concrete piles. Therefore, no attenuation value was assumed when calculating the estimated zone of influence for underwater noise from concrete piles.

4.4. Assumptions

Assumptions that were used to complete the noise analysis are as follows:

- Up to 10 piles of any type could be installed during an active pile driving day.
- Vibratory driving would be the primary installation method for 36-, 30-, and 24-inch (90-, 76-, and 60-centimeter) steel piles; 18-inch (45-centimeter) concrete piles would be driven with an impact hammer (incorporating a cushion block).
- Proofing of steel piles, if needed, would require up to 200 strikes per pile; the actual amount of impact driving is expected to be significantly less than this number, yielding a conservative (i.e., larger than anticipated during actual pile installation) effect range for fish and marbled murrelet injury criteria (described in Sections 3.3 and 3.5, respectively).
- Installation of each concrete pile would require up to 300 strikes per pile.
- A bubble curtain will be used to minimize noise levels during impact pile driving of steel piles, with an average reduction of 8 dB from unattenuated pile driving source levels.
- No bubble curtain would be used during impact pile driving of concrete piles, or during vibratory driving of steel piles.

Table D–5 summarizes the number of piles and active driving / proofing days modeled for each alternative.

Table D–5. Summary of Pile Numbers and Active Driving / Proofing Days Modeled

DEIS Alternatives	Size / Type	Number	Number of Days	In-Water Work Window
LWI Alternative 2	24-inch (60-centimeter) steel	54 (north)	80	first
		202 (south)		
	24-inch steel	5 (north) (in the dry)		
		5 (south) (in the dry)		
	36-inch (90-centimeter) steel	15 (north) (in the dry)		
		16 (south) (in the dry)		
LWI Alternative 3	**36-inch steel**	**15 (north) (in the dry)**	**30**	**first**
		16 (south) (in the dry)		
	30-inch (76-centimeter) steel	**Up to 12 (north) (in the dry)**		
		Up to 12 (south)(in the dry)		
	24-inch steel	**15 (north) (in the dry)**		
		15 (south) (in the dry)		
SPE Alternative 2	**36-inch steel**	**230**	**125**	**first**
	24-inch steel	**50**		
	18-inch (45-centimeter) concrete	**105**	**36**	**second**
SPE Alternative 3	24-inch steel	500	155	first
	18-inch concrete	160	50	second

Bolded text denotes preferred Alternatives; "in the dry" refers to piles driven on shore – no underwater noise is associated with these piles.

4.5. METHODOLOGY

4.5.1. Underwater Propagation

Modeling sound propagation is useful in evaluating noise levels to determine distance from the pile driving activity that certain sound levels may travel. The decrease in acoustic intensity as a sound wave propagates outward from a source is known as transmission loss (TL). The formula for transmission loss is:

$$TL = B * log_{10}\left(\frac{R_1}{R_2}\right) + C * R_1,$$

where

B = logarithmic (predominantly spreading) loss,
C = linear (scattering and absorption) loss,
R_1 = range from source in meters,
R_2 = range from driven pile to original measurement location (generally 10 meters for underwater values, and 15 meters for airborne values).

The amount of linear loss (C) is proportional to the frequency of a sound. Due to the low frequencies of sound generated by impact and vibratory pile driving, this factor was assumed to be zero for all calculations and transmission loss was calculated using only logarithmic spreading. Therefore, using practical spreading (B = 15), the revised formula for transmission loss is $TL = 15 \log_{10} (R_1/10)$.

The practical spreading loss model ($TL = 15 \log_{10} (R_1/10)$) discussed above was used to calculate the underwater propagation of pile driving noise in and around the proposed LWI and SPE project locations.

The estimated effects ranges for fish, marine mammals, and marine birds are detailed in Sections 3.3, 3.4, and 3.5, respectively, of the DEIS. The ensonified areas are assumed to take a circular shape around the notional pile being driven; proximity to land features (e.g., shorelines) may result in some areas being "clipped" as sounds will attenuate as they encounter land or other solid obstacles. As a result, the ranges calculated may not actually be attained.

4.5.2. Airborne Propagation

Spherical spreading predicts that sound produced by a source will propagate through the environment and attenuate at a rate of 6 dB per doubling of distance. The mathematical formula for this model is the same as described above for underwater propagation. For airborne propagation, B (logarithmic loss) = 20 rather than 15 as for practical spreading. Airborne noise is analyzed in Section 3.9 of the DEIS.

4.5.3. Masking Effects

Masking is the increase in the detection threshold of sounds due to the presence of another sound such as the ambient or background sound level or an intermittent source such as pile driving. As determined by the Marbled Murrelet Hydroacoustic Science Panel II (SAIC 2012), masking of marbled murrelet vocalizations due to in-air pile driving noise has the potential to affect foraging behavior and efficiency because murrelets forage in pairs and it is assumed that foraging murrelets must be able to detect their partner's calls within 100 feet (30 meters). The amount of masking of a signal is measured by the critical ratio (i.e., signal-to-noise ratio) in the frequency range of the signal. For both TTS and noise masking of communication signals, the levels of concern are always dependent on existing ambient noise levels. Thus, these levels are site-specific and temporally variable. The USFWS (2013) has provided guidance on evaluating the significance of airborne masking effects for pile driving projects. "Typical" pile driving projects involve:

- Installation of 24-inch or 36-inch (60- or 90-centimeter) steel piles,
- Use of vibratory pile drivers,
- Use of impact pile drivers for proofing only, and
- Adherence to a 2-hour timing restriction (i.e., no pile driving 2 hours after sunrise and 2 hours before sunset during the breeding season).

The distances affected by masking due to pile driving noise were calculated for 36-inch (90-centimeter) steel piles (SAIC 2012) and 24-inch (60-centimeter) steel piles (USFWS 2013), representing the airborne construction source levels measured during the TPP in 2011 (Illingworth & Rodkin 2012). These distances are 138 feet (42 meters) and 550 feet (168 meters), respectively. Results of acoustic monitoring for EHW-2 construction have indicated that average airborne source levels during impact driving of 36-inch (90-centimeter) steel piles are the same as, and in some cases lower than, 24-inch steel piles; and levels for concrete piles are generally lower than for steel piles of comparable size. The effects of masking noise due to pile driving on marbled murrelets are reported in Section 3.5.

4.6. ADDITIVE EFFECTS OF CONCURRENT PILE DRIVING

If impact pile driving for NAVBASE Kitsap Bangor projects occurred at the same time, underwater noise levels could increase by as much as 3 dB at sites roughly equidistant between the multiple pile-driving rigs, for both impact and vibratory driving. Noise from multiple simultaneous sources produces an increase in the overall noise field. A doubling in sound power results in an increase of 3 dB, which is the result of two sources incoherently adding acoustic pressures in the combined noise environment. The resultant sound pressure level (SPL) from n-number of multiple sources is computed with the following relationship, using principles of decibel addition:

$$CombinedSPL = 10 \cdot \log_{10}\left(10^{\frac{SPL1}{10}} + 10^{\frac{SPL2}{10}} + \ldots + 10^{\frac{SPLn}{10}}\right)$$

In areas not roughly equidistant between the two sites, representing the majority of the area affected by noise from one of the pile drivers, noise levels at a given location would be dominated by the closer pile-driving activity, with little to no increase in levels above those from one pile driving operation.

5.0 DEFINITIONS

Ambient sound. Background sound levels on a site; may include project-generated noise.

Broadband. Sound containing frequencies across a wide range, e.g., 20 Hz to 20 kHz.

Critical ratio. The ratio of a signal level to the spectrum level of a non-signal sound. Ambient (background) noise in the frequency range of the signal is most important in masking the signal.

Masking. The increase in the detection threshold of a sound (signal) due to the presence of another sound (non-signal) in the same frequency range.

Source level. Sound energy, in decibels above a reference level, at a specified distance from the source of the sound.

Spectrum level. Sound energy at a particular frequency with 1.0 Hz bandwidth. The frequency of 3,150 Hz is a relevant frequency for birds because it is centered on the zone of maximum hearing sensitivity for many species.

//. Spectrum level notation; e.g., 5 dB//Hz signifies a spectrum sound level of 5 dB at a specified frequency such as 3 kHz.

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