Appendix J Underwater Noise Impacts of Encina Power Stations Marine Oil Terminal Decommissioning, Carlsbad, California 2015 (Greeneridge Sciences Report 518-1), Prepared by Greeneridge Sciences, Inc.

UNDERWATER NOISE IMPACTS OF ENCINA POWER STATION'S MARINE OIL TERMINAL DECOMMISSIONING, CARLSBAD, CALIFORNIA, 2015

by

Greeneridge Sciences, Inc.
90 Dean Arnold Place, Unit D
Santa Barbara, CA 93117

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UNDERWATER NOISE IMPACTS OF ENCINA POWER STATION'S MARINE OIL TERMINAL DECOMMISSIONING, CARLSBAD, CALIFORNIA, 2015

by

Dawn M. Grebner and **Katherine H. Kim**

Greeneridge Sciences, Inc.
90 Dean Arnold Place, Unit D
Santa Barbara, CA 93117
Phone: 619-241-6608; e-mail: grebner@greeneridge.com

for

Padre Associates, Inc.
1861 Knoll Drive
Ventura, CA 93003

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Executive Summary

This report examines the potential noise impacts of dynamic pipe ramming (DPR) on marine species (marine mammals, fishes, sea turtles and birds) during the decommissioning of the Encina Power Station's (EPS) Marine Oil Terminal (MOT). Vibratory pile driving was used as a proxy to compare potential sound emissions at the MOT with hearing sensitivities of animals known to inhabit the area, although only qualitative comparisons were made due to the lack of acoustic data for both DPR and vibratory pile driving. The hearing ranges of all marine species examined herein shared some degree of overlap with the sound frequencies produced by the vibratory pile driving proxy. Some species (baleen whales, pinnipeds, and birds) showed extensive overlap in hearing sensitivity with the proxy, while others showed more limited overlap (dolphins, fishes, and turtles). Potential impacts on marine species are dependent on the sound source levels and frequencies, animal hearing sensitivity, proximity to the sound source, noise duration, and time of operation. The potential impacts to pinnipeds may be comparatively high compared to other species because (1) they are a local, nearshore species, and (2) their hearing is most sensitive in the frequency bands in which the proxy sounds are highest. Hearing in fishes only partially overlap the frequencies in the proxy; however, fishes are particularly sensitive to high sound levels since they can detect both sound pressure and particle motion. Although dolphin hearing only becomes sensitive as the proxy levels are decreasing, the coastal bottlenose dolphin has the potential to be impacted by the DPR activity since they are residents that exhibit nearshore fidelity. For all species, duration of DPR will be important when assessing disturbance. The impacts on some species (*e.g.*, gray whales, turtles) may be dependent on the season when DPR activity occurs. For instance, if DPR occurs outside the December–February timeframe, gray whales will not be impacted because they will either be migrating further offshore or be absent from the area. Since the location of many marine animals is unpredictable, mitigation plans should be considered for local, migratory, and especially *endangered* or *threatened* species, particularly those that come within close proximity of the sound source. The distance at which sound levels may be a concern cannot be accurately quantified with the limited data available; however, acoustic propagation conditions at the MOT site suggest that sound levels will decrease relatively rapidly with increasing range from the DPR activity. Sound attenuation measures (*e.g.*, bubble curtains) and on-site mitigations (*e.g.*, slow-start ups) may be implemented to further reduce sound emissions into the environment near the MOT decommissioning location.

Introduction

The Cabrillo Power I LLC is developing a project execution plan for the decommissioning of the Encina Power Station's (EPS) Marine Oil Terminal (MOT) in Carlsbad, California. The geographic location of the MOT is shown in Figure 1. This project would include, among other tasks, the removal of an offshore pipeline. The pipeline is a 20-inch diameter, welded steel, fuel oil pipeline that extends from the onshore facility, Encina Power Station (EPS), underneath Carlsbad Boulevard, Carlsbad State Beach, and the surf zone, to a point approximately 1000 m (3300 ft) offshore. Submarine pipeline removal may be conducted using the construction technique of dynamic pipe ramming (DPR). Dynamic pipe ramming is a form of vibratory pile driving and would be used in this project to extract horizontal pipeline from under the seafloor.

The objective of the present report is to identify potential biological impacts resulting from underwater noise produced by the decommissioning of the MOT, in particular, by sound produced during dynamic pipe ramming. An awareness of animal hearing sensitivity to particle motion and pressure, sound source characteristics and levels, and environmental conditions that affect sound propagation are important factors in assessing noise impacts. Underwater sound measurements of dynamic pipe ramming are not known to exist, so this report provides a critical analysis of existing underwater sound measurements of pile driving, an activity hypothesized to share similar sound source characteristics. This report also analyzes the relevance of these sounds to the hearing of animal species that could occur near the MOT decommissioning location. For the given study site, the potential impact on a variety of marine wildlife (marine mammals, sea turtles, fishes, and birds) is discussed.

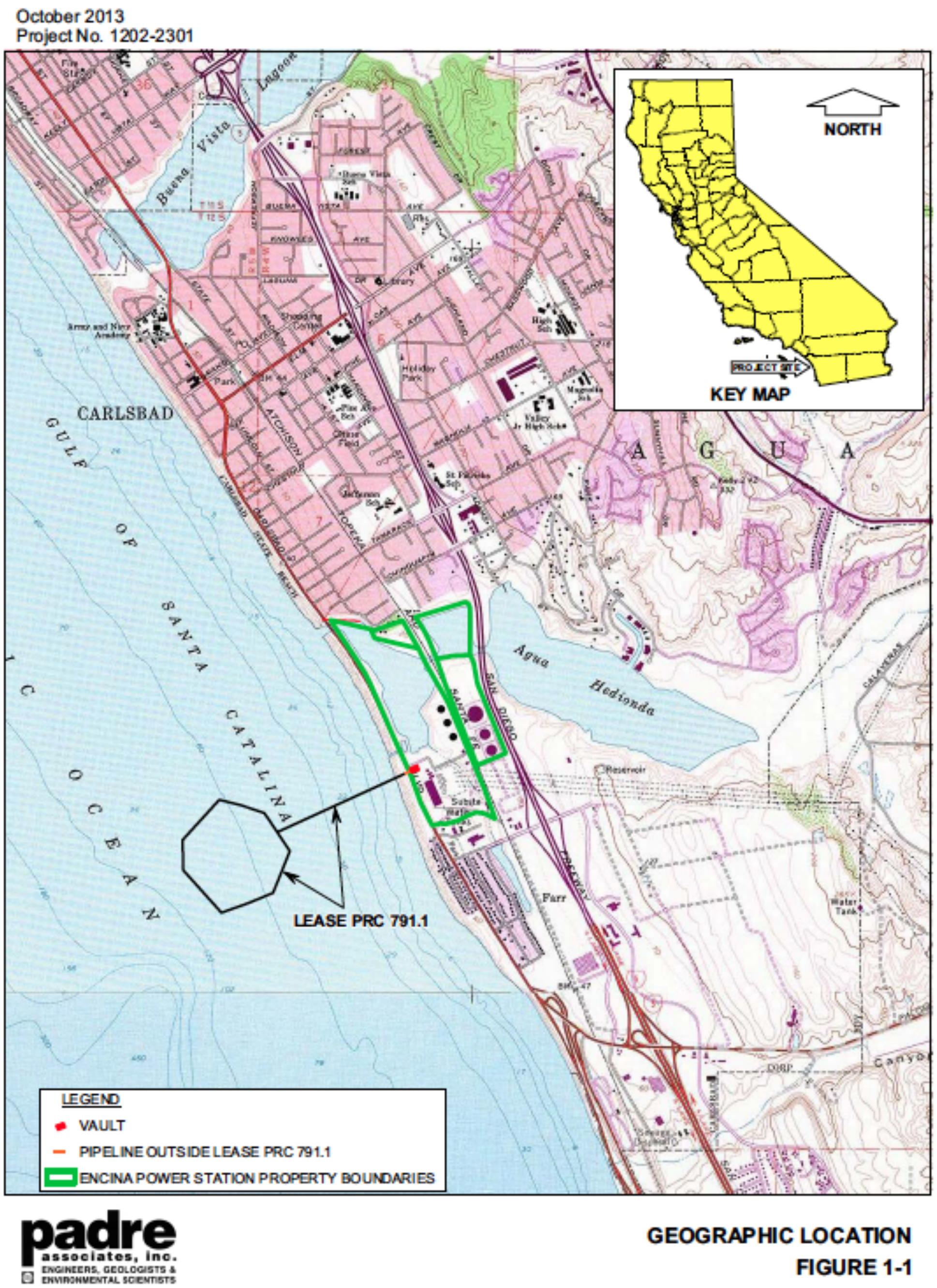

Figure 1. Geographic location of Encina Marine Oil Terminal (MOT) in Carlsbad, CA. (Source: EPS, 2013)

Regulatory Guidelines for Acoustic Threshold Levels

Marine species may exhibit both physiological and behavioral responses to high sound levels that are either impulsive (*e.g.*, airguns, impact pile drivers) or non-impulsive (*e.g.*, sonar, vibratory pile drivers) in nature (NOAA, 2013). The U.S. National Marine Fisheries Service (NMFS), a division of the National Oceanic and Atmospheric Administration (NOAA) has established guidelines regarding the impact of sound on marine mammals (NOAA, 2013). The Acoustical Society of America (ASA) has published similar criteria for fishes and sea turtles (Popper *et al.*, 2014). The effects of sound on marine life is an active area of scientific research and, thus, regulatory guidance in this area is subject to change as scientific understanding evolves.

Marine Mammals

NMFS has identified acoustic threshold (received sound level) criteria above which marine mammals are predicted to experience changes in their hearing sensitivity, either permanent or temporary hearing threshold shifts (NOAA, 2013). Physiological responses such as auditory or non-auditory tissue injuries are known as *Level A Harassment* in the Marine Mammal Protection Act (MMPA) and *harm* in the Endangered Species Act (ESA). *Level A Harassment* becomes a concern when the sound levels from man-made sounds reach or exceed the acoustic threshold associated with auditory injury in marine species. Permanent threshold shift (PTS) is a permanent, irreversible increase in an animal's auditory threshold within a given frequency band or range of the animal's normal hearing. A temporary threshold shift (TTS) is a temporary, reversible increase in the threshold of audibility at a specific range of frequencies. While TTS is not an injury it is considered *Level B Harassment* by the MMPA and *harassment* by the ESA. Along with TTS, *Level B Harassment* also includes behavioral impacts.

For pinnipeds and cetaceans, NMFS has specified Level A thresholds as 190 and 180 dB re 1 µPa SPL_{rms} (root-mean-square, broadband, received sound pressure level), respectively (NOAA, 2000). In addition, rms SPLs of 160 dB re 1 µPa or greater are assumed to disrupt marine mammal behavior patterns (Level B harassment). These current acoustic threshold levels, used for most sound sources, consist of a single threshold for cetaceans and a single threshold for pinnipeds regardless of sound source. That is, they do not take into account exposure duration, sound frequency composition, repetition rate, and animals' hearing sensitivity.

In 2013, NMFS proposed new acoustic threshold levels for the onset of PTS and TTS using the latest scientific findings. The proposed guidelines will change current practice by: (1) dividing marine mammals into functional hearing groups and developing auditory weighting functions for these groups, (2) utilizing different metrics, namely, peak sound pressure level (dB_{peak}) and cumulative sound exposure level (SEL_{cum}) in lieu of SPL_{rms}, and (3) dividing sound sources into two groups (impulsive and non-impulsive). NMFS anticipates these new guidelines will be finalized and become effective in 2015. Due to their potential impact on the MOT decommissioning project, the proposed guidelines are described briefly below.

Based upon Southall *et al*. (2007), the proposed acoustic guidelines divides marine mammals into five functional hearing groups: low-, mid-, and high-frequency cetaceans, phocid pinnipeds and otariid pinnipeds (Southall *et al*., 2007; NOAA, 2013). The assumption is that all species within a functional hearing group have approximately the same hearing sensitivity. The frequency ranges and acoustic threshold levels of the functional hearing groups were further refined from those suggested by Southall based upon the latest scientific data on animal hearing sensitivity, specifically via the application of auditory weighting functions (Houser *et al.*, 2001; Hemilä *et al.*, 2006; Parks *et al*., 2007; Southall *et al*., 2007; Kastelein *et al.*, 2009; Finneran and Jenkins, 2012). The functional hearing groups and their hearing ranges are summarized in Table 1.

Table 1. Functional hearing groups and hearing ranges for marine mammals. (Source: NOAA, 2013)

Functional Hearing Group	Functional Hearing Range*
Low-frequency (LF) cetaceans+ (baleen whales)	7 Hz to 30 kHz
Mid-frequency (MF) cetaceans (dolphins, toothed whales, beaked whales, bottlenose whales)	150 Hz to 160 kHz
High-frequency (HF) cetaceans (true porpoises, *Kogia*, river dolphins, cephalorhynchid, *Lagenorhynchus cruciger* and *L. australis*)	200 Hz to 180 kHz
Phocid pinnipeds (true seals)	75 Hz to 100 kHz
Otariid pinnipeds (sea lions and fur seals)	100 Hz to 40 kHz

* Represents frequency band of hearing for entire group as a composite (i.e., all species within the group), where individual species' hearing ranges are typically not as broad.

+ Estimated hearing range for low-frequency cetaceans is based on behavioral studies, recorded vocalizations, and inner ear morphology measurements. No direct measurements of hearing ability have been successfully completed.

The proposed criteria for onset TTS and PTS acoustic thresholds are based on cumulative sound exposure levels (SEL_{cum}) and peak pressure (dB_{peak}). SEL_{cum} includes both source level and duration of exposure (*e.g.*, in units of dB re 1 $\mu Pa^2 \cdot s$). The SEL_{cum} is normalized to the duration of the exposure (*e.g.*, 1 second, 1 hour, 24 hours). The proposed guidelines recommend 1 hr or 24 hrs. In order to determine the onset of TTS (or PTS), the frequency content of the sound source must be determined, a weighting function is used to weight each frequency band, then the weighted SEL_{cum} is calculated by integrating the weighted frequency content (Finneran and Jenkins, 2012; NOAA, 2013). Finally, the resultant SEL_{cum} of the sound source is compared to the NMFS onset thresholds for TTS and PTS for each functional hearing group (Table 2). Peak pressure is in units of dB re 1 µPa and is not weighted. Note that the phocid and otariid pinniped threshold levels in Table 2 are for hearing in water. Southall *et al.* (2007) also proposed threshold levels for pinniped hearing in air (with phocids and otariids as one group). The in-air threshold levels for both PTS and TTS were 149 dB re 20 µPa for dB_{peak} and 144 dB re 20 µPa for $SEL_{cum.}$

Proper implementation of these noise exposure criteria requires knowledge about the type of sound emitted, its source level and duration, and how the sound may attenuate with distance. For example, if an LF cetacean is exposed to an impulsive sound level (*e.g.*, from impact pile driving) that exceeds 187 dB SEL_{cum} or 230 dB_{peak} levels, the animals may experience permanent hearing damage (*i.e.*, PTS), which is considered a *Level A Harassment* as defined by the Marine Mammal Protection Act (MMPA) and *harm* under the Endangered Species Act (ESA). Likewise, if an MF cetacean is exposed to more than 178 dB SEL_{cum} for a non-impulsive sound source (*e.g.*, vibratory pile driving), but less than 198 dB S SEL_{cum}, the MF cetacean has been exposed to the possible onset of TTS, which is considered a *Level B harassme*nt by the MMPA and *harassment* by the ESA. If animals are within areas where the sound levels are less than the criteria in Table 2 the marine mammals are considered unharmed.

Table 2. NOAA specifications for onset PTS and TTS in five marine mammal functional hearing groups. The units for dB_{peak} are dB re 1 μPa, while those for dB SEL_{cum} are dB re 1 $μPa^2$-s. (Source: NOAA, 2013)

a. Numeric Level*+				
	PTS Onset (Received Level)		TTS Onset (Received Level)	
Hearing Group	**Impulsive**	**Non-impulsive**	**Impulsive**	**Non-impulsive**
Low-Frequency (LF) Cetaceans	*Cell 1* 230 dB_{peak} & 187 dB SEL_{cum}	*Cell 2* 230 dB_{peak} & 198 dB SEL_{cum}	*Cell 11* 224 dB_{peak} & 172 dB SEL_{cum}	*Cell 12* 224 dB_{peak} & 178 dB SEL_{cum}
Mid-Frequency (MF) Cetaceans	*Cell 3* 230 dB_{peak} & 187 dB SEL_{cum}	*Cell 4* 230 dB_{peak} & 198 dB SEL_{cum}	*Cell 13* 224 dB_{peak} & 172 dB SEL_{cum}	*Cell 14* 224 dB_{peak} & 178 dB SEL_{cum}
High-Frequency (HF) Cetaceans	*Cell 5* 201 dB_{peak} & 161 dB SEL_{cum}	*Cell 6* 201 dB_{peak} & 180 dB SEL_{cum}	*Cell 15* 195 dB_{peak} & 146 dB SEL_{cum}	*Cell 16* 195 dB_{peak} & 160 dB SEL_{cum}
Phocid Pinnipeds (Underwater)	*Cell 7* 235 dB_{peak} & 192 dB SEL_{cum}	*Cell 8* 235 dB_{peak} & 197 dB SEL_{cum}	*Cell 17* 229 dB_{peak} & 177 dB SEL_{cum}	*Cell 18* 229 dB_{peak} & 183 dB SEL_{cum}
Otariid Pinnipeds (Underwater)	*Cell 9* 235 dB_{peak} & 215 dB SEL_{cum}	*Cell 10* 235 dB_{peak} & 220 dB SEL_{cum}	*Cell 19* 229 dB_{peak} & 200 dB SEL_{cum}	*Cell 20* 229 dB_{peak} & 206 dB SEL_{cum}

* Dual acoustic threshold levels: Use whichever level [dB_{peak} or dB SEL_{cum}] exceeded first. All SEL_{cum} acoustic threshold levels (re: 1 $μPa^2$-s) are weighted. Note that acoustic threshold levels for impulsive or non-impulsive sources are based on characteristics at the source and not the receiver.

\+ The SEL_{cum} could be exceeded in multitude of ways (i.e., varying exposure levels and durations). It is valuable for applicants, if possible, to indicate under what conditions these acoustic threshold levels will be exceeded.

Fishes

In 2008, the only U.S. regulatory guidelines for the effects of sound on fish was an "agreement in principle" signed by members of the Fisheries Hydroacoustic Working Group (FHWG, 2008). The FHWG memorandum stated 206 dB re 1 µPa peak SPL as interim criteria for onset of physiological effects of pile driving on fish.

In 2014, an ANSI-accredited standards committee of the Acoustical Society of America developed guidelines for sound exposure criteria for both fishes and turtles (Popper *et al.*, 2014). These guidelines were developed because fishes are a diverse group and more populous than marine mammals, they respond to particle motion in addition to sound pressure, and very little information on either fishes or turtles is known (Popper *et al.*, 2014).

For a pile driving source, the exposure criteria grouped animals into five categories (Table 3). The first two fish groups rely on particle motion to detect sound, since they lack a swim bladder or the swim bladder does not aid in sound detection. The third group is comprised of fishes with swim bladders that have either appendages or additional air sacs that enhance sound pressure detection. The last two categories encompass sea turtles and fish eggs and larvae. Barotrauma is defined as tissue injury that results from rapid pressure changes, explosions, and intense sounds (Halvorsen *et al*., 2011, 2012). Table 4 provides sound exposure criteria for these fish (and turtles) for impact pile driving only. Mortality and potential mortal injury thresholds for fishes with swim bladders are lower than those for fishes without swim bladders, because gas chambers within the bodies of the former group are more sensitive to sound pressure. Fishes with swim bladders involved in hearing may have additional air sacs which drive acoustic thresholds even lower. For vibratory pile driving, Popper *et al.* (2014) merely noted that continuous sound and peak pressure levels were expected to be lower than those for impact pile driving.

Table 3. Descriptions of five types of animal categories used in the guideline threshold criteria. (Source: Popper et al., 2014)

- *Fishes with no swim bladder or other gas chamber* (e.g., dab and other flatfish). These species are less susceptible to barotrauma and only detect particle motion, not sound pressure. However, some barotrauma may result from exposure to sound pressure.
- *Fishes with swim bladders in which hearing does not involve the swim bladder or other gas volume* (e.g., Atlantic salmon). These species are susceptible to barotrauma although hearing only involves particle motion, not sound pressure.
- *Fishes in which hearing involves a swim bladder or other gas volume* (e.g., Atlantic cod, herring and relatives, Otophysi). These species are susceptible to barotrauma and detect sound pressure as well as particle motion.
- *Sea turtles*
- *Fish eggs and larvae*

Table 4. Pile driving exposure criteria for fishes, turtles, and fish eggs and larvae. The units for dB_{peak} are dB re 1 μPa, while those for dB SEL_{cum} are dB re 1 $\mu Pa^2 \cdot s$. (Source: Popper *et al.*, 2014)

Table 7.3 Pile driving. Data on mortality and recoverable injury are from Halvorsen et al. (2011, 2012a, c) based on 960 sound events at 1.2 s intervals. TTS based on Popper et al. (2005). See text for details. Note that the same peak levels are used both for mortality and recoverable injury since the same SEL_{ss} was used throughout the pile driving studies. Thus, the same peak level was derived (Halvorsen et al. 2011).

Type of Animal	Mortality and potential mortal injury	Impairment: Recoverable injury	Impairment: TTS	Impairment: Masking	Behavior
Fish: no swim bladder (particle motion detection)	>219 dB SEL_{cum} or >213 dB peak	>216 dB SEL_{cum} or >213 dB peak	>>186 dB SEL_{cum}	(N) Moderate (I) Low (F) Low	(N) High (I) Moderate (F) Low
Fish: swim bladder is not involved in hearing (particle motion detection)	210 dB SEL_{cum} or >207 dB peak	203 dB SEL_{cum} or >207 dB peak	>186 dB SEL_{cum}	(N) Moderate (I) Low (F) Low	(N) High (I) Moderate (F) Low
Fish: swim bladder involved in hearing (primarily pressure detection)	207 dB SEL_{cum} or >207 dB peak	203 dB SEL_{cum} or >207 dB peak	186 dB SEL_{cum}	(N) High (I) High (F) Moderate	(N) High (I) High (F) Moderate
Sea turtles	210 dB SEL_{cum} or >207 dB peak	(N) High (I) Low (F) Low	(N) High (I) Low (F) Low	(N) High (I) Moderate (F) Low	(N) High (I) Moderate (F) Low
Eggs and larvae	>210 dB SEL_{cum} or >207 dB peak	(N) Moderate (I) Low (F) Low	(N)Moderate (I) Low (F) Low	(N) Moderate (I) Low (F) Low	(N) Moderate (I) Low (F) Low

Notes: peak and rms sound pressure levels dB re 1 μPa; SEL dB re 1 $\mu Pa^2 \cdot s$. All criteria are presented as sound pressure even for fish without swim bladders since no data for particle motion exist. Relative risk (high, moderate, low) is given for animals at three distances from the source defined in relative terms as near (N), intermediate (I), and far (F).

Definitions of effects listed among the exposure criteria in Table 4 can be found in Table 5. Masking is considered the impairment of the ability to detect sounds, and the degree of masking is dependent on the level and frequency of the source (Richardson *et al.*, 1995; Popper *et al.*, 2014). In Table 4, the relative risk of the effect occurring is indicated by High, Moderate, and Low. For example, fishes with no swim bladders were at a moderate risk of masking near the source, while the level of risk is low at far distances from the source due to sound attenuation.

Table 5. Definition of effects used in guideline table seen in Table 4. (Source: Popper *et al.*, 2014)

Table 7.1 Definition of Effects Used in Guidelines Tables

- *Mortality and mortal injury* – immediate or delayed death.
- *Recoverable injury* – injuries, including hair cell damage, minor internal or external hematoma, etc. None of these injuries are likely to result in mortality.
- *TTS* – short or long term changes in hearing sensitivity that may or may not reduce fitness. TTS, for these Guidelines, is defined as any change in hearing of 6 dB or greater that persists. This level is selected since levels less than 6 dB are generally difficult to differentiate. It is also the view of the WG that anything less than 6 dB will not be a significant effect from the standpoint of hearing.
- *Masking* – impairment of hearing sensitivity by greater than 6 dB, including all components of the auditory scene, in the presence of noise.
- *Behavioral effects* – substantial change in behavior for the animals exposed to a sound. This may include long-term changes in behavior and distribution, such as moving from preferred sites for feeding and reproduction, or alteration of migration patterns. This behavioral criterion does not include effects on single animals, or where animals become habituated to the stimulus, or small changes in behavior such as a startle response or small movements.

The relative risk of an effect taking place is indicated as being "high," "moderate," and "low."

Sea Turtles

Very few hearing studies have involved sea turtles (Popper *et al*., 2014). Sea turtles appear to be sensitive to low frequency sounds with a functional hearing range of approximately 100 Hz to 1.1 kHz (Ridgway *et al.*, 1969; Bartol *et al*., 1999; Ketten and Bartol, 2006; Martin *et al.,* 2012). It has been suggested that sea turtle hearing thresholds should be equivalent to TTS thresholds for LF cetaceans when animals are exposed to impulsive and non-impulsive anthropogenic sounds (Southall *et al*., 2007; Finneran and Jenkins, 2012). More recently, the aforementioned ASA standards committee suggested that turtle hearing was probably more similar to that of fishes than marine mammals (Popper *et al.*, 2014). Green and loggerhead sea turtles have typical reptilian ears with a few underwater modifications, and the functional basilar papilla in the turtle ear is not similar to the cochlea in those of mammals (Ridgway *et al*., 1969; Popper *et al.*, 2014). In Table 4, turtles were presumed to have the same thresholds as those fishes with swim bladders not involved in hearing. Thus, sea turtle mortality and mortal injury would be expected at pile driving sound levels greater than 210 dB SEL_{cum} and 207 dB_{peak} (Table 4).

Birds

In 2007, Dooling and Popper proposed interim in-air sound exposure criteria for birds and construction-related sounds (Table 6). The limited knowledge regarding how construction noise may affect birds and that many birds are protected under the Endangered Species Act motivated the work. Birds, similar to other species, exhibit shifts in hearing sensitivities when exposed to high sound levels and long exposure durations. Birds can tolerate continuous sound sources up to levels of 110 dB(A) re 20 µPa for 72 hours without experiencing hearing damage or PTS. [In air, the reference pressure is 20 µPa (compared to 1 µPa in water), and sound pressure levels are typically A-weighted for humans or terrestrial animals to account for differences in perceived loudness as a function of frequency (Dooling and Popper, 2007).] The suggested criteria for onset TTS for continuous sound sources is 93 dB(A) re 20 µPa (Table 6); vibratory pile driving would fall under the "non-strike continuous" type of noise source. The criteria for onset PTS by impulsive sources (e.g., impact pile driving) is 125 dB(A) re 20 µPa.

Table 6. Recommended interim in-air guidelines for potential effects on birds from different sound sources. (Source: Dooling and Popper, 2007)

Table 3: Recommended Interim Guidelines for Potential Effects from Different Noise Sources

Noise Source Type	Hearing Damage	TTS	Masking	Potential Behavioral/ Physiological Effects
Single Impulse (e.g., blast)	140 dB(A)[1]	NA[3]	NA[7]	Any audible component of highway noise has the potential of causing behavioral and/or physiological effects independent of any direct effects on the auditory system of PTS, TTS, or masking
Multiple Impulse (e.g., jackhammer, pile driver)	125 dB(A)[1]	NA[3]	ambient dB(A)[5]	
Non-Strike Continuous (e.g., construction noise)	None[2]	93 dB(A)[4]	ambient dB(A)[5]	
Highway Noise	None[2]	93 dB(A)[4]	ambient dB(A)[5]	
Alarms (97 dB/100 ft)	None[2]	NA[2]	NA[6]	

[1] Estimates based on bird data from Hashino et al.1988 and other impulse noise exposure studies in small mammals.
[2] Noise levels from these sources do not reach levels capable of causing auditory damage and/or permanent threshold shift based on empirical data on hearing loss in birds from the laboratory.
[3] No data available on TTS in birds caused by impulse noises.
[4] Estimates based on study of TTS by continuous noise in the budgerigar and similar studies in small mammals.
[5] Conservative estimate based on addition of two uncorrelated noises. Above ambient noise levels, critical ratio data from 14 bird species, well documented short term behavioral adaptation strategies, and a background of ambient noise typical of a quiet suburban area would suggest noise guidelines in the range of 50—60 dB(A).
[6] Alarms are non-continuous and therefore unlikely to cause masking effects.
[7] Cannot have masking to a single impulse.

Figure 2 illustrates the relationship between the distance to the sound source and the potential effects on birds. Beyond zone 4 (far right column) the noise is far away and undetectable to the birds. In the next column (moving right to left), the sound becomes audible. Moving closer to the source, the sound level is higher and masking may occur if the frequency range of the sound source overlaps the most sensitive hearing frequencies of the birds. Above 93 dB(A) re 20 µPa the bird may experience TTS and above 110 dB(A) of a continuous source type a bird may experience PTS.

To our knowledge, no underwater acoustic guidelines exist for diving birds potentially affected by the MOT decommissioning project. Training birds for underwater audiograms is difficult and was only recently measured for a single diving bird (Therrien, 2014). Extrapolation of in-air thresholds to underwater ones is tenuous, for example, due to the use of different reference pressures (a 26 dB difference), potential differences in auditory weighting functions, and the different impedances of air and water. Regardless, since the duration of underwater sound exposure is expected to be short, TTS and PTS resulting from underwater sound sources are deemed unlikely.

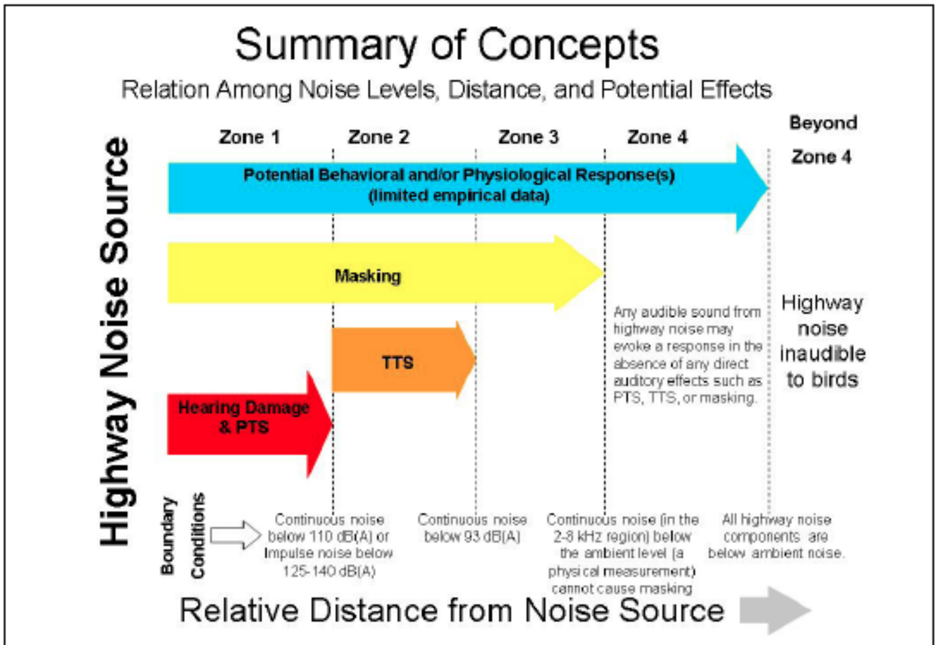

Figure 5: Effects of Highway Noise on Birds

Categories of highway noise effects on birds with distance from the source. Zone 1 is closest to the source while Zone 4 is furthest away. Sound level decreases further from the source. See text for discussion.

Figure 2. Relationship between noise levels, distances, and potential effects on birds. (Source: Dooling and Popper, 2007)

Sound Source Characteristics

The impact potential of a sound source on marine species in an environment is reliant on level and duration (Hastings and Popper, 2005; NOAA, 2013). Anthropogenic sounds can be separated into two sound types, impulsive and non-impulsive sounds (Southall *et al*., 2007; NOAA, 2013). Impulsive sound sources are brief, generally broadband, transient sounds that are characterized by rapid rise times to maximum pressure followed by an oscillating decay in pressure (Southall *et al*., 2007; NOAA, 2013). They may occur as a single event or as repetitive signals. Examples of anthropogenic, oceanic impulsive sounds include airgun pulses, explosions, gunshots, impact pile driving pulses, and sonic booms (Southall *et al*., 2007; NOAA, 2013). Non-impulsive sound sources can be broadband or tonal, intermittent or continuous sounds. They may be short in duration, but they lack the rapid rise times to peak pressures that define impulsive sounds. Examples of non-impulsive sound sources include vessels, aircraft, some active sonars, and machinery operations such as wind turbines and vibratory pile drivers (Southall *et al*., 2007; NOAA, 2013). While exposure to impulsive sounds has a greater potential to cause hearing fatigue or damage in animals (Henderson *et al.*, 1991), long periods of exposure to non-impulsive sounds may be nearly as detrimental (Oestman *et al.*, 2009). Recognition of differences in how impulsive and non-impulsive sounds potentially impact hearing sensitivity has been incorporated into NMFS's proposed acoustic guidelines (refer to the previous section, *Regulatory Guidelines for Acoustic Thresholds*).

There are two main types of pile driving: impact and vibratory. Impact pile driving includes a piston system with weights that are usually raised by a power source (diesel, hydraulic, or steam) and then dropped onto the pile, hammering the pipe into the ground. Impact pile driving generates high amplitude, impulsive sounds (Southall *et al*., 2007; NOAA, 2013). Vibratory pile drivers produce lower sound amplitudes and have, therefore, gradually become more popular to help mitigate noise exposure levels on marine species (Nedwell *et al.*, 2003; Michel *et al.*, 2007; Brandt *et al.*, 2011; Dazey *et al.*, 2012). In vibratory pile driving, the vibrator case is attached to the pipe that is to be installed and vibrations are then transferred from the case to the pile (Warrington, 1992). The power packs are usually hydraulic, electric, or pneumatic (Warrington, 1992; Studlein and Meskele, 2013). One example of a vibratory pile driver uses an impact hammer to help produce the vibrations. The efficiency of these *impact-vibration* hammers is greater than traditional vibratory hammers (Warrington, 1992; Stuedlein and Meskele, 2013). For all of these pile drivers, sound waves produced from pipe driving can be coupled from the seafloor sediments into the seawater and emit varying sound levels into the aquatic environment (Hastings and Popper, 2005).

Although peak sound levels of vibratory hammers can be substantially lower than those of impact pile driving (Oestman *et al.*, 2009; Dazey *et al.*, 2012; Rodkin and Pommerenck, 2014), there are some drawbacks and cautions when using vibratory pile driving. Many vibratory hammers need to be driven for longer time periods to install a pile compared to impact hammers, so if the pile driving takes an extended period of time, the total energy (*e.g.*, SEL_{cum}) emitted by the vibratory pile driving may actually be comparable to that of impact pile driving (Oestman *et al.*, 2009; Halvorsen *et al.*, 2012). In addition, sound levels may rise with increased pipe diameters, power to the hammer, and presence of rock; however, this is also true for other pipe drivers (Simicevic & Sterling, 2001).

Impact hammers usually produce higher sound levels than vibratory hammers; however, comparison of sound levels between the two should be approached with caution. Since vibratory hammers are non-impulsive, sound energy is usually distributed over a wider range of frequencies, so defining and applying the exposure duration is essential (Oestman *et al.*, 2009). In 2005, Blackwell measured impact pile driving and obtained broadband sound levels (SPL_{rms}) of 189–190 dB re 1 µPa at 62 m from the source (at two depths of 1.5 m and 10 m) and dominant frequencies in the 100–2000 Hz range. In this example, the impact measurements were obtained over a time interval corresponding to 5% and 95% of the total energy of the pulse (Blackwell, 2005). In contrast, vibratory pipe driving levels in the same study were calculated over a longer duration (8.5 s). Sound levels (SPL_{rms}) for vibratory driving were 163–164 dB re 1 µPa at 56 m from the source with a dominant frequency range of 400–2500 Hz (Blackwell, 2005). If sound levels for impact pile driving were calculated over a longer time period, the apparent difference in sound levels between impact and vibratory driving would decrease.

Another study examined sound levels with respect to frequency and provided a visual comparison between sound source characteristics of impact and vibratory pile driving on the same pile (Fig. 3) (Matuschek and Betke, 2009). The highest received sound exposure level (SEL) from the impact pile driver (about 160 dB re 1 µPa, in red) is greater than that for the vibratory pile driver (about 140 dB re 1 µPa, in blue) by approximately 20–30 dB at 200–300 Hz; SELs were calculated over the duration of the pulse or vibratory sound. The received levels in this study were determined at much greater distances (1200 m away) from the sound source than in Blackwell (2005), and the calculations of pressure levels differed (SEL and SPL_{rms}, respectively).

The MOT decommissioning project proposes the use of dynamic pipe ramming for submerged pipeline removal. Dynamic pipe ramming uses a hammer that is pneumatically or hydraulically powered to drive (push) or extract (pull) an attached section of pipe through an embankment usually in the horizontal plane (Simicevic & Sterling, 2001; Stuedlin and Meskele, 2013). The repeated application of the hammer to the pipe produces a forward compressional stress wave, which travels from the point of contact along the pipe then into the ground and a lateral stress wave that radiates from the sides of the pipe.

In the EPS MOT application, "the hammer would probably be attached to the offshore end of the pipeline and used in the pulling mode to pull the pipeline segment out of the surf zone… and tension applied during the ramming process to drag the recovered pipeline segment offshore as the hammer vibrates the pipe segment out of the surf zone seafloor" (Cabrillo Power I LLC, 2014). Due to its physical similarities, vibratory pile driving will serve as a rough proxy for dynamic pipe ramming in this report.

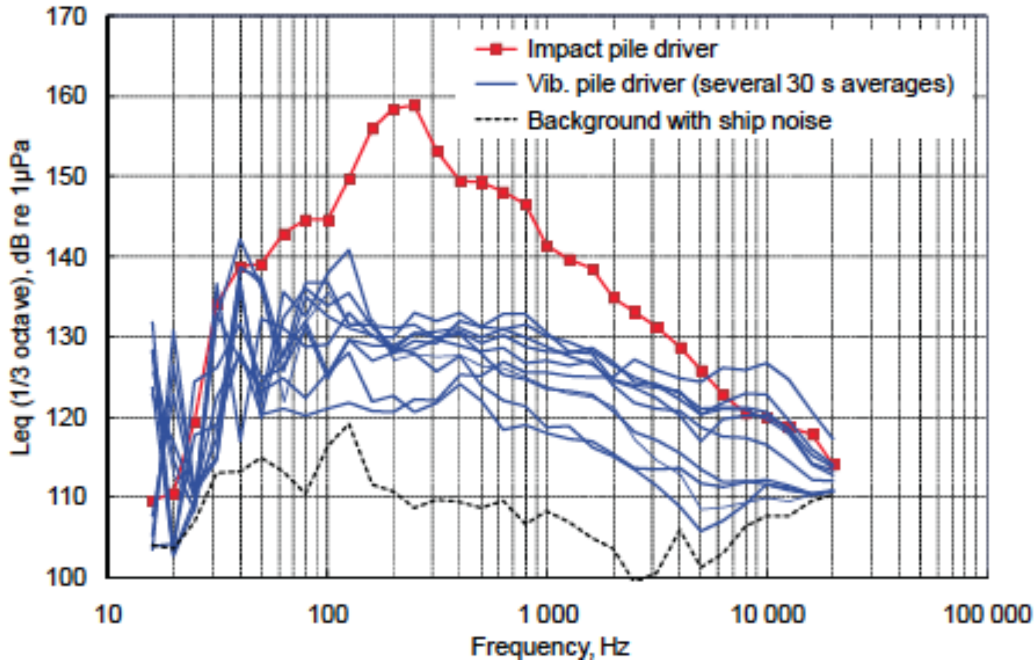

Figure 3. Impact and vibration pile driving of the same pile. Vibrator frequency was about 20 Hz. Pile diameter was 2.6 m. Spectrum was measured 1200 m from the sound source. (Source: Matuschek and Betke, 2009).

Since no published information is available on the sound levels and frequency composition of dynamic pipe ramming, sound characteristics of vibratory pile driving are presented herein. McCrodan and Hannay (2014) reviewed and utilized results from previous datasets (*e.g.*, including Blackwell, 2005, Oestman *et al.*, 2009, Appendix I: Compendium) to estimate source levels for vibratory pile driving (Fig. 4). The model used a pipe diameter of 1.0–1.3 m (39–51 in). The largest SPL values were extracted from each 1/3 octave band and were then back-propagated to 1 m. Spectrum levels were then reduced equally across all 1/3 octave bands to simulate a previously estimated broadband source level of 185 dB re 1 µPa at 1 m considered relevant to McCrodan and Hannay's particular modeling study. Prior to this adjustment, the broadband source level based upon measurements was 204.1 dB re 1 µPa. Figure 4 shows the resulting estimated 1/3 octave band source levels at 1 m for vibratory pile driving (in blue). The highest energy level (~ 180 dB re 1 µPa) occurred around 1000 Hz. Energy levels greater than 170 dB re 1 µPa and 160 dB re 1 µPa spanned the frequency ranges of 400 Hz to 3 kHz, and 200 Hz to 10 kHz, respectively. Figure 4 also shows additional sound attenuation possible with the application of a bubble curtain around the vibratory pile driver (in red).

Numerous factors contribute to the disparity of sound levels seen between Figures 3 and 4. For instance, the source-to-receiver (pile-driver-to-hydrophone) distance in Figure 3 was 1200 m, while Figure 4 depicts an estimated source level, *i.e.*, 1 m distance between source and receiver. In addition, the pile diameters among studies varied from 2.6 m (Fig. 3) and 1.0-1.3 m (Fig. 4), and the pipe and soil resistances to penetration likely differed among measurements but were not specified. Furthermore, environmental conditions that affect sound propagation—such as sound speed profiles, water depth, and seafloor composition— between pile driver and hydrophone greatly influence the received sound levels reported in all studies. Thus, even assuming vibratory pile driving is a reasonable proxy for DPR, the limited as well as highly variable acoustic measurements for vibratory pile driving prohibit accurate quantitative estimates of regulatory metrics such as SPL_{rms}, dB_{peak}, and SEL_{cum} for the MOT environment. (For planning purposes, conservative estimates of safety radii will be discussed in the section "Acoustic Waveguide Environment," but *in situ* sound measurements are highly recommended given the scarcity of relevant existing measurements.) Qualitative comparisons between existing vibratory pile driving source levels and marine species' hearing sensitivities will be made in the following section.

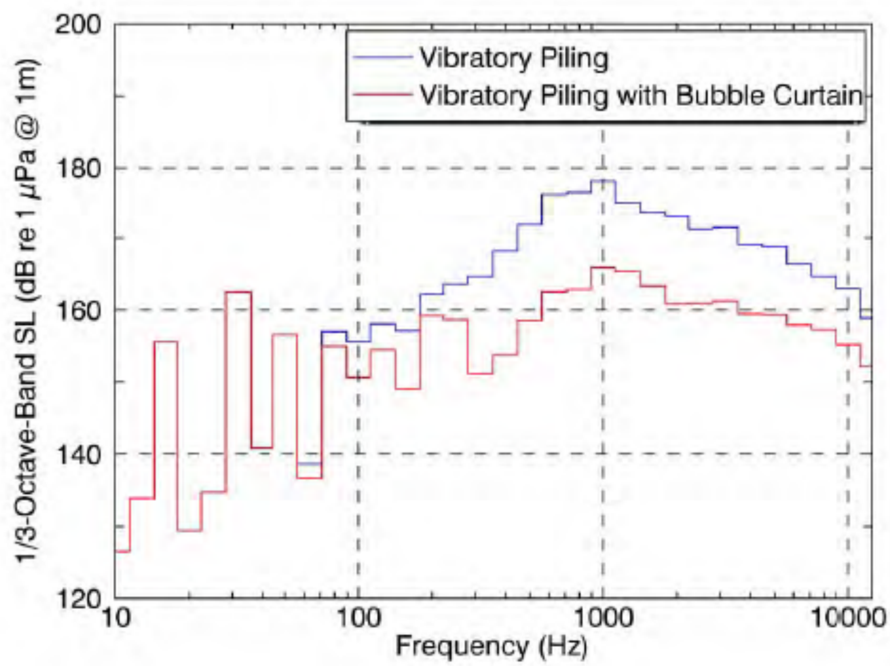

Figure 4. One-third octave band source levels for vibratory pile driving with (red) and without (blue) bubble curtain mitigation. Pile diameter was 1.0–1.3 m. Measured sound levels were back-propagated to 1 m distance from the sound source. (Source: McCrodan and Hannay, 2014)

Hearing in Local Species and Potential Impacts

Sound can be described by both acoustic pressure and particle motion (Simmonds and MacLennan, 2005; Southall *et al*., 2007). Sound energy is transmitted in the form of a mechanical wave by the periodic pressure changes (compression and expansion of molecules) in compressible media (solid, gas, or liquid; *e.g.,* water), The resultant pressure wave travels outward from the sound source (Urick, 1983; Simmonds and MacLennan, 2005). Sound waves can also cause local particles (*i.e.,* molecules) in the medium to oscillate. This particle motion can be quantified in terms of particle displacement, velocity, and acceleration. Particle motion is often described as a directional, 3-dimensional vector quantity (Simmonds and MacLennan, 2005; Southall *et al*., 2007). Marine species appear to have different sensitivities to these two sound wave components. For instance, marine mammals seem to be more sensitive to sound pressure, while fish appear to be more sensitive to particle motion (Ketten, 2000; Hastings and Popper, 2005; Southall *et al*., 2007).

Analysis of a species' anatomy, physiology and behavior can be used to determine its hearing ability (Ketten, 2000; Dooling, 2002; Hastings and Popper, 2005). Audibility curves (*e.g.*, audiograms) can be derived from determining the minimum sound pressure that is audible to an animal at different frequencies throughout its hearing range (Richardson *et al*., 1995; Dooling, 2002). The hearing curves of many animals are U-shaped (or V-shaped) and illustrate how well an animal hears at different frequencies. A schematic of a representative audiogram is shown in Figure 5 indicating the audible and inaudible regions in the hearing curve. In a given audiogram, lower pressure levels or thresholds (*i.e.,* the bottom of the curve) are regions of highest hearing sensitivity for that species. Higher sound pressure levels indicate less sensitive hearing at that frequency. In comparing two species, the one with the lower threshold values will have better (more sensitive) hearing, provided testing conditions (*e.g.*, ambient sound conditions) are the same.

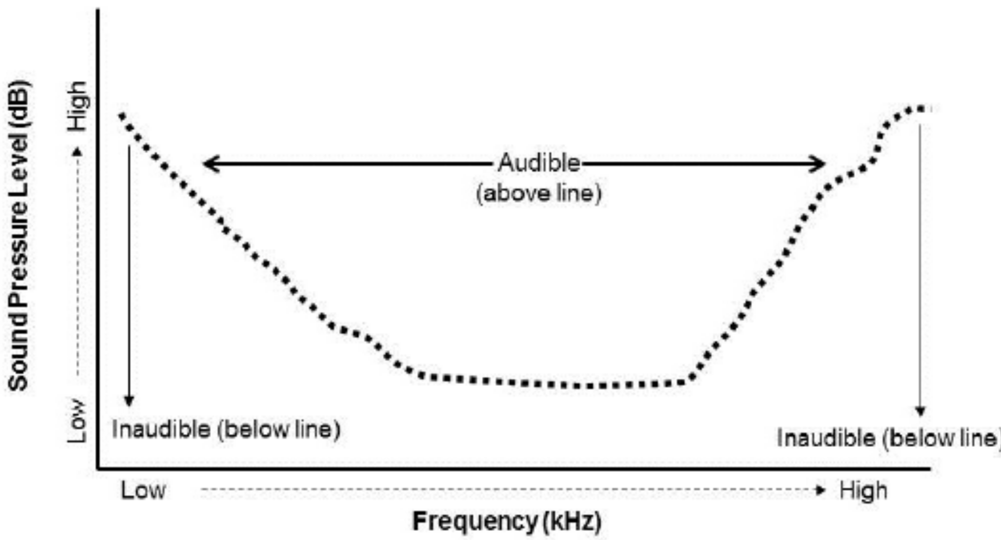

Figure 5. Schematic of an audiogram showing hearing threshold as a function of frequency. (Source: NOAA, 2013)

Auditory masking occurs when a sound of interest becomes inaudible due to interfering sounds, such as anthropogenic sounds or increased ambient sounds (Richardson *et al.*, 1995; Popper *et al.*, 2014). Masking has the potential to disrupt vocal communication between conspecifics, locating prey, detecting predators, and navigation. The degree of masking is dependent on how close the frequency range of the interfering sound is to a species' most sensitive hearing range. If the frequency range of the anthropogenic sound source does not overlap the range of hearing of a species, then the animal should not be disturbed, unless the sound level is extremely high and organ tissue damage is possible (Caltrans, 2004; Laughlin, 2007; Popper *et al.*, 2013). If the frequency ranges of the source and animal's hearing overlap, then understanding the animal's hearing sensitivity in the region of the source's highest energy is imperative for assessing the level of exposure to the animal.

In the sections that follow, for species likely to occur in the MOT area, hearing sensitivities, as illustrated by audiograms, will be compared to the vibratory pile driving proxy source levels in Figure 4 (blue line, with no bubble curtain attenuation). The vibratory pile driving proxy showed sound energy over a broad range of frequencies. The highest sound level was approximately 180 dB re 1 μPa, for the one-third octave band centered at 1 kHz (McCrodan and Hannay, 2014, see Fig. 4). Figure 4 shows that the frequency range 400 Hz to 3 kHz is a region of high energy for vibratory driving, with received levels of 170 dB re 1 μPa or more. Within a wider frequency range, 200 Hz to 10 kHz, received levels exceeded 160 dB re 1 μPa.

Marine Mammals

Cetaceans

California gray whale (*Eschrichtius robustus, O. Cetacea, F. Eschrichtiidae*)

In 1994, California gray whales were removed from the Endangered Species Act of 1973; however, they are still protected along with all other marine mammals under the Marine Mammal Protection Act of 1972 (NMML, 2015). The Eastern Pacific population of gray whales migrate from northern Arctic waters where they forage in summer to the warmer waters off Baja California, Mexico where they calve, nurse and breed in winter (Leatherwood and Reeves, 1983; NMML, 2015). By mid-December to early January gray whales are abundant from Monterey Bay to San Diego, California and are often visible nearshore (NPS, 2015). Off San Diego, gray whales usually swim within 10 km (6 mi) of the coast, with peak sightings in early January (Hornblower Cruises, 2015). By mid-February to mid-March, most of the gray whales are off Baja California, Mexico. The gray whale northern migration past California is usually further offshore than the southern migration and occurs late March to early April.

Due to the difficulties of performing hearing tests on large whales, there are no known audiograms for gray whales. Gray whales are considered part of the low frequency functional hearing group described in Table 1 (Southall *et al.*, 2007; NOAA, 2013).

Common dolphin (*Delphinus delphis, O. Cetacea, F. Delphinidae*)

Off southern California, common dolphins are a pelagic species that forage at night and are usually associated with long or steep slopes “along or seaward of the 100-fathom contour” (Leatherwood and Reeves, 1983). The 100-fathom contour is the region where the seafloor is 600 ft deep (183 m). Seasonal distributions of common dolphins off southern California occur and peak in June, September to October, and January.

Audiograms for odontocetes have a traditional U-shaped curve. The best hearing sensitivity (*i.e.*, lowest thresholds) for a common dolphin were found to be in the range 10–70 kHz, with peak hearing at 60–70 kHz (Fig. 6) (Popov and Klishin, 1998). The highest hearing threshold was at 128 kHz, but sensitivity was greatly reduced at this frequency with the threshold being nearly 100 dB re 1 μPa above the minimum threshold at 60–70 kHz. Popov and Klishin (1998) only examined hearing above 10 kHz; nevertheless, less sensitive hearing for the common dolphin should occur below 10 kHz as seen with the other dolphin species presented below.

Pacific white-sided dolphin (*Lagenorhynchus obliquidens, O. Cetacea, F. Delphinidae*)

Pacific white-sided dolphins exhibit a temperate distribution in the Pacific Ocean. Some intermingling residential communities appear to exist off Monterey, southern California and Baja California, Mexico and are seasonally present from fall through spring (Leatherwood and Reeves, 1983). They are usually seen seaward of the continental shelf and the 100-fathom isobath, but occasionally come closer to shore. Pacific white-sided dolphins are mostly nocturnal predators.

In 1998, Tremel *et al.* measured the hearing sensitivity in a Pacific white-sided dolphin in the frequency range 75 Hz to 150 kHz (Fig. 7). Their investigations showed a typical U-shaped audiogram with best hearing sensitivity (threshold level < 90 dB re 1 μPa) between 2 and 128 kHz.

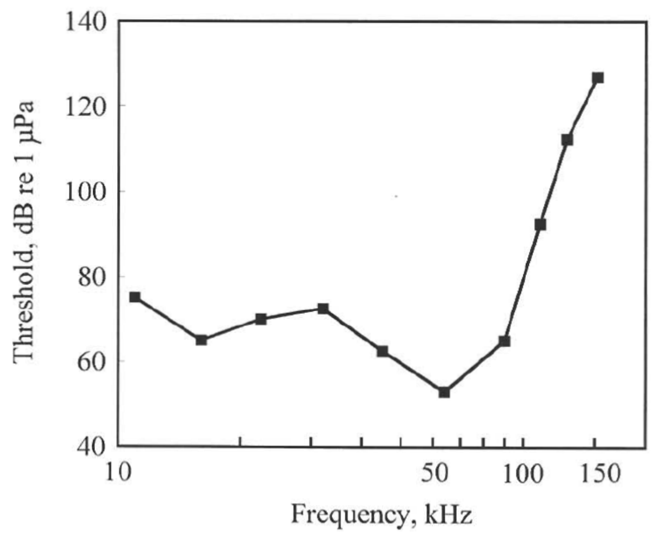

Figure 6. Underwater audiogram of a common dolphin. (Source: Popov and Klishin, 1998)

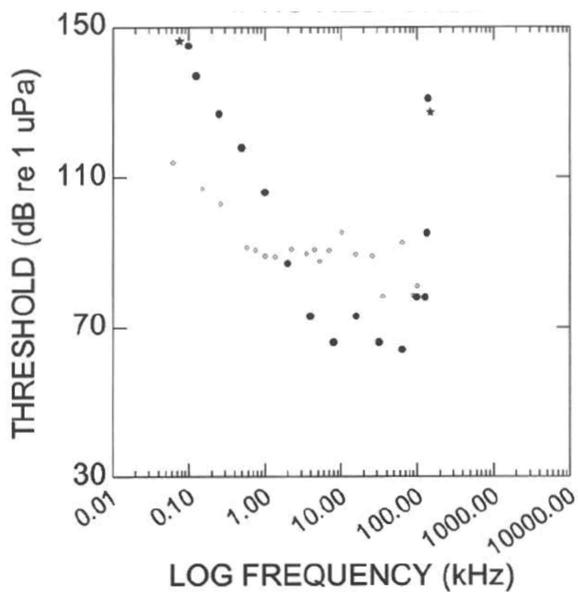

Figure 7. Underwater audiogram of a Pacific white-sided dolphin. The solid black circles denote hearing sensitivity for the white-sided dolphin. Open gray triangles are the ambient pool levels and solid stars are no responses. (Source: Tremel *et al.*, 1998)

Bottlenose dolphin (*Tursiops truncates, O. Cetacea, F. Delphinidae*)

In the eastern Pacific Ocean, bottlenose dolphins are found off southern California to Chile. Hanson and Defran (1993) found that coastal bottlenose dolphins off northern San Diego County showed site fidelity for nearshore waters, spending 99% of their time within 500 m (1640 ft) of shore and 90% within 250 m (820 ft). Some dolphins appear to be year-round residents (Defran *et al.*, 1999) that travel and forage nearshore between Baja, southern, and central California (Hwang *et al.*, 2014).

Hearing is probably better known in the bottlenose dolphin than any other cetacean species. A complete audiogram showing the hearing sensitivity for a single bottlenose dolphin obtained by Johnson in 1967 is shown in Figure 8 (Kastelein *et al.*, 2002). The hearing frequency range of this dolphin approximately spanned 200 Hz to over 100 kHz. Highest hearing sensitivity was between 10–100 kHz at the 60 dB re 1 μPa threshold. Another study testing hearing loss in bottlenose dolphins measured hearing thresholds from 10 kHz to 150 kHz for 43 bottlenose dolphins in the age range 4–47 years old (Fig. 9) (Houser and Finneran, 2006). Younger dolphins had a better range of hearing and less variability in thresholds compared to older dolphins. Most animals exhibited some hearing loss after the age of 27 years. In Figure 9, the peak sensitivities for bottlenose dolphins were in the frequency range 40–50 kHz.

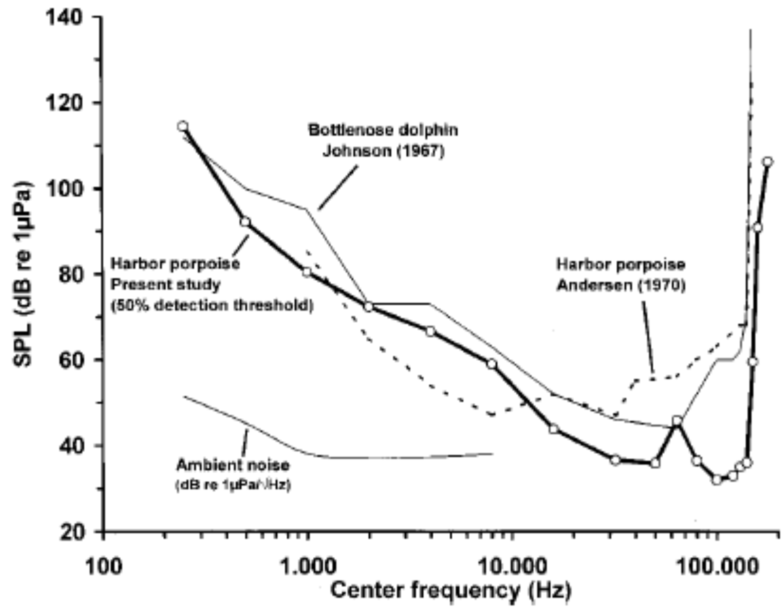

Figure 8. Underwater audiograms of a bottlenose dolphin and harbor porpoise. The bottlenose dolphin audiogram is the solid gray line, while harbor porpoise audiograms are the dashed gray and solid black lines. (Source: Kastelein *et al.*, 2002)

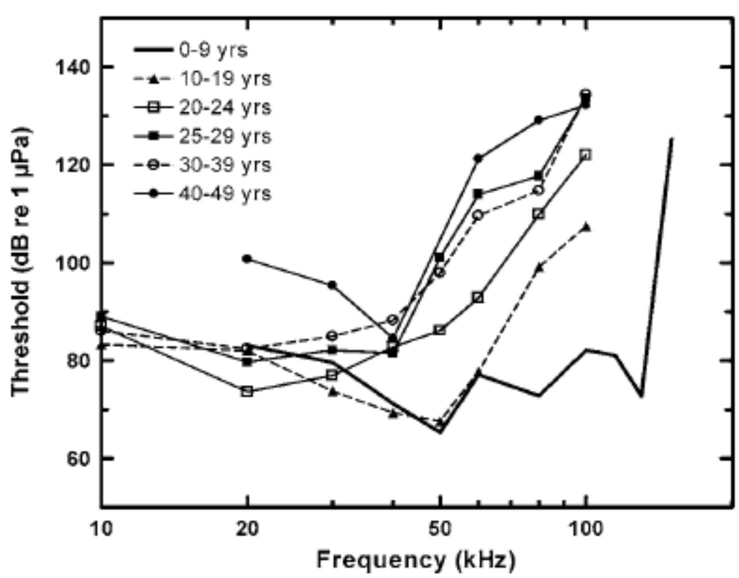

Figure 9. Mean underwater audiograms for bottlenose dolphins by age group. (Source: Houser and Finneran, 2006)

Pinnipeds

Pacific harbor seal (*Phoca vitulina richardsi, O. Carnivora, F. Phocidae*)

Pacific harbor seals, like all Phocids (*true seals*), lack external ear appendages. Harbor seals generally do not migrate and can be found in coastal and estuarine waters off California.

California sea lion (*Zalophus californianus, O. Carnivora, F. Otariidae*)

California sea lions are known as Otariid pinnipeds or *eared seals*. California sea lions reside in the eastern North Pacific in shallow coastal or estuarine waters (NOAA-OPR, 2014).

Reichmuth *et al.* (2013) compared in-air and underwater hearing sensitivities for three pinniped species (Fig. 10, top row for harbor seal and third row for California sea lion). In this study, underwater hearing sensitivities for both the harbor seal and the California Sea lion were congruous with audiograms from other studies (right column, Reichmuth *et al.* study in black, other studies in gray); however, the in-air tests showed lower thresholds for both species (left column, in black). The best underwater hearing frequency range for the harbor seal was 900 Hz to 41 kHz, while that of the California sea lion extended from 350 Hz to 37 kHz (Fig. 10 second column, first and third rows, respectively). The lowest pinniped hearing threshold was in the range 55–58 dB re 1 µPa, which is slightly higher than the lowest thresholds for fully aquatic mammals (bottom right), indicating that pinniped underwater hearing is slightly less sensitive. The "fully aquatic mammals" in Figure 10 include a manatee, a false killer whale, a bottlenose dolphin, and a harbor porpoise (the latter two, from Kastelein *et al.*, 2002, were shown earlier in Fig. 8).

Other Marine Mammal Species

Many marine mammal species have the potential to be seen in the area of interest, so for completeness, they are listed here. Unless otherwise indicated, information on the presence of these species were obtained from whale watching websites and daily logs from such groups as Hornblower Cruises, Newport Whale Watching, and San Diego Whale Watch. Other possible baleen whales in the region include blue whales (*Balenoptera musculus*), fin whales (*Balaenoptera physalus*), minke whales (*Balaenoptera acutorostrata*), and humpback whales (*Megaptera novaeangliae*). Fin whales are seen more frequently off San Diego than other baleen whales (Hornblower Cruises, 2015). There are no audiograms for blue whales, fin whales, and minke whales. A modeled audiogram for the humpback whale showed a typical U-shaped hearing curve with the most sensitive frequencies between 700 Hz and 10 kHz, with the greatest sensitivity in the range 2–6 kHz (Houser *et al.*, 2001). Other potential toothed whales in the region include killer whales (*Orcinus orca*) and Risso's dolphins (*Grampus griseus*).

The southern sea otter (*Enhydralutris lutris nereis*) is considered *threatened, wherever found* along the Pacific Coast of California on the U.S. Fish and Wildlife Service website under provisions of the Endangered Species Act (USFWS-ECOS, 2015). While southern sea otters are rare off San Diego, single otters have been seen in kelp beds located off San Diego Bay and La Jolla (Lee, 2011 and 2012). Kelp beds are located about 150–400 m (500–1300 ft) south of the MOT location. An in-air hearing test on a sea otter showed similar hearing thresholds to sea lions, with their best hearing threshold around 70 dB re 20 µPa at 8 kHz (Ghoul and Reichmuth, 2014). In contrast, underwater hearing sensitivity of the sea otter was greatly reduced compared to underwater hearing in the sea lions and other pinnipeds, indicating that sea otters are better adapted for airborne hearing.

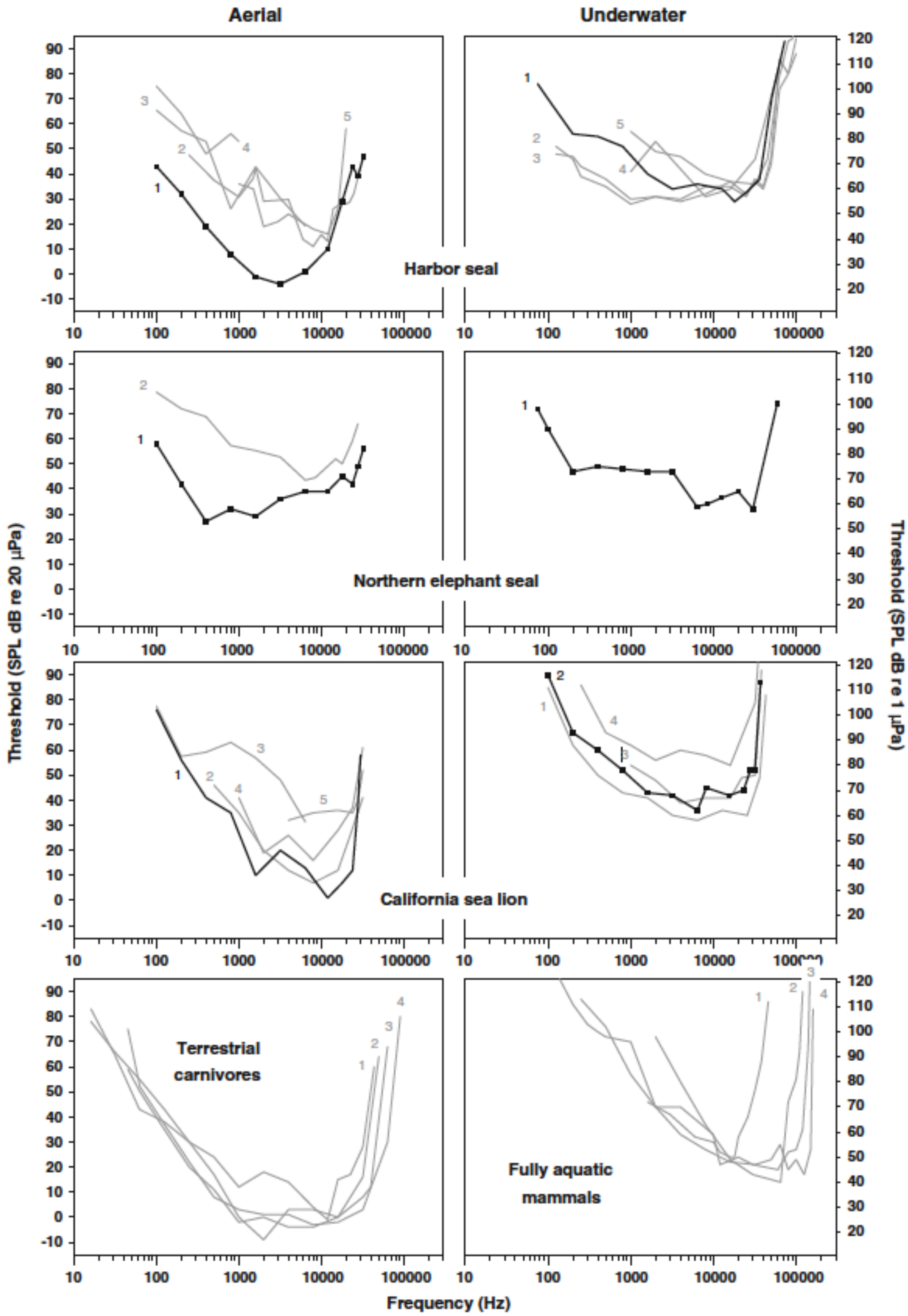

Figure 10. In-air and underwater hearing thresholds for three species of pinniped. Threshold levels in air are in dB re 20 µPa (on left y-axis) while underwater levels are in dB re 1 µPa (on right vertical axis). Black lines are from the Reichmuth *et al.*, 2013 study, while gray lines show results from other studies. (Source: Reichmuth *et al.*, 2013)

Potential Impacts on Marine Mammals

Gray whales migrate annually past the southern California region within 6 miles (10 km) of shore from approximately December to mid-February. LF cetacean hearing overlaps the entire higher energy region of the pile driver proxy (Table 1 and Fig. 4). If the pile driving occurs during their southern migration, gray whales have the potential to be exposed to the maximum energy levels emitted. If the vibratory pile driving characteristics of the proxy (*e.g.*, frequency range and sound levels) is a close approximation to the actual unknown pipe ramming emissions at the MOT location and gray whales are within 10 km of shore, then behavioral impacts are potentially a concern. Proximity to the sound source is important for this species; however, impacts due to sound duration should be temporary since these whales are predominantly migrating and should not be deterred by any short divergences from their path, especially with a man-made sound nearshore. Outside of the December to mid-February timeframe, gray whales should not be impacted because they will be swimming far offshore or absent from the area.

Mid-frequency cetacean audiograms only partially overlap the frequency range of the proxy, so impact to these dolphins is expected to be minimal (Fig. 4 and 6 through 8), except for the coastal bottlenose dolphin. Both the common and Pacific-white sided dolphins are expected to found along or seaward of the 100-fathom curve (*i.e.*, region where water depth is 600 ft or more), which is several kilometers from the sound source at the MOT location. While these dolphins may detect the pipe ramming, impact is expected to be low. These two species also forage at night when presumably construction operations will be ceased. The coastal bottlenose dolphin spends most of its time within 500 m of shore, and shoreward of the MOT location. The proxy sound levels are highest at ~1 kHz, which is a region of low hearing sensitivity in bottlenose dolphins. Meanwhile, the region of the dolphins' greatest sensitivity (~10 kHz) corresponds to frequencies at which the energy content of the pile driving is low. Close proximity and duration of the sound source will be important factors for assessing overall exposure and could potentially impact their behaviors. If these coastal dolphins are in the area, their foraging, communication, and normal swimming trajectories could be impacted, as well as vocal communication masked.

The hearing ranges for both the harbor seal and California sea lion overlap the entire frequency range of the pile driving proxy (Fig. 4 and 10). Furthermore, the highest sound levels for the pile driving proxy overlap frequencies at which pinniped hearing is most sensitive. Harbor seals and California sea lions that may be seen near the MOT location are likely local inhabitants that swim close to shore. Both the amplitude and duration of exposure will increase the impact on these pinnipeds. While pinnipeds are capable of swimming away from the construction site, special consideration should be made for animals that remain, since the immediate area may be their habitat or they may be disoriented by the sound.

Indicators that may predict stress or behavioral harassment in marine mammals subjected to anthropogenic sounds (*e.g.*, pile driving) include avoidance of the area containing the sound source, disruption of foraging or social activities, changes in swimming direction or speeds, and changes in surface-dive behaviors (Richardson *et al.*, 1995; Caltrans, 2001; Koschinski *et al.*, 2003; Nedwell *et al.*, 2003; Southall *et al.*, 2007; Brandt *et al.*, 2011; Finneran and Jenkins, 2012; Dähne *et al.*, 2013; NAVFAC SW, 2014); some of these responses may also have physiological effects. Masking due to man-made sounds may also make it more difficult to communicate with conspecifics or locate food, and may force animals to modify their vocalizations to be heard (Richardson *et al.*, 1995; Koschinski *et al.*, 2003; Scheifele *et al.*, 2005).

Fishes

Fishes are a very diverse group of marine species with over 32,000 extant species (Popper *et al.*, 2014) that can be divided into two major groups based on their skeletal structure: bony fish (Osteichthyes) and cartilaginous fish (Chordrichtyes). Bony fish include the teleost fishes (*e.g.*, commercial fishes like salmon, perch) and more primitive fishes (*e.g.*, sturgeons) (Hastings and Popper, 2005). Cartilaginous fish are sharks and rays. Bony fish can also be divided into two hearing groups, hearing specialists and hearing generalists (Popper, 2003; Ladich and Popper, 2004).

Animals hear sounds by detecting the mechanical motion of a sound source within a medium (Hastings and Popper, 2005; Popper *et al.*, 2014). Fishes have three otolithic organs in their inner ears. Otoliths are stiff fluid-filled calcareous masses that lay near sensory epitheliums that contain thousands of sensory hair cells thought to be involved in sound detection (Popper, 2003). Hair cells are also present along the lateral lines of their bodies to detect water movement. Fishes hear when hair cells are directly stimulated by particle motion in the water. Some fishes also have swim bladders or other air sacs that can detect and convert the pressure component of a sound field into particle motion, which indirectly stimulates the inner ear, allowing the fishes to detect sound.

Hearing specialists have adaptations that lower their hearing threshold, thereby enhancing their ability to detect sounds in their hearing range (Popper, 2003; Hastings and Popper, 2005). For instance, unlike hearing generalists, whose primary hearing is provided by direct stimulation of the inner ear, hearing specialists have evolved several mechanisms to acoustically couple the swim bladder to the ear. Specializations that enhance hearing vary among species and may include an extension on the swim bladder, a direct mechanical connection between the bladder and inner ear, or a separate bubble of gas that lies near the ear (Ramcharitar *et al*. 2001; Hastings and Popper, 2005; Popper *et al.*, 2014). Fishes with adaptations that affect their hearing generally have lower sound pressure thresholds and wider frequency ranges of hearing (Popper *et al.*, 2014). Some hearing specialists can hear up to 3–4 kHz (Mann *et al.*, 2001; Hastings and Popper, 2005), while a few species can detect ultrasound (Mann et al., 2001).

The majority of fishes are hearing generalists, and it is thought that the fishes in the Pacific Ocean are also mostly hearing generalists (Hastings and Popper, 2005). Hearing generalists usually only hear in the frequency range of 1.0–1.5 kHz.

Osteichthyes (Bony Fish)

Bony fish can be divided into ray-finned fish (class *Actinopterygii*) and lobe-finned fish (*Sarcopterygii*) (Moyle and Cech, 1996). The ray-finned fish are the dominant fish in the oceans and are a highly diverse class of fishes comprised mostly of teleosts. All the representative bony fish presented here are from the class *Actinopterygii*.

Most teleost fish have swim bladders or a gas-filled cavity (Paxton and Eschmeyer, 1998). However, adaptations associated with the swim bladder for improving hearing thresholds vary greatly among species. Since similar fish in different oceans may not have evolved the same hearing adaptations, Hastings and Popper (2005) warned against making hearing threshold assumptions about similar species, without sufficient knowledge. However, based on their research and findings, Hastings and Popper (2005) were comfortable making a few cross-ocean comparisons, which are shown in the upcoming section.

Northern anchovy (*Engraulis mordax, O. Clupeiformes, F. Engraulidae*)

Clupeiformes (*e.g.*, sardines, herrings, shads, menhaden, anchovies) have swim bladders and are known hearing specialists in the Pacific Ocean (Paxton and Eschmeyer, 1998; Hastings and Popper, 2005).

Hastings and Popper (2005) provided audiograms of fish thought to have equivalent hearing sensitivities to some species found in the Pacific Ocean (Fig. 11). The audiogram (in green) of the sardine is thought to be equivalent to Pacific Ocean sardines and anchovies. In Figure 11, the sardines had one of the widest auditory bandwidths. This audiogram suggests that the upper frequency range of the northern anchovy may reach 2 kHz, which is higher than the upper range of hearing generalists.

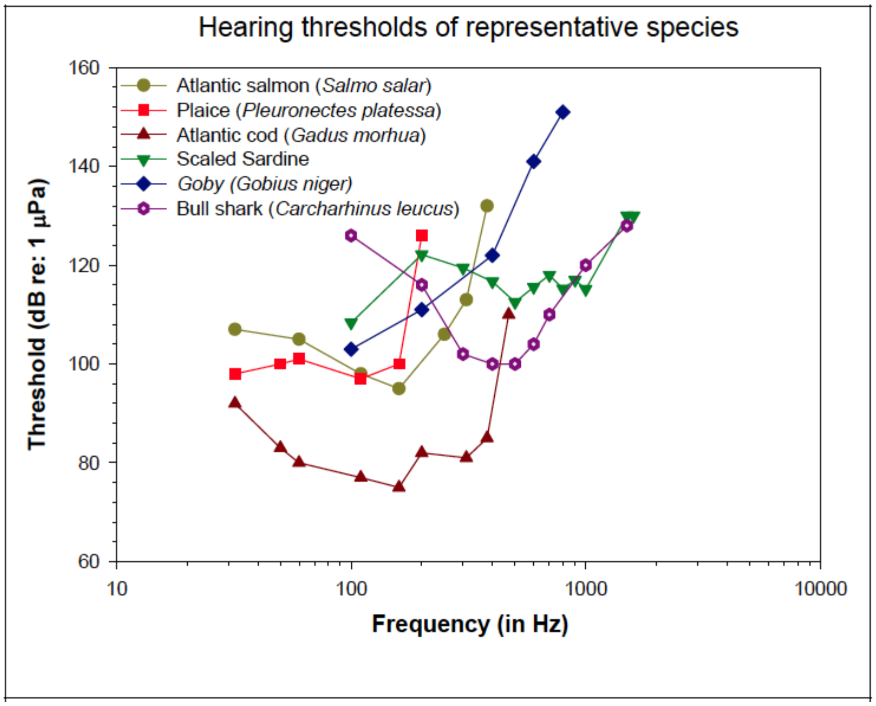

Figure 11. Representative fish audiograms thought to be equivalent to Pacific Ocean species. (Source: Hastings and Popper, 2005).

<u>Blackeye goby (*Rhinogobiops nicholsii, O. Perciformes, F. Gobiidae*)</u>

In contrast to most other fish, gobies do not have lateral sensory lines along the sides of their bodies (*e.g.*, to detect motion) (Paxton and Eshmeyer, 1998; Popper, 2003). The blackeye goby inhabits areas with hard substrates. A representative goby audiogram can be seen (in blue) in Figure 11 (Hastings and Popper, 2005). The upper frequency limit of the goby in this example is less than 1 kHz.

<u>Kelp bass (*Paralabrax clathratus, O. Perciformes, F. Serranidae*)</u>

Kelp bass are a nearshore, shallow-water fish off southern California (CDFW, 2015). Kelp bass are one of several larger fishes, along with surfperch and rockfish that swim in kelp beds to forage (Moyle and Cech, 1996). Kelp beds are located immediately south of the MOT location.

<u>Barred sand bass (*Paralabrax nebulifer, O. Perciformes, F. Serranidae*)</u>

Barred sand bass reside in sandy environments often at very shallow depths. Figure 12 shows audiograms of two species of bass that have a hearing range from 100 Hz to approximately 1 or 2 kHz.

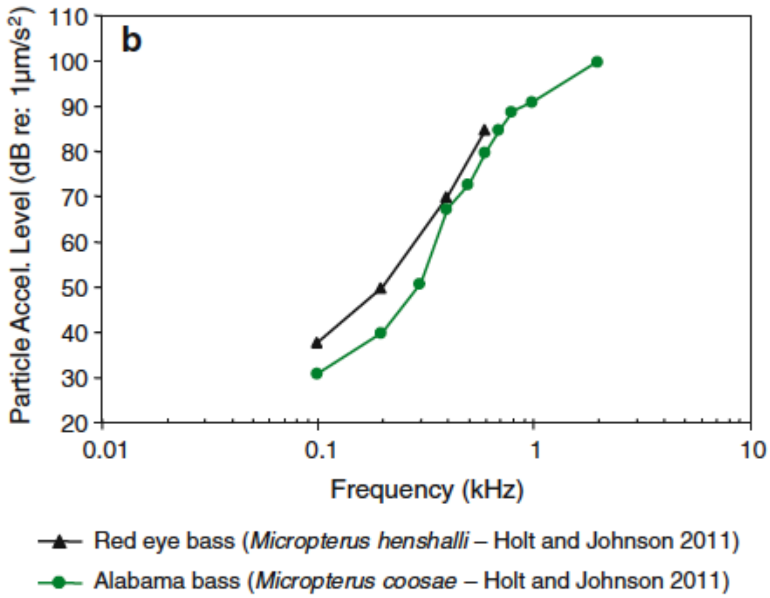

Figure 12. Audiograms for two bass species. (Source: Ladich and Fay, 2013)

Pacific Chub Mackerel (*Scomber japonicas, O. Perciformes, F. Scombridae*)

Pacific chub mackerel have swim bladders (Paxton and Eschmeyer, 1998). Juveniles live off sandy beaches and near kelp beds, while adults often live further out near shallow banks. Populations of Pacific mackerel are more abundant nearshore from July to November and more common offshore from March to May. Their peak spawning time nearshore is June through October.

White croaker (*Genyonemus lineatus, O. Perciformes, F. Sciaenidae*)

Swim bladders and otoliths (inner ear organs) are very diverse between croaker species (Paxton and Eschmeyer, 1998). White croakers occur near shallow, sandy bottoms (CDFW, 2015).

Queenfish (*Seriphus politus, O. Perciformes, F. Sciaenidae*)

Queenfish are a species of croaker closely related to the white croaker. The queenfish are a shallow water fish, preferring sandy substrates (CDFW, 2015).

California barracuda (*Sphyraena argentea, O. Perciformes, F. Sphyraenidae*)

California barracuda usually prefer coastal areas near reefs or kelp (Moyle and Cech, 1996; CDFW, 2015). In southern California waters, spawning takes place from April to September, peaking in June.

California lizardfish (*Synodus lucioceps, O. Aulopiformes, F. Synodontidae*)

Lizardfish and their relatives have both primitive and modern body attributes (Paxton and Eschmeyer, 1998). One of the more modern attributes is the presence of a swim bladder without a duct. California lizardfish sit at the bottom with pectoral fins on the seafloor. They reside in shallow, sandy environments and often congregate in groups to spawn beginning in summer and peaking in fall.

Speckled sanddab (*Citharichthys stigmaeus, O. Pleuronectiformes, F. Paralichthyidae*)

Speckled sanddabs are a flounder species that inhabit the intertidal zone and are common over muddy or sandy seafloors (Rackowski and Pikitch, 1989). Most flatfish lose their swim bladders in the transition between larva and fish stages (Paxton and Eshcmeyer, 1998).

California halibut (*Paralichthys californicus, O. Pleuronectiformes, F. Bothidae*)

The California halibut is a lefteye flatfish (Goodsen, 1998; CDFW, 2015). California halibut generally occur over sandy bottoms in shallow waters nearshore.

Horneyhead turbot (*Pleuronichthys verticalis, O. Pleuronectiformes, F. Pleuronectidae*)

Horneyhead turbot are righteye flatfish that are closely related to flounders, halibuts, sanddabs and soles (Goodson, 1988; Paxton and Eschmeyer, 1998). They reside on or in sandy bottoms.

Chordrichthyes (Cartilaginous Fish)

Thornback ray (*Platyrhinoidis triseriata, O. Rajiformes, F. Platyrhinidae*)

Thornback rays are an abundant species off southern California and are often found near kelp beds (Tricas *et al*., 1997). The upper hearing frequency limit for Chordrichthyes is usually only 800 Hz (Hastings and Popper, 2005). Audiograms for three cartilaginous fish species are shown in Figure 13. The blue line is an audiogram for a ray species. There is no known audiogram for the Thorback ray.

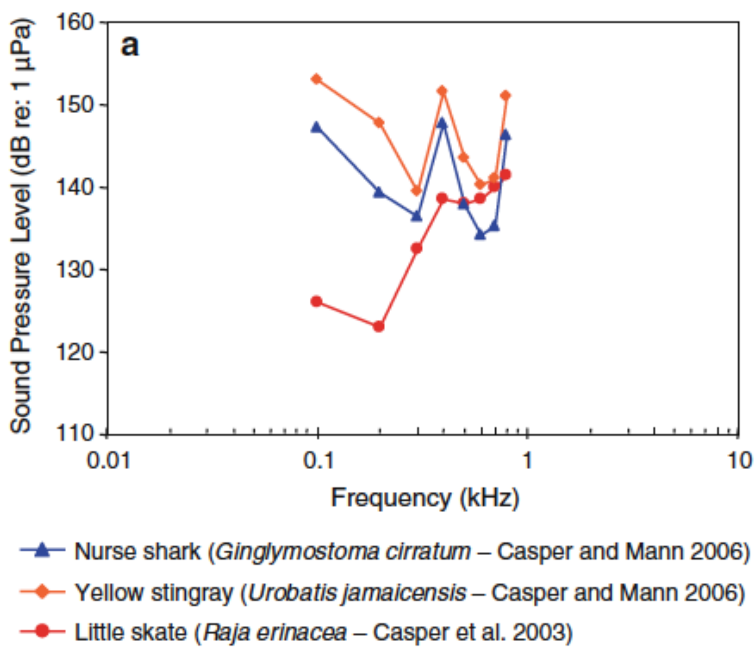

Figure 13. Audiograms for three species of cartilaginous fish. (Source: Ladich and Fay, 2013)

Other Fish Species

Since there are kelp beds immediately south of the MOT location (Fig. 1), a few more species that may be impacted by the pipe ramming are listed here. The California sheephead (*Semicossyphus pulcher*), rock wrasse (*Halichoeres semicinctus*), topsmelt (*Atherinops affinis*), black surfperch (*Embiotoca jacksoni*), kelp surfperch (*Brachyistius frenatus*), white surfperch (*Phaenerodon furcatus*), and senorita

(*Oxyjulis californica*) (Moyle and Cech, 1996; CDFW, 2015). None of the fishes described here are considered *endangered* or *threatened* species by the U. S. Fish and Wildlife Service for San Diego County.

Potential Impacts on Fishes

Obtaining audiograms on individual fish species is difficult because thousands of fish species exist and hearing abilities vary within taxonomical groups and between oceans (Hastings and Popper, 2005). Many fishes in the Pacific Ocean are probably hearing generalists and hear only up to 1.0–1.5 kHz, while hearing specialists mostly hear up to 2 kHz (*e.g.*, northern anchovy) (Hastings and Popper, 2005). Cartilaginous fish (*e.g.*, thornback ray) hearing abilities are less sensitive and only reach ~800 Hz. Fish audiograms presented above partially overlap the frequency region of high energy for the proxy (Fig. 4 and 11 through 13). Since fishes have such diverse ecologies, both the sound level exposure and duration will be important to the overall fish environment in the MOT area. Considering hearing sensitivity alone, the northern anchovy, a hearing specialist, would be able to detect the highest energy levels and may be the most sensitive to sound levels emitted by DPR. Fish injuries are more related to particle motion than pressure and increased sound levels may affect sensory cilia located along their bodies and in their inner ears (Popper, 2003; Hastings and Popper, 2005). A fish's placement with respects to the seafloor may also alter the types of sounds they receive (Popper *et al*., 2014). While fishes normally associated with the water column will be exposed to waterborne sounds (*e.g.*, mackerel, barracuda), fishes close to the seafloor may be exposed to both waterborne and subsurface sounds (*e.g.*, flatfish, lizardfish).

Fishes are especially sensitive to sound and those within close proximity to a loud or prolonged sound source may be impacted by death, hearing loss and non-auditory tissue damage (McCauley *et al.*, 2003; Popper, 2003; Caltrans, 2004; Laughlin, 2007; Popper *et al.*, 2013). Fishes with swim bladders or other air cavities may be more sensitive than fishes lacking these attributes (Popper *et al.*, 2013). Complicating matters, the size of a fish species' environment may be much smaller compared to other marine species, with some animals being more sedentary. For some fishes swimming several meters or kilometers away may be energetically costly or not an option. Hence, proximity and duration are very important components when assessing the impact of DPR on fish. Rest periods in pile driving bouts could potentially help the hearing cilia and air cavities to recover to minimize damage, while soft start-ups may give time for nearby sedentary fishes to move further away from the sound source.

Indicators of stress or behavioral impacts by man-made activities (*e.g.*, sound, physical disturbance) on fish vary greatly. Non-fatal responses of fish to sound include changes in swimming behavior, water column position, and schooling patterns, and may also elicit startle responses, area evacuation, and *freezing* in place reactions (Anderson, 1990; Pearson *et al*., 1992; McCauley *et al.*, 2000; Wardle *et al.*, 2001; Nedwell *et al*., 2003; Popper, 2003; Hassel *et al*., 2004). An additional vulnerability for fish during pile driving and decommissioning construction is disturbance to their benthic habit, such as displacement of soils. Fish may be impacted by smothering, changes in water turbidity and sediments, and chemical contaminants (Michel *et al.*, 2007). These conditions may not only have physiological impacts but could make finding prey or detecting predators more difficult.

Sea Turtles

Sea turtles are highly migratory and little is known about their pelagic life outside nesting habitats (Eckert, 1993), making it difficult to study their hearing and responses to anthropogenic sounds (Popper *et al.*, 2014). Sea turtle ear anatomy shows basic reptilian ears with some underwater adaptations (Popper *et al.*, 2014). Their hearing sensitivity is thought to be more similar to fishes than marine mammals. The hearing sensitivities of a few species of sea turtles have been examined. Small variations in hearing have been found between green, loggerhead, and Kemp's ridley sea turtles, however results suggest that they are all sensitive to low-frequency sounds (Ridgway *et al.*, 1969; Bartol *et al*., 1999; Ketten and Bartol, 2006; Martin *et al.,* 2012). Sea turtles appear not to use sound for communication, however sound may play a role in their navigation, prey and predator detection, and general movement in their environment (Piniak *et al*., 2012).

Leatherback sea turtle (*Dermachelys coriacea, O. Testudines, F. Dermochelyidae*)

Leatherback sea turtles are listed as *endangered, wherever found*, on the U.S. Fish and Wildlife Service under the Endangered Species Act of 1973 for the Pacific Ocean including San Diego County (USFWS-ECOS, 2015). Adult leatherback sea turtles have extensive migration ranges (Eckert, 1993; NMFS-USFWS, 1998b). They are the most common sea turtle in U.S. waters north of Mexico and have been seen in San Diego Bay (NMFS-USFWS, 1998b). They frequent the waters north of central California during the summer and fall when surface temperatures are the highest (Eckert, 1993).

Recently, Piniak *et al.* (2012) tested the hearing sensitivities of leatherback sea turtle hatchlings in both water and air and determined that they are capable of detecting anthropogenic sounds in both media. The detectable underwater frequency range was 50 Hz to 1.2 kHz (Fig. 14), while in-air ranges were slightly wider from 50 Hz to 1.6 kHz (Fig. 15). Highest sensitivity to underwater sounds was in the range 100–400 Hz, with a lowest threshold of 84 dB re 1 μPa_{rms} at 300 Hz. In-air leatherback hearing was most sensitive in the range 50–400 Hz, with a 62 dB re 20 μPa_{rms} threshold at 300 Hz. Leatherback hearing declined rapidly above 400 Hz.

Green sea turtle (*Chelonia mydas, O. Testudines, F. Cheloniidae*)

The green sea turtle is listed as *threatened* on the U.S. Fish and Wildlife Service throughout the Pacific range (including San Diego County) under the Endangered Species Act of 1973 (USFWS-ECOS, 2015). As with other sea turtles little is known about their pelagic locations and migrations. In the 1990s, there was a resident population of green sea turtles in San Diego Bay, California (NMFS-USFWS, 1998a). There is no known nesting on the U.S. West Coast; however, nests have been seen in the Hawaiian archipelago and other islands in the Pacific Ocean and Mexico (Eckert, 1993). Green sea turtles reside in nearshore benthic (close to the seafloor) environments.

Underwater audiograms for subadult green turtles indicate a hearing range of 100–500 Hz, with the most sensitive hearing at 200–400 Hz (Fig. 16) (Bartol and Ketten, 2006). Hearing thresholds at the most sensitive frequency, 300 Hz, were in the range 83–100 dB re 1 μPa.

Olive ridley sea turtle (*Lepidochelys olivacea, O. Testudines, F. Cheloniidae*)

The olive ridley sea turtle is listed as *threatened* on the U.S. Fish and Wildlife Service along the Pacific Ocean coast of the U.S. under the Endangered Species Act of 1973 (including San Diego County) (USFWS-ECOS, 2015). Olive ridley numbers are low in U.S. waters, however they have been found as fishery bycatch in the San Diego region (NMFS-USFWS, 1998c). Sea turtles mostly inhabit shallow coastal waters, bays, lagoons and estuaries but can also be found in the open sea (NOAA, 2014). In the eastern Pacific, larger aggregations of nesting olive ridley females occur from northern Costa Rica to southern Mexico from September through December, however smaller groups are found nesting as far north as southern Baja California (Plotkin, 1995; NMFS-USFWS, 1998c). Olive ridley sea turtles have been seen mating off La Jolla, California, however no nesting has been seen in the region (NMFS-USFWS, 1998c).

There is no known hearing information for the olive ridley sea turtle; however, there are some data on hearing for another sea turtle in their taxonomic genus, the Kemp's ridley sea turtle (*Lepidochelys kempii*), which may be applicable. The underwater hearing for the two juvenile Kemp's ridley turtles examined ranged 100–500 Hz, with a lowest threshold level of approximately 110 dB re 1 µPa at 200 Hz (Bartol and Ketten, 2006).

Loggerhead sea turtle (*Caretta caretta, O. Testudines, F. Cheloniidae*)

The loggerhead sea turtle is listed as *endangered* in the North Pacific Ocean under the Endangered Species Act of 1973 (NOAA, 2015). In waters off the U.S. West Coast, loggerheads are an open ocean species that have been seen from Alaska to Chili. An important foraging habitat for juvenile loggerheads is located off Baja California Sur, Mexico. While occurrences off southern California are rare, juvenile loggerheads have recently been observed (NOAA-SWFSC, 2015).

Hearing sensitivities of a loggerhead sea turtle were determined using both audio evoked potential and behavioral methodologies (Martin *et al.*, 2012). Best hearing for the loggerhead sea turtle was in the frequency range 100-400 Hz (Fig. 17).

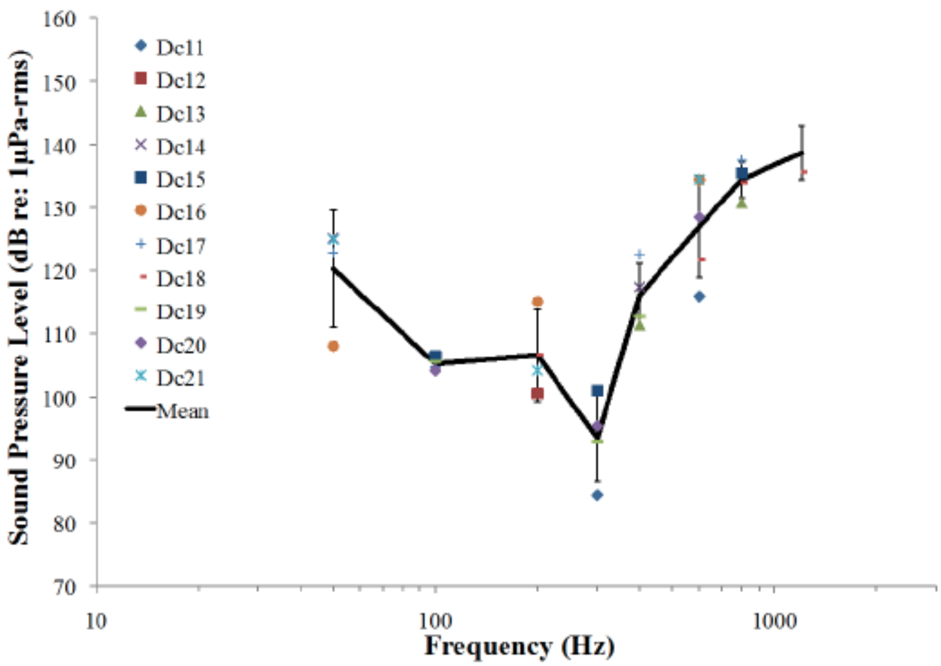

Figure 14. Underwater audiograms of eleven leatherback sea turtle hatchlings. Mean audiogram is highlighted in black. (Source: Piniak *et al.*, 2012)

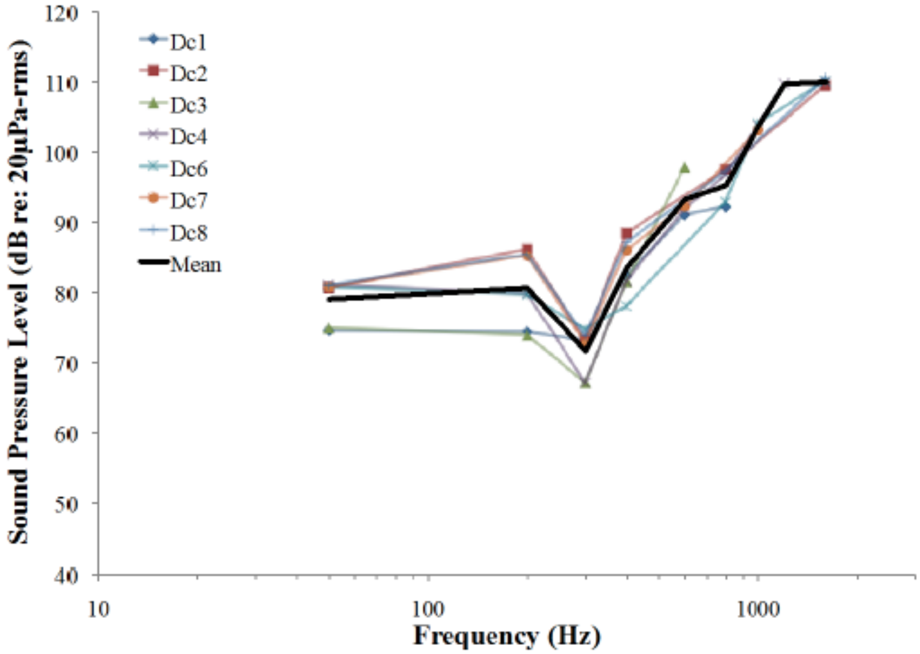

Figure 15. In-air audiograms of seven leatherback sea turtle hatchlings. Mean audiogram is shown in black. (Source: Piniak *et al*., 2012)

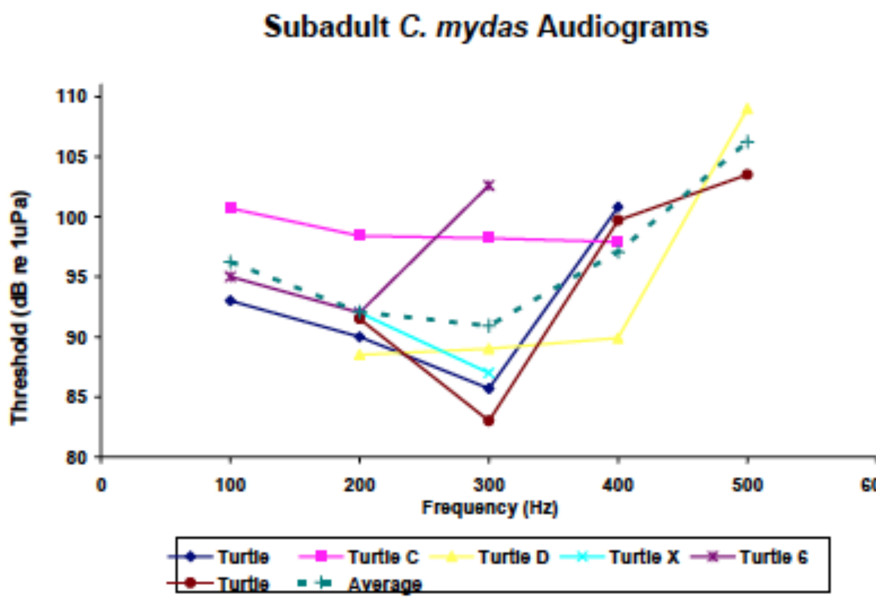

Figure 16. Underwater audiograms for six subadult green turtles. (Source: Bartol and Ketten, 2006)

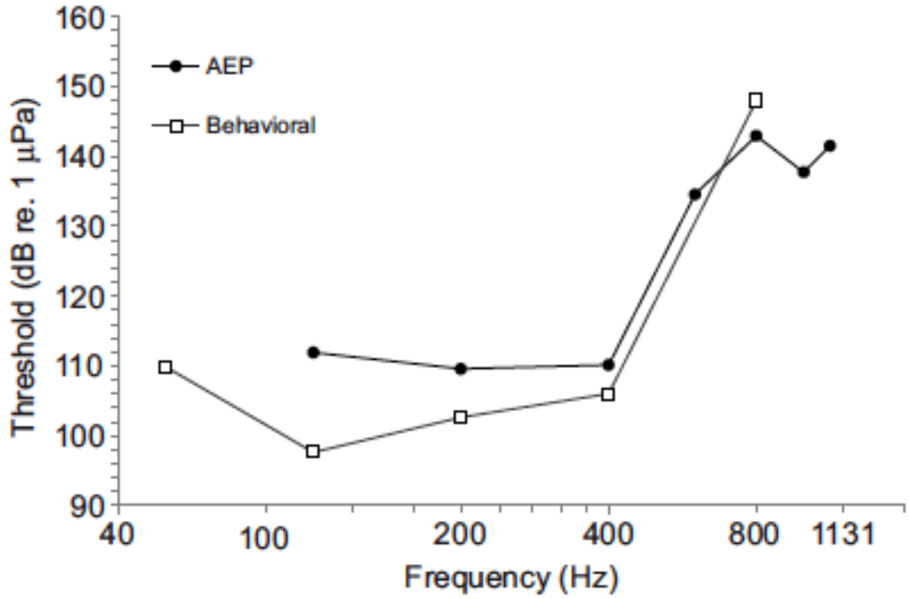

Figure 17. Underwater audiograms of a loggerhead sea turtle using both AEP and behavioral methods. (Source: Martin *et al*., 2012)

Potential Impacts on Sea Turtles

There is overlap between the hearing range of turtles and the sound frequencies produced by the vibratory pile-driving proxy (see Fig. 4 versus Fig. 14 ,16, and 17), but the proxy's frequency of maximum energy (1 kHz) is at the upper end of the turtle hearing range, where the turtles' ability to detect the sound is expected to be poor. The sound level and duration of exposure are likely important components for sea turtles since they are slow swimmers, and it would take longer for them to leave an area. Leatherback and loggerhead sea turtles may be most impacted by noise exposure due to their broader hearing range (*i.e.*, 200–1000 Hz) (Fig. 4, 14, and 17). However, the likelihood of them being in the MOT area is very low.

Leatherback and loggerhead sea turtles are *endangered* species, while both the green and olive ridley sea turtles are *threatened* species, so extra precautions and potential mitigation need to be taken if they enter the area.

Some potential responses of sea turtles to man-made sounds include increased surface time, decreased foraging, displacement, and startle reactions (Michel *et al.*, 2007; Finneran and Jenkins, 2012). Another species of sea turtle, loggerheads (*Caretta caretta*), have been observed avoiding the region near loud sound sources and both green and loggerhead sea turtles were observed swimming at increased speeds away from the source, possibly indicating stress (McCauley *et al*., 2000; Finneran and Jenkins, 2012). Loggerheads have also been seen diving in response to airgun sounds (DeRuiter and Doukara, 2012).

Birds

Compared to other vertebrates, birds have relatively consistent auditory structures and hearing capabilities (*e.g.*, absolute thresholds, range of hearing) regardless of bird size (Dooling, 2002). The center frequency and high frequency limits of bird hearing, however, are inversely proportional to the bird's size and weight. On average, a bird's hearing ranges from 500 Hz to 6 kHz, with some exceptions (Dooling, 2002). No birds are known to hear over 15 kHz. Birds are limited in their upper frequency hearing abilities because they retained the single ossicle middle ear (Manly and Gleich, 2011).

Due to their higher hearing thresholds, birds are not as sensitive to sounds at the same frequency as humans. In 2002, Dooling examined in-air bird hearing sensitivities in relation to wind-turbine noise and deterrent devices (*e.g.*, pingers), the latter used to signal to animals the presence of man-made objects or structures (*e.g.*, turbines). He concluded that using human hearing abilities to choose appropriate deterrent devices was erroneous, since humans have lower auditory thresholds than birds at the same frequency. For instance, while humans can detect sounds at 5 dB re 20 μPa SPL at 1 kHz, while birds need 20 dB re 20 μPa SPL to detect the same frequency. Considering sound propagation and distance to the sound source, birds would need to be half the distance to the source, compared to humans, before they would detect the sound. This could be detrimental since the bird has less response time before encountering the sound source.

Dooling (2002) provided median in-air audiograms for three greater groups of birds (Fig. 18): Passeriformes, non-Passeriformes and Strigiformes. The species within the southern California coastal region can be separated into two of these groups (Passeriformes and non-Passeriformes). Bird species of the order Passeriformes, otherwise known as passerines, contain more than half the bird species. Passerines include songbirds such as sparrows, canaries, starlings and finches (Dooling, 2002; Dooling and Popper, 2007). The non-Passeriformes group includes chickens, turkeys, pigeons, and parrots. In Figure 18, the night-foraging birds (*e.g.*, many owl species) of taxonomic order Strigiformes appear to have the most sensitive hearing. Passeriformes tend to have better high frequency hearing than non-Passeriformes, while non-Passeriformes are slightly more sensitive to quieter, low-frequency sounds (Dooling, 2002; Dooling and Popper, 2007).

Therrien (2014) measured in-air audiograms for 10 species of diving birds and found that their hearing had the typical U-shaped curve with the highest sensitivity in the range 1–3 kHz. Hearing thresholds, however, varied among species with the duck species having the lowest in-air hearing abilities. A second experiment tested in-air and underwater hearing in a single species, the long-tailed sea duck (*Clangula hyemalis*), an arctic species that rarely reaches as far south as southern California (Alderfer, 2014). Due to the difficulties of training birds for underwater audiograms, the results presented here are the first auditory threshold measurements for a diving bird species. Therrien (2014) showed that in-air hearing sensitivity for long-tailed sea ducks is greatest at 2 kHz, while underwater tests showed they reliably respond to signal levels of 117 dB re 1 μPa between the frequencies of 500 Hz and 2.86 kHz.

Since our knowledge of underwater hearing in birds is limited, information on bird hearing presented in this section is derived from in-air audiograms.

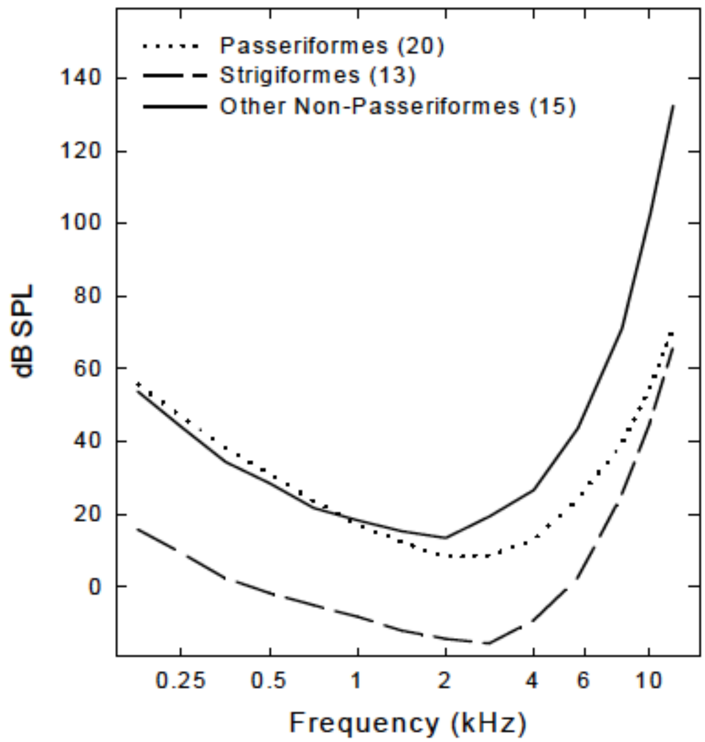

Figure 18. Mean in-air audiograms from Passeriformes, non-Passeriformes and Strigiformes. (Source: Dooling, 2002)

Passeriformes

Coastal California gnatcatcher (*Polioptila californica, O. Passeriformes, F. Polioptilidae*)

Coastal California gnatcatcher are classified as *threatened, wherever found* along coastal southern California, including San Diego County, and northwestern Baja California, Mexico (USFWS-ECOS, 2015). The coastal gnatcatchers are a non-migratory species that breeds from February through July in coastal shrubs and nests from mid-March to mid-May in California sagebrush (USFWS, 2010). While there are no audiograms for the coastal California gnatcatcher, hearing for this songbird is expected to be similar to Passeriformes (Fig. 18).

Representative Passeriformes in the local area that are not endangered or threatened include the house finch (*Carpodacus mexicanus*), European starling (*Sturnus vulgaris*), house sparrow (*Passer domesticus*), American crow (*Corvus branchyrhynchos*), black phoebe (*Sayornis nigricans*), common yellowthroat (*Geothlypis trichas*), California towhee (*Pipilo crissalis*).

Non-Passeriformes

Western snowy plover (*Charadrius alexandrinus nivosus, O. Charadriiformes, F. Charadriidae*)

In 1993, the Pacific coastal population of the western snowy plover was listed as *threatened* under provisions of the Endangered Species Act of 1973, as amended (16 U.S.C. 1531 *et seq.*) (USFWS, 2007; USFWS-ECOS, 2015). The Pacific coast population is defined as western snowy plover individuals that nest within 50 miles of the Pacific Ocean coast, peninsulas, offshore islands, bays, estuaries, or rivers from southern WA, U.S. to southern Baja California, Mexico (Wilson, 1980; USFWS, 1993). Resident and migrant snowy plovers nest in the region from March to September (USFWS, 2007). There are no known audiograms for the western snowy plover, however their hearing should be similar to that of the non-Passeriformes (Fig. 18).

<u>California least tern (*Sternula antillarum browni, O. Charadriiformes, F. Sternidae*)</u>

The California least tern is classified as *endangered, wherever found* along the Pacific Coast, including San Diego County (USFWS-ECOS, 2015). The least tern is a migratory bird that nests in southern California usually from April to August (USFWS, 1985). They have been sighted in many locations around San Diego (*e.g.*, Agua Hedionda Lagoon). There are no known audiograms for the California least tern, but hearing should be similar to non-Passeriformes (Fig. 18).

Representative non-Passeriformes in the local area that are not endangered or threatened include the rock pigeon (*Columba livia*), mourning dove (*Zenaida macroura*), and western gull (*Larus occidentalis*).

Other Bird Species

A few other bird species may come within proximity of the MOT, since they may inhabit, forage, or nest at the nearby Aqua Hedionda Lagoon. The most noteworthy due to its endangered status is the light-footed clapper rail; however, a few other species will also be mentioned. Some of these species may be resident, while others are transitory and may travel near the site. These species include the white-faced ibis (*Plegadis chihi*), the American peregrine falcon (*Falco peregrinus*), osprey (*Pandion haliaetus*), elegant tern (*Sterna elegans*), Belding's savannah sparrow (*Passerculus sandwichensis*), and the California brown pelican (*Pelecanus occidentalis*).

<u>Light-footed clapper rail (*Rallus longirostris levipes, O. Passeriformes, F. Rallidae*)</u>

This clapper rail is considered an *endangered* species in San Diego County (USFWS, 2009; USFWS-ECOS, 2015). They are usually found in coastal marshes in California. There are no known audiograms for the light-footed clapper rail.

Potential Impacts on Diving Birds

The only known underwater audiogram for a bird species is for a long-tailed sea duck (Therrien, 2014), a diving bird associated with cold northern waters such as the Bering Sea, Hudson Bay, and Great Lakes and rarely sighted in California. The region of greatest underwater hearing sensitivity for this sea duck was between 500 Hz and 2.86 kHz, the ducks correctly responding to a 117 dB re 1 μPa source with over 80% accuracy at these frequencies. Ducks had lower hearing thresholds than other diving birds in-air, although how that correlates to underwater bird hearing is not known. Therefore, the predominant information we have on bird hearing result from in-air tests. The frequency regions of high energy levels in the pile driving proxy (Fig. 4) coincide with the greatest in-air hearing sensitivity for diving birds (1–3 kHz) and for birds, in general (~1–4 kHz) (Fig. 18). Diving birds are especially vulnerable approaching a sound source not only because birds have higher thresholds of hearing (*i.e.*, less sensitive hearing) than humans, but also because the sound-reflecting nature of the air-sea interface tends to trap waterborne sounds beneath the sea surface. Birds are likely to detect lower-level DPR sounds only shortly before encountering the support vessel, and there likely would be few or no indicators of underwater DPR noise until a bird lands upon or dives into the water. Birds on the water or diving in the area have the potential of being exposed to the maximum sound energy from the proposed pipe ramming. Near a pile driving site off Point Loma, CA, least tern counts were lower on days with pile driving compared to days without pile driving (NAVFAC SW, 2014).

Potential indicators of behavioral stresses due to noise on birds may include a startle response, difficulty detecting prey or predators, masking of communication sounds, physical displacement, and changing breeding or nesting sight locations (Dooling and Popper, 2007; Michel *et al.*, 2007). Birds may also exhibit an attraction to an area lured by a potential new or readily available food source (*e.g.*, fish) stirred up by noisy construction activities (Michel *et al.*, 2007; NAVFAC SW, 2014). Awareness of bird species and their responses are especially important since some of the birds in the area are listed as *endangered* or *threatened* species.

Acoustic Waveguide Environment

In addition to understanding the source level and frequency characteristics of a sound source (in this case, dynamic pipe ramming) and the hearing sensitivities of the sound receiver (marine mammals, fishes, sea turtles, and birds), the acoustic propagation environment through which sound from the source travels to the receiver plays a vital role in received sound levels and those levels as a function of frequency. Numerous factors influence the efficiency of sound transmission in the ocean: the variation of sound speed within the water column, bottom bathymetry, sediment and subbottom layer composition and thickness, to name a few.

The topography of the seafloor off Carlsbad State Beach moderately slopes westward to a depth of 30.5 m (100 ft), which is 427 m (1400 ft) seaward of the pipeline termination and 1430 m (4700 ft) from shore. Beyond 30.5 m depth the slope is steep. The seafloor close to the pipeline is a soft, sandy bottom substrate with some cobble-like rocks underneath. The composition of this substrate varies seasonally when sand is pushed farther offshore and more cobbles are exposed. In the immediate nearshore area north and south of the MOT site are low relief rocky substrates. Merkel and Associates collected active sonar data to develop a 387-acre seafloor map of the area. They found that 90% of the acres had a seafloor with fine sand throughout. Seven percent was reef rock with probable grassy patches located to the south at 1.5–6.1 m depths (5–20 ft), which is approximately 30.5–152 m (100–500 ft) from the pipeline and 152–244 m (500–800 ft) from shore. The remaining acreage, located to the south, contained kelp beds in water depths of 6–14 m (20–45 ft), which is about 30.5–396 m (500–1300 ft) from the pipeline and 183–914 m (600–3000 ft) offshore.

The parameters describing the acoustic waveguide environment of the MOT decommissioning site are generally associated with high transmission loss, *i.e.,* sound energy decreases rapidly over range in this environment. The very shallow waters (roughly 30 m or less) lend themselves to repeated interactions of sound waves with the seafloor and sea surface, with sound energy lost in each interaction. In addition, the fine sand comprising the sediment layer attenuates sound energy more than sediments of larger grain size. Furthermore, historical sound speed profiles measured in the shallow waters off California are typically isovelocity (approximately the same sound speed throughout the water column) or downward-refracting (refracts sound waves toward the seafloor) and, thus, do not enhance long-range sound transmission like, *e.g.,* ducts found in deeper waters. All of these waveguide characteristics suggest that sound originating at the MOT decommissioning site will likely suffer from relatively high acoustic transmission loss and its received levels will decrease rapidly with distance from the source.

One simple model for underwater acoustic propagation is based upon logarithmic spreading loss. In this model, received sound level is given by:

$$RL = A - B \bullet \log(R) - C \bullet R \tag{1}$$

where RL is the received sound pressure level in dB re 1 µPa (for peak or SPL_{rms} values) or dB re 1 µPa^2-s (for SEL values) and R is range from the source in meters. The constant term A is the source level or the hypothetical extrapolated sound level at 1 m from the source based upon far-field measurements. The transmission loss parameters, B and C, vary with frequency, temperature, sea conditions, source depth, receiver depth, water depth, water chemistry, and bottom composition and topography. The logarithmic, predominantly spreading, loss term B is typically between 10 dB (cylindrical spreading) and 20 dB (spherical spreading). The linear loss term C has several physical components, including absorption in seawater, absorption in the sub-bottom, scattering from inhomogeneities in the water column and from surface and bottom roughness, and (for RMS levels of transient pulses) temporal pulse spreading.

Conservative values were utilized for the three parameters in Equation 1. For example, 204.1 dB re 1µPa was selected for the proxy source level A, as discussed in the text accompanying Figure 4. Lacking detailed spatial-temporal acoustic waveguide information specific to the MOT site, three different logarithmic spreading factors B were examined: 10, 15 and 20. Based on Figure 4, maximum acoustic energy for vibratory pile driving, the DPR proxy, occurs around 1 kHz. Sound absorption losses increase with increasing frequency; however, for the calculations that follow, we have conservatively assumed no absorption and scattering ($C = 0$). Figure 19 shows the received sound pressure levels given the aforementioned propagation model parameters. Received SPL as a function of range are shown for 10 log(R), 15 log(R), and 20 log(R) spreading functions as blue, green, and red lines, respectively.

As discussed in the section "Regulatory Guidelines for Acoustic Threshold Levels," NMFS has specified that pinnipeds and cetaceans should not be exposed to sounds at received SPL exceeding, respectively, 190 and 180 dB re 1 µPa (NMFS 2000). Current information suggests that these values are a conservative upper limit of ***non-injury*** exposure for these animals. A received level of 160 dB re 1 µPa is currently considered the upper limit of ***non-disturbing*** sounds for marine mammals generally. However, for some marine mammals this value could be too high. For example, bowhead whales have been shown to modify their behavior by leaving areas where received RMS levels were above ~120 dB re 1 µPa during seismic exploration (Richardson 1999, MMS 2006). In Figure 19, the 190, 180, and 160 dB re 1 µPa thresholds are indicated by solid black, dashed black, and solid gray lines, respectively. The safety radii, i.e., the distances at which received levels are 190, 180, and 160 dB re 1 µPa, are summarized in Table 7 for the three spreading loss terms of 10, 15 and 20 dB/tenfold change in distance.

For fishes and sea turtles, neither the FHWG (2008) nor Popper *et al.* (2014) offered guidelines for the DPR proxy, vibratory pile driving. Consequently, Figure 19 and Table 7 pertain to marine mammals only. Peak SPL threshold levels suggested by FHWG and Popper *et al.* for impact pile driving were far greater, as expected, than anticipated sound levels produced by vibratory pile driving.

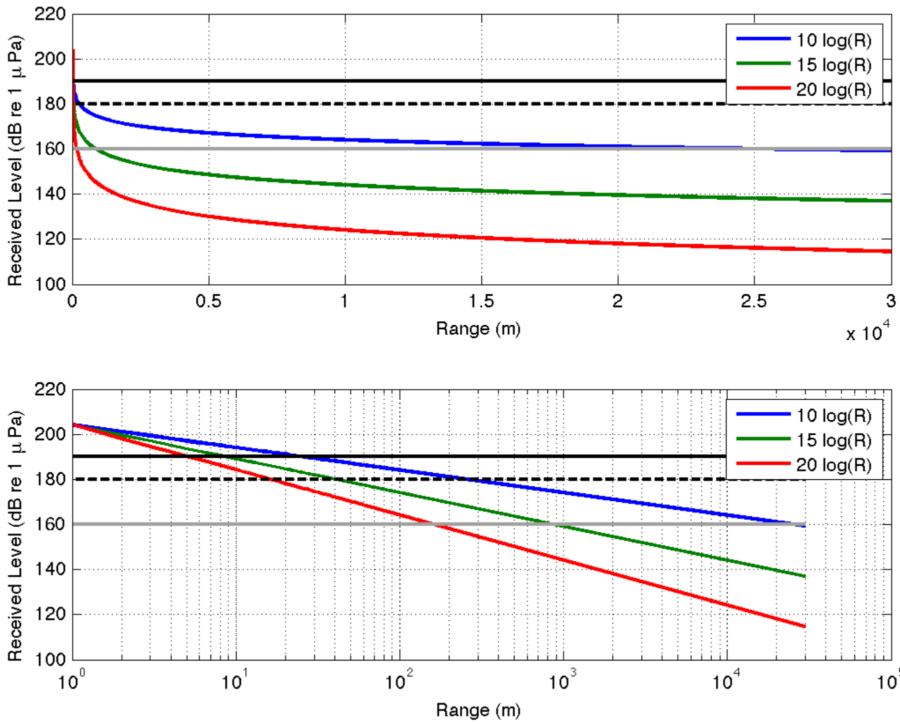

Figure 19. Received sound pressure levels as a function of distance for a source level of 204.1 dB re 1 µPa-m and spreading loss terms of 10, 15 and 20 dB/tenfold change in distance. Regulatory threshold levels of 190, 180, and 160 dB re 1 µPa are indicated by solid black, dashed black, and solid gray lines, respectively. The top plot shows range linearly on the x-axis, and the bottom plot shows range logarithmically on the x-axis.

Table 7. Distances in meters at which received levels for the DPR proxy are expected to be 190, 180, and 160 dB re 1µPa for A = 204.1 dB re 1 µPa-m, B = 10, 15, and 20 dB/tenfold change in distance, and C = 0. The calculated distances are shown in gray font. These distances are unrealistically precise and should be rounded upwards, consistent with a conservative evaluation. Rounded distances are shown in black font.

Spreading Loss (dB/decade)	Received Level (dB re 1 µPa)	Safety Radii (m)
10	190	26 / 30
	180	257 / 260
	160	25704 / 25710
15	190	9 / 20
	180	40 / 40
	160	871 / 900
20	190	5 / 10
	180	16 / 20
	160	160 / 180

Mitigation Measures

Several techniques may be applied to mitigate construction-related noise impacts on marine species. Determining the best mitigation measures for a construction site may depend upon: the actual sound levels of the construction; the presence of sensitive species or habitats; the practicality of applying a mitigation measure at a location; weighing benefits to costs; and the potential to further harass marine species when applying mitigation measures.

Sound Attenuation Mitigations

Mitigation measures to attenuate noise from a pile-driving-type source require understanding of the pile driving features and its application at the actual construction site. Knowledge of the types of hammers (*e.g.*, vibratory, impact) being used will aid in assessing the environmental impacts on marine species (Oestman *et al.*, 2009). The diameter and size of the pipe are also important. Pipes of greater diameter tend to produce higher sound levels (Oestman *et al.*, 2009, Appendix A). Information on the conservative estimate of the number of strikes per pile, pile size, number of piles per day and the total pile driving days to complete construction would also be essential for estimating more accurate cumulative sound exposure levels for marine species within a given region.

Some mitigation measures have been developed to reduce underwater sound for pile driving. Two goals are to (1) reduce the transmission of sound into the water and (2) reduce the sound generated by the pile (Oestman *et al.*, 2009).

Sound Transmission Reduction

The deployment of a bubble curtain around a pile creates a barrier around the pile that disrupts the propagation of sound waves, reducing sound radiation from the pile into the water. Several types of bubble curtains have been implemented, resulting in sound attenuation ranging from 5–20 dB re 1 µPa (Fig. 3, highlighted in red) (Würsig *et al.*, 2000; Matuschek and Betke, 2009; Oestman *et al.*, 2009; McCrodan and Hannay, 2014). Bubble curtains have not only been found to attenuate pressure but also particle velocity. MacGillivray and Racca (2006) found that active bubble curtains not only reduced peak pressure levels by 9.1 dB re 1 µPa but also attenuated particle velocity by 11.4 dB re 1 µPa (the latter being more biologically important for fishes). In another study, the greatest sound reduction by a bubble curtain was seen in the frequency range of 400–6400 Hz (Würsig *et al.*, 2000), a vital hearing range for many marine species. Effectiveness of bubble curtains depends on several factors, including bubble layer thickness and the size of the bubbles in relation to sound wavelength (McCrodan and Hannay, 2014). Bubble curtains may be efficient for flat or sloped seafloors; however, they may be less effective in fast currents and deeper water (Caltrans, 2001; PND Engineering, 2005). Fabric barriers or sleeves can also be added to the outside of bubble curtains to further attenuate sound transmitted into the water (Caltrans, 2001; Funk and Rodrigues, 2005; PND Engineering, 2005).

Cofferdams are a more effective means of sound attenuation than bubble curtains, especially when surrounding water is removed between the pile and dam. However, they require considerable construction for installation and may be costly (Funk and Rodrigues, 2005; PND Engineering, 2005).

Sound Generation Reduction

The reduction of the sound generated from the pile itself may be achieved by using alternative hammer types, such oscillating, rotating or press-in systems (Warrington, 1992; Oestman *et al.*, 2009).

Lubrication of pipes can also reduce sound levels. These alternate methods may be limited in the size of piles they can handle or the material of the piles themselves.

Acoustic blankets are very effective in absorbing sound energy for in-air industrial noise control. However, they have not been utilized commercially in ocean environments. Innovative ocean engineering approaches would need to be brought to bear for the successful application of acoustic blankets in the MOT environment.

On-site Mitigations

Adjusting daily or seasonal timing of dynamic pipe ramming activity, especially for *endangered* or *threatened* species, may be a viable means of mitigation to protect animals from harassment (Nedwell *et al.*, 2003). For instance, gray whales migrate close to the Pacific shoreline during the winter into early spring. Exposure to high source levels may not only harass the whales during those months, but also deter them from their normal nearshore migration or alter their habitat usage (Richardson *et al.*, 1995; Tougaard *et al*., 2003; Bailey *et al*., 2010). Any modifications to their normal migration may be physically costly, both in energy (*e.g.*, increased swimming speeds) and predation (*e.g.*, by killer whales) (Würsig *et al.*, 2000; Caltrans, 2001). Some fishes exhibit diurnal variations in the water column (*e.g.*, northern anchovy) due to changes in prey locations, so understanding the aquatic sound field around the construction site and possible animal locations are important factors when assessing impacts (Paxton and Eschmeyer, 1998).

One useful deterrent method to alert marine species to the onset of construction-related noise, especially in cases of high level sounds, is the soft-start procedure. In this procedure, the conductor begins the sound source of interest (*e.g.*, pile driving) at reduced levels and repeats the sound over a given duration (Nedwell *et al.*, 2003; PND Engineering, 2005). The sound levels should be high enough for marine species to detect but lower than the recommended onset TTS levels (SEL_{cum} or dB_{peak} levels) (Table 2, 4, and 6). After the determined soft-start ends, normal construction levels would begin.

The implementation of safety radii (*i.e.*, impact zones) around the sound source, together with soft start-ups and shut-down protocols, are thought to be effective mitigation methods for reducing high sound level impacts on some marine species (*e.g.*, marine mammals, sea turtles, birds) (Funk and Rodrigues, 2005; Balloch, 2007; Michel *et al.*, 2007; NAVFAC SW, 2014). Several factors must be considered when establishing these protocols and whether or not they should be implemented. Accurate knowledge of the DPR sound source level must be known. The acoustic threshold criteria to prevent PTS (or injury) and TTS in marine species should be obtained and applied. Since sound attenuates as it propagates from the source (Urick, 1983), safety zones (usually defined as concentric circles) are determined first at the highest levels near the source, and then at biologically meaningful locations from the source until the sound is eventually attenuated to ambient levels. Safety zones should include ranges to the source where onset PTS and TTS may occur, and extend to the range where the animals would be unharmed (Oestman *et al*., 2009).

Figure 19 and Table 7 summarize gross estimates of safety radii based upon vibratory pile driving measurements depicted in Figure 4 and general acoustic waveguide characteristics. However, the assumptions in the calculation of these radii estimates are necessarily poor, likely inaccurate representations of source level and acoustic propagation conditions due to the scarcity of *in situ* measurements for both. Given the complete lack of acoustic measurements for DPR, DPR's novel use in the MOT application, and the paucity of acoustic waveguide data for the MOT site, Greeneridge Sciences' highly recommends conducting sound source characterization prior to DPR operations to directly measure sound pressure levels generated by DPR. Such measurements could then be used to empirically determine safety radii appropriate for this source and environment. Sound measurements should be made at multiple ranges along two transects—one perpendicular and one parallel to the coastline—to characterize anticipated transmission loss differences in these two bathymetric regimes. Measurements should also begin as close in range to the sound source as practicable given construction site safety considerations and surf zone limitations and then extend offshore along the submarine pipeline into progressively deeper waters and alongshore perpendicular to the pipeline roughly along an isobath.

Safety zone mitigation measures require the presence of on-site marine mammal observers (MMOs) and/or protected species observers (PSOs) to detect species of interest within the prescribed safety zones (*i.e.*, within each concentric circle) (Nedwell *et al.*, 2003; URS, 2013). Monitoring would need to occur prior to and during DPR operations. Monitoring would also include determining and recording the number of *takes* during DPR activities for IHA or LOA requirements (Funk and Rodrigues, 2005; NMFS, 2010). If animals enter or approach safety zones, immediate or temporary shutdowns of DPR activity may apply (NAVFAC SW, 2014). Disruption of DPR activity could be costly endeavors if the planned construction is in an area or occurs in a season that is dense with animals, especially for protected, *threatened* or *endangered* species.

Passive acoustic monitoring (PAM) may be used to monitor not only the DPR sound but also to detect species in the area or approaching the area (Nedwell *et al.*, 2003; URS, 2013; Gordon *et al.*, 2004). While PAM is limited to vocalizing animals, PAM may be a more effective monitoring method than visual observations for detecting marine mammals when adverse weather conditions lower visibility. For marine mammals that often vocalize, PAM may detect the presence of marine mammals more readily than MMOs.

Other potential mitigations may be considered when establishing animal protection protocols, but the potential impacts from the mitigation may outweigh the benefits. Acoustic deterrents (*e.g.*, acoustic pingers, boat noise) may be used to warn marine species of the presence of construction in an area (Dooling, 2002; Funk and Rodrigues, 2005). Deterrents would need to be within the hearing frequency range of the species of interest and loud enough to be detected but not so loud to induce hearing damage. Acoustic deterrents near the sound source may also help mitigate potential *Level A Harassment* or death in some marine species (Caltrans, 2004; Laughlin, 2007). However, many of these deterrents are considered harassment by NOAA fisheries and may not be permitted under IHAs or LOAs, so appropriate caution should be taken (Funk and Rodrigues, 2005). The use of physical barriers or netting may help in some instances to deter animals from a construction site; however, marine mammals and turtles have both been found entangled in netted fishing gear (Mazzuca *et al*., 1998; Finkbeiner *et al.,* 2011). Netted barriers may also not be feasible if the site location has high currents (Funk and Rodrigues, 2005). Solid barriers may be more effective, but require considerable construction costs and potentially may induce more noise into the environment during barrier construction. However, if the barrier is constructed in an off-season for a species of interest, this option may be feasible.

Summary and Conclusions

In this report, we investigated the potential noise impacts of dynamic pipe ramming (DPR) on marine species (marine mammals, fishes, sea turtles and birds) in the vicinity of the Encina Power Station's (EPS) Marine Oil Terminal (MOT). No acoustic information on DPR has been published to date, so vibratory pile driving, a physically similar process to DPR, was used as a proxy and its source levels compared to the hearing sensitivities of local marine fauna. Some species (baleen whales, pinnipeds, and birds) showed extensive overlap in hearing sensitivity with the proxy, while others showed more limited overlap (dolphins, fishes, and turtles). Of these species, individuals that might travel nearshore and in close proximity to the DPR activity include gray whales during their winter southbound migration, pinnipeds, and coastal bottlenose dolphins.

The availability of acoustic data is non-existent (DPR) or too limited (vibratory pile driving) to accurately estimate safety radii for the MOT decommissioning project. However, general descriptions of the acoustic waveguide environment suggest that sound energy will attenuate relatively rapidly with increasing distance from the sound source. Greeneridge Sciences recommends that *in situ* measurements of DPR be conducted as a function of range in order to (1) fill in the data gap on DPR sound source characteristics and (2) enable estimation of an acoustic propagation model specific to the MOT site and, thus, appropriate safety radii to inform MMO/PSO mitigation measures. In addition, sound attenuation measures such as bubble curtains and slow-start ups may be implemented to further reduce potential noise impact at the MOT decommissioning location.

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