H1. Underwater Acoustic Assessment Report (May 2022)

Underwater Acoustic Assessment of Pile Driving during Construction at the Maryland Offshore Wind Project

Prepared For:

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Research – Operations – Engineering – Design - Analysis

Executive Summary

The predicted effect on marine mammals of the underwater sound generated by impact and vibratory pile driving proposed to be conducted during the construction of the US Wind Maryland Offshore Wind Project (the Project) were modeled. The physical environment of the bathymetry, sediment properties, seasonal sound velocity profiles in the water column, and surface roughness were all input into the propagation model. Representative sound source spectra for the hammers used to drive piles with diameters of 11 and 3 meters (m) were obtained from published literature. A sound source spectrum for the vibratory hammer to drive the 1.8-m monopiles was also derived from previous published reports. The resulting sound fields for each sound source were then used to determine the ranges to regulatory isopleths (e.g., 160 dB for behavioral responses).

Modeling assumptions included the use of a single modeling location within the proposed windfarm. The sound velocity profiles for 16,800 and May were chosen to represent the two time periods being considered (April to November and May to October). These sound velocity profiles were selected as they represented the best acoustic propagation characteristics for these time periods (i.e., largest propagation ranges). The 11-m diameter monopile was assumed to be driven in two hours using a 4,400 kiloJoules (kJ) hammer energy, based on the projected pile progression. The smaller pinpiles are assumed to be driven using a 1,500 kJ hammer energy, and these piles will take three hours to drive. The vibratory pile driving of the 1.8-meters (m) diameter monopiles is assumed to only require one hour to complete. Information on animal density was the best available (Roberts *et al*., 2020; 2021) and mean density values for the geographic area and time frame were calculated from the density fields. Animals were assumed to remain in the 1.75° longitude x 1.5° latitude box surrounding the modeling site for the entire period of driving of a pile.

The Acoustic Integration Model© (AIM) was used in conjunction with these resulting sound fields and modeled animal movements (swim speeds and dive depths) to simulate the four-dimensional movements of marine mammals and sea turtles through the water and time. These simulated animals are referred to as 'animats'. The predicted sound received level at each animat every 30 seconds was used to create a sound exposure history over 24 hours of modeled operation. Each of these exposure histories are subsampled to create multiple estimates of sound exposure for each source-animal combination (for example, the monopile is projected to be driven in 2 hours, so twelve different two-hour exposure histories were extracted). The exposure history for each animat was analyzed to produce the metrics of maximum root- mean square sound pressure level, cumulative sound exposure level, and peak sound pressure level. These modeled exposure estimates were then scaled by the ratio of real-world density estimates to the modeled animat density. This results in the predicted number of exposures for each species or species group for each pile driven.

The effect of applying mitigation methods (e.g., bubble curtains) to pile-driving scenarios was also explored, and the associated reductions in ranges to regulatory isopleths and the number of marine mammal exposures was determined. A mitigation scenario in which source level reductions of 6, 9, 12, 15, 18, and 20 decibels (dB) for the pile driving of an 11-m monopile were considered (Figure ES-1). The range to the 160 dB isopleth (behavioral exposure) is > 16,000 m for an unmitigated driving of an 11-m monopile. Just a 10 dB reduction in the pile-driving source level drops the range to the behavioral exposure isopleth to 6,000 m while a 20 dB source level reduction reduces it to just 2,000 m (Figure ES-1).

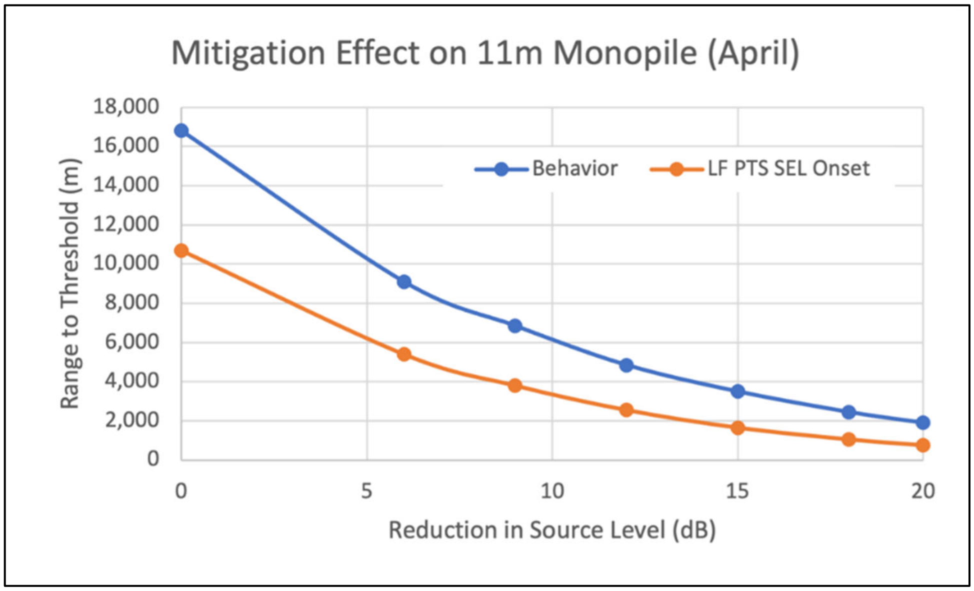

Figure ES-1. The effects of the potential mitigation measure of reducing source levels associated with the pile driving of a 11-meter monopile on the range to the regulatory isopleths for marine mammal behavior and physiologic (permanent threshold shift [PTS]) effects.

The effect of temporal mitigation was also considered by examining the number of potential physiological injury exposures for the April to November versus May to October timeframes. Considering the difference in the number physiological injury exposures to the highly endangered North Atlantic right whale resulted in a decrease of 7.8 times the number of exposures by delaying the beginning driving monopiles until May, which reflects the seasonal drop in right whale density that occurs from April to May annually.

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Acronyms and Abbreviations

°	degrees
ρ	density of a medium
µPa	microPascal(s)
3D	three-dimensional
ADEON	Atlantic Deepwater Ecosystem Observatory Network
AIM	Acoustic Integration Model©
BOEM	Bureau of Ocean Energy Management
c	speed of sound in a medium
C	Celsius (Centigrade)
CRM	Coastal Relief Model
dB	decibel(s)
dB re 1 μPa^2	decibel referenced to a pressure of 1 microPascal squared
dB re 1 $\mu Pa^2 m^2$	decibel referenced to a pressure of 1 microPascal squared per meter squared
dB re 1 $\mu Pa^2 m^2$	decibel referenced to a pressure of 1 microPascal squared at a squared meter
DP	Dynamic Positioning
DPS	distinct population segment
ESA	Endangered Species Act
F	Fahrenheit
FE	Finite Element
g	gram(s)
GARFO	Greater Atlantic Regional Fisheries Office (NOAA Fisheries)
GPa	gigaPascal(s)
h	hour(s)
HF	High Frequency
Hz	Hertz
ISO	Organization for International Standardization
kHz	kiloHertz
kJ	kiloJoule(s)
km	kilometer(s)
kph	kilometers per hour
kt	knot(s)
I	acoustic intensity
$LE_{,24h}$	cumulative sound exposure level over a 24-hour period
$LE_{(cum)}$	cumulative sound exposure level
$LE_{(SEL)}$	sound exposure level
$LE_{(ss)}$	single strike sound exposure level
LP	root-mean-square sound pressure level
L_{pk}	peak sound pressure level
L_{pp}	peak to peak sound level for a given event
$I_{.}$	reference intensity level
λ	lambda (wavelength)
LF	Low Frequency

MAI	Marine Acoustics, Inc.
MF	Mid Frequency
MMPA	Marine Mammal Protection Act
MW	megawatt(s)
m^3	cubic meters
m	meter(s)
ms	millisecond(s)
N	Number of Samples (Sample Size)
NOAA	National Oceanic and Atmospheric Administration
NARW	North Atlantic right whale(s)
OCS	outer continental shelf
OSS	offshore substation
OW	otariid pinnipeds in water
p	pressure
po	reference pressure
p(t)	squared sound pressure time series
PE	parabolic equation
pk-pk	peak to peak
PTS	permanent threshold shift
PW	phocid pinnipeds in water
RAM	range-dependent acoustic model
RL	received level
RMS	root-mean-square
s	second(s)
SD	standard deviation
SEL	sound exposure level
SL	source level
SPL	sound pressure level
spp.	species
ST	sea turtle
SVP	sound velocity profile
t	time
T	time interval
T_0	reference time interval of 1 second
T_{90}	90 percent of the sound level
T_{100}	time-integral of the squared pressure over the full event duration
the Project	US Wind Maryland Offshore Wind Project
TOL	third-octave level
TTS	temporary threshold shift
U.S.	United States of America
U.S.C.	U.S. Code
USGS	United States Geological Survey
v.	versus
WEA	wind energy areas
WTG	wind turbine generator

1 INTRODUCTION

US Wind proposes to construct and operate the Maryland Offshore Wind Project (the Project) to generate clean, renewable energy using available wind resources. The Project will be located within US Wind's Lease area, approximately 10 nautical miles east of Maryland's Eastern Shore (Figure 1). All Project analysis is centered at the modeling site, 38.3°N, 74.7°W.

Construction and operation of the Project has the potential to cause acoustic harassment to marine species, in particular marine mammals, sea turtles, and fish populations. Marine Acoustics, Inc. (MAI) was contracted to model and assess the sources of underwater noise generated during the construction and installation of the Project and the effect of sound attenuation methods as a means of mitigation. The objective of this modeling study was to predict the ranges to acoustic thresholds that could result in permanent threshold shift (PTS), temporary threshold shift (TTS), or behavioral disruption of marine mammals, sea turtles, and fish during construction of the Project.

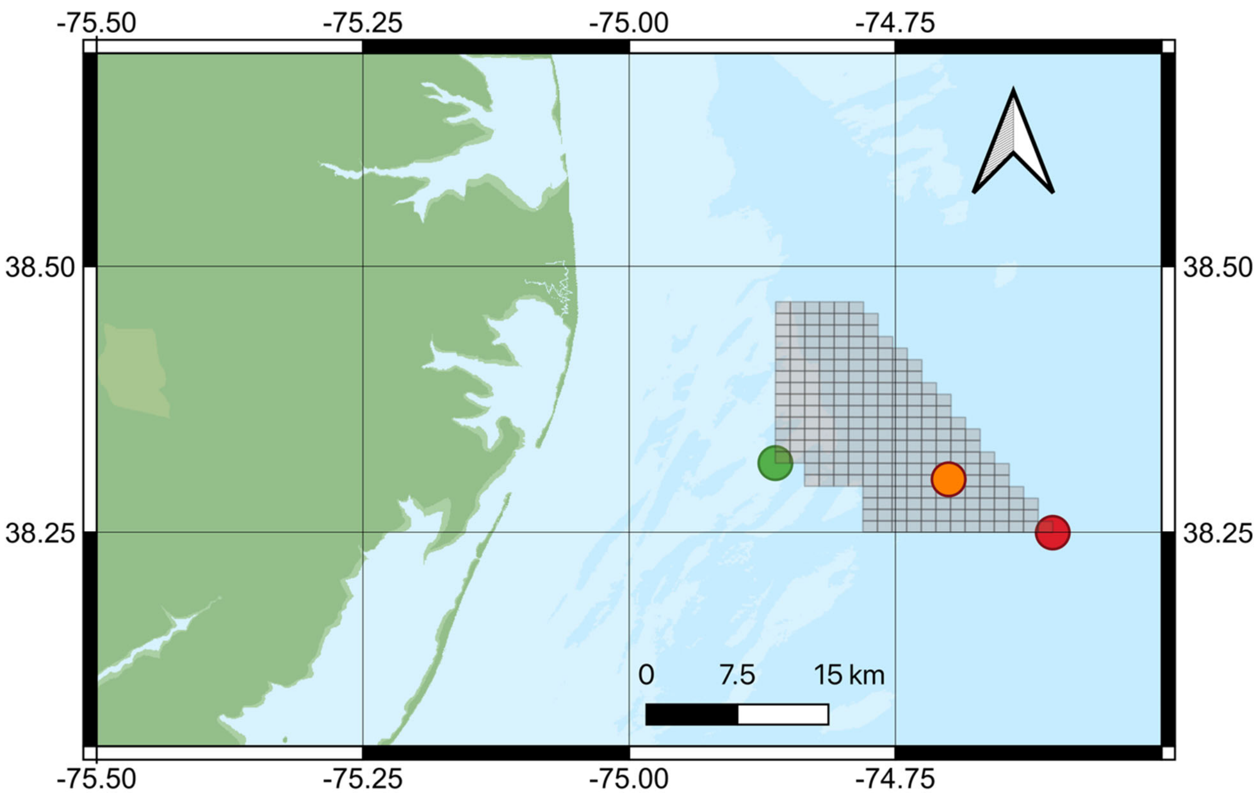

Figure 1. US Wind Offshore Wind Project schematic. The lease areas are shown as grey shaded grid boxes and the modeling site is the orange circle at 38.3°N, 74.7°W. The green and red dots represent the shallowest and deepest locations within the Project bounds.

1.1 Acoustic Concepts and Terminology

This section outlines some of the relevant concepts in acoustics, particularly underwater acoustics, to help the non-specialist reader better understand the modeling assessment and results presented in this report. Sound is the result of particles vibrating to create mechanical waves that travel through a medium, such as air or water. These waves create pressure changes that vary in space and time, resulting in time-varying pressure disturbances that oscillate above and below the ambient pressure.

Sound levels are typically reported in units of decibels (dB). The decibel is defined as a ratio of measured acoustic intensity (I) and a reference intensity level (I_{ref}).

$$\text{decibels (dB)} = 10 \times \log_{10}(I/I_{ref})$$

However, sound is often measured as pressure (p) rather than directly as intensity. The intensity of a plane sound wave in the far field is proportional to the square of its pressure, as shown in the following equation:

$$I = p^2/\rho c$$

where ρ is the density of the medium (e.g., water) and c is the speed of sound in that medium. The sound pressure level (SPL) in decibels can be computed directly from the measured pressure with the following equations, where p is the pressure and p_o is the reference pressure.

$$\text{SPL} = 10 \times \log_{10}(p^2/p^2_o)$$

$$\text{SPL} = 20 \times \log_{10}(p/p_o)$$

Care must be taken when reporting and reading sound levels in decibels to ensure that measurements are properly described. To compare sound levels given in decibels to one another, a standard reference intensity or reference pressure must be used. In underwater acoustics, the traditional standard reference pressure (p_o) is 1 microPascal (μPa), leading to the use of the unit "dB re 1 μPa^2", which represents a decibel referenced to a pressure of 1 microPascal squared. This unit is a slight update to the previously commonly used "dB re 1 μPa", and is compliant with the Atlantic Deepwater Ecosystem Observatory Network (ADEON) (Ainslie *et al.* 2018) and ISO 18405 (2017) standards.

In addition to units, the acoustic measurement type and measurement bandwidth must be considered. Measurement type refers to how the pressure was measured. Changing the" type" of measurement from peak-to-peak (pk-pk) to root-mean-square (RMS) can change the reported sound level of a given continuous sound by up to 9 dB. RMS, peak (also reported as 0-peak), and pk-pk are the most common sound measurement types. RMS measures are essentially an average intensity over a given amount of time, which is often not stated as part of the method for calculating the RMS sound level. These RMS measures are most appropriate for longer (i.e., non-impulsive) signals. Impulsive signals, such as those from impact pile driving, are best measured with a peak or peak-to-peak measurement. The primary portion of these signals is of such limited duration that it is difficult to define a start and end point of the signal. A typical approach is to use the time between the 5^{th} and 95^{th} percentile of cumulative amplitude. Zero to peak or pk-pk measurements simply measure the maximum amplitude of the signal, without consideration of time and avoid this problematic issue. Sound Exposure Level (SEL) also avoids the problem by specifying a fixed time value.

Another measurement type that is applied to impulsive signals and their effect upon animals is sound exposure level (SEL). This metric, appropriate for all signal types, is the integration of sound energy produced from a source, normalized to the level necessary to produce that amount of energy in a single second. These values are reported with units of dB re 1 μPa^2-s. SEL can be the energy accumulated over a given time period, indicated as L_E(cum), or it can be the energy integrated over a single pile driving strike, indicated as L_E(ss).

The measurement bandwidth, or frequency range, of a sound signal, and the frequencies over which the sound level is calculated must also be properly considered. In general, most sounds can be classified as tonal (or narrow band in that the signal spans only one or a small range of frequencies) or broadband (spanning many frequencies). When SPL is calculated, the frequencies over which the measurements were made should be indicated. Spectral levels are measurements made at a single frequency and have units of dB re 1μPa^2/Hz. Broadband SPL measurements encompass the energy contained in all the frequencies in a signal and are reported in units of dB re 1μPa^2. There can be a significant difference between spectral and broadband measurements of the same signal (Figure 2).

It is also critical to define bandwidths when presenting spectra. Spectra are frequently presented in third-octave bands in bioacoustics to approximate the bandwidths of mammalian auditory system. **Error! Reference source not found.**, for instance, shows two spectra of the same vessel recording, where the blue line is the power spectral density spectrum and the frequency resolution is 1 Hz; that is, the amount of energy that occurs in each single frequency over the full range of analyzed frequencies. In Figure 3, not surprisingly, the red line is always higher than the blue line, since it is aggregating energy over multiple frequencies. Furthermore, the difference between the two types of spectra increases with frequency because the bandwidth of the third-octave bands increases in proportion to the frequency.

The formal definitions of the sound metrics used in this report are:

- **RMS Sound Pressure Level (SPL_{rms} or L_P)** – Defined as an integral over a specified time interval (*T*) of squared sound pressure time series (*p(t)*) divided by the duration of the time interval and the squared reference pressure (P_o), for a specified frequency range. For impulsive signals, such as from impact pile driving, the measurement period is defined as the time

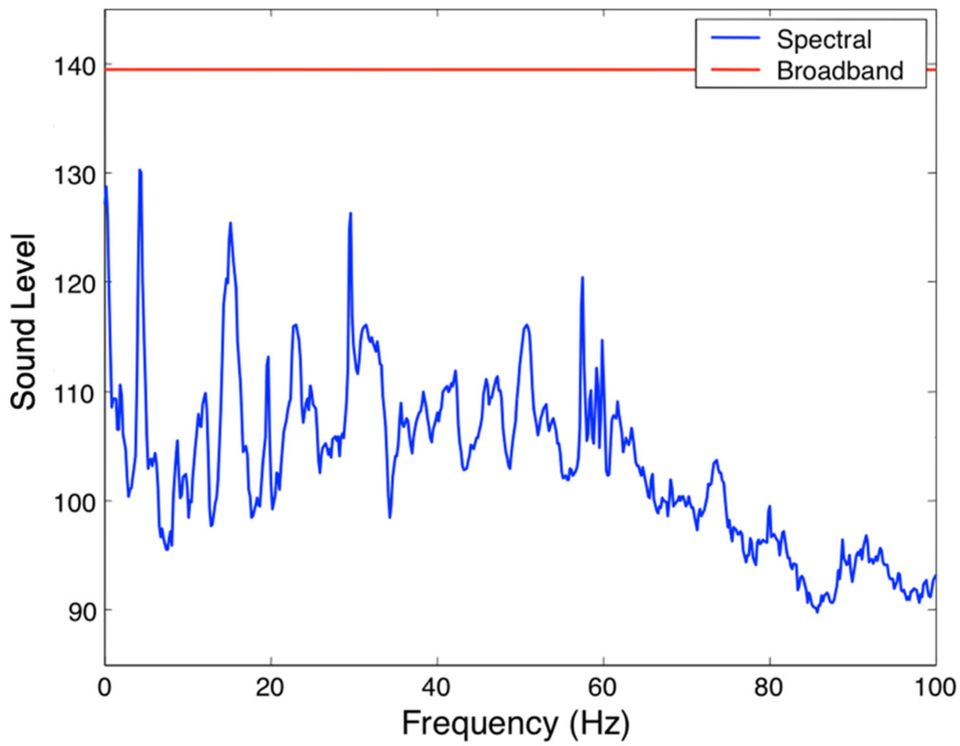

Figure 2. Comparison of spectral and broadband source levels. A sample sound spectrum is shown in blue. The maximum spectral level of this signal is 130 dB re 1μPa^2/Hz. The broadband level is the integration of all the energy from all frequencies. In this example, the broadband level is 139 dB re 1µPa^2. Thus, depending on the measurement bandwidth, the same sound can have different numerical values accurately describing its amplitude.

period that contains 90 percent of the sound energy (T_{90}) (Madsen 2005). Continuous sources, such as vibratory piling driving, thruster operations, and shipping are commonly described in terms of an RMS sound pressure level (L_p).

- L_P (dB re 1 μPa^2) = $10\log_{10}\left(\frac{1}{T_{90}}\int_{T_{90}} p^2(t)dt \Big/ p_0^2\right)$

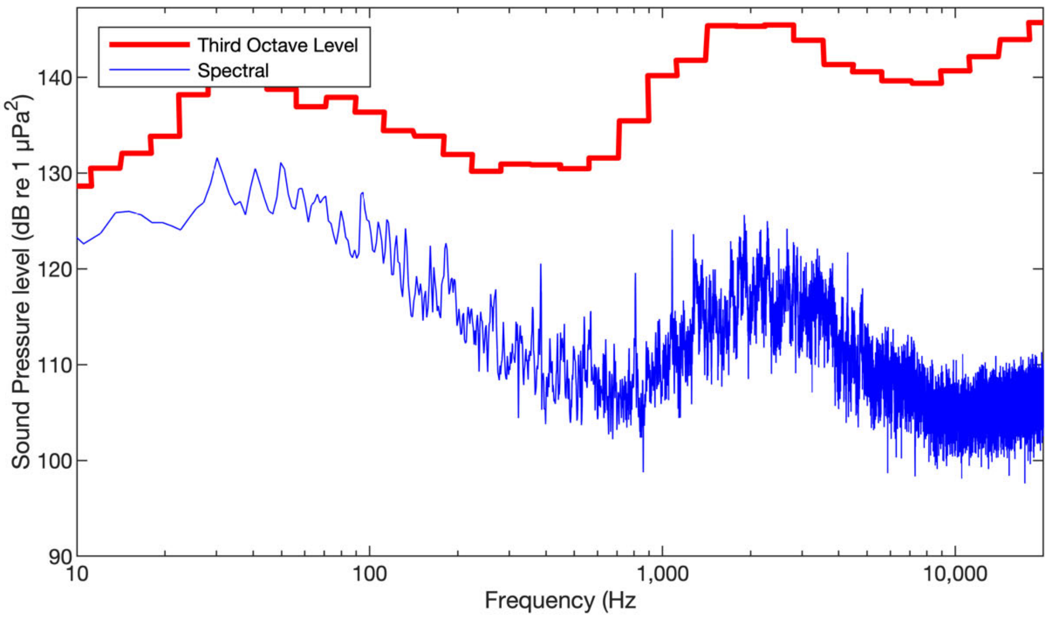

Figure 3. Comparison of spectral (blue) and third-octave band level (red) spectra.

Sound Exposure Level (SEL or L_E) – Sound exposure level is similar to the L_P but further specifies the sound pressure over a specified time interval or event, and for a specified frequency range expressed in dB re 1 µPa²s. The SEL for a single event is computed from the time-integral of the squared pressure over the full event duration (T_{100}):

$$L_E \text{ (dB re 1 µPa}^2\text{•s)} = 10\, log_{10}\left(\frac{1}{T_0}\int_{T_0}^{T_{100}} p^2(t)dt\ /\ p_0^2\right)$$

where T_0 is a reference time interval of 1 s. The L_E represents the total acoustic energy received at a given location. Unless otherwise stated, sound exposure levels for pulse noise sources (*i.e.*, impact hammer pile driving) presented in this report refer to a single pulse.

L_E can be calculated as a cumulative metric over periods with multiple acoustic events. In the case of impulsive sources like impact piling, L_E describes the summation of energy for the entire impulse normalized to one second and can be expanded to represent the summation of energy from multiple pulses. The latter is written L_E (cum) denoting that it represents the cumulative sound exposure over the duration of the activity. The sound exposure level is often used in the assessment of marine mammal and fish behavior over a 24-hour period and will be written as $L_{E,\,24h}$.

The cumulative SEL (dB re 1 µPa2·s) can be computed by summing (in linear units) the LE of the *N* individual events:

$$L_E\,(\text{cum}) = 10\,log_{10}\left(\sum_{i=1}^{N} 10^{\frac{L_{Ei}}{10}}\right)$$

- **Peak Level (L_{pk})** – Maximum noise level over a given event is expressed as $L_{pk.}$ and is calculated using the maximum variation of the absolute value of the pressure from zero within the wave. The peak level is commonly used as a descriptor for impulsive sound sources. The L_{pk} can be calculated using the formula below where *t* is the time. Pulses are characterized by a relatively rapid rise from ambient pressure to a maximal pressure value followed by a decay period that may include a period of diminishing, oscillating maximal and minimal pressures.

$$L_{pk}\,(\text{dB re 1 µPa}^2) = 10\,log_{10}\left[\frac{max(|p^2(t)|)}{p_0^2}\right]$$

- **Peak-to-Peak Level (L_{pp})** – Noise level over a given event is expressed as $L_{pp.}$ and is calculated using the minimum to maximum variation within the wave. The L_{pp} can be calculated using the formula below where *t* is the time:

$$L_{pp}\,(\text{dB re 1 µPa}^2) = 20\,\log_{10}\,(\max p(t) - \min\,(p(t))).$$

1.2 Acoustic Modeling Scope

There are various activities that are expected to generate underwater sound during the construction of the proposed Project. These activities include impact pile driving of monopile foundations for wind turbine generators (WTG), and offshore substations (OSS), impact pile driving for pin piles for OSS jacket foundations, as well as vibratory pile driving of the smaller monopiles. The impact pile driving results in impulsive sounds while vibratory pile drivers produce non-impulsive sounds. These activities were modeled to produce the resulting unweighted and frequency-weighted broadband underwater acoustic fields. The ranges to various physiological and behavioral auditory thresholds for marine mammals, fishes, and sea turtles were determined from these broadband sound fields. The appropriate regulatory thresholds for impulsive and non-impulsive sounds have been used accordingly.

1.3 Animat Modeling Scope

The modeled broadband sound fields associated with the impact pile driving of monopile and pin piles were used to conduct animat modeling to determine exposures of marine mammals to the underwater sound. The potential acoustic exposures of protected marine mammals were estimated using the Acoustic Integration Model© (AIM). AIM is a Monte Carlo-based statistical model (Frankel *et al.* 2002) in which many repeated simulations provide the probability of an outcome. AIM simulations create realistic animal movement tracks that, collectively, provide a reasonable representation of the movements of the animals in a population. Animats are programmed with a range of values for movement parameters, such as minimum and maximum speed or dive depth. The underlying statistical distribution for these parameters is uniform, with the exception of speed. Speed can be specified with a uniform, normal or gamma distribution. Multiple behavioral states can be specified to best represent real animal movement. These simulated movements are integrated with the three-dimensional (3D) acoustic field produced by sound sources to estimate the animals' exposure to the acoustic field. The AIM model simulated the four-dimensional (range, depth, bearing, and time) movements of marine mammals during impact and vibratory pile driving at the modeling location. Animats were distributed in a box from 37.5° to 39°N and 73.75° to 75.5°W (168 x 154 kilometers (km)) centered on the modeling site (38.3°N, 74.7°W). Animats were further limited within this modeling box by the coastline and the minimum occurrence depth for each species. These animat movements were convolved with the 3-D propagation modeling outputs to predict exposure histories for each simulated animal over a 24-hour period. Movements of marine mammal species potentially occurring in the US Wind Project area were modeled to predict their exposure to the sounds resulting from impact and vibratory pile driving.

2 REGULATORY CRITERIA AND SCIENTIFIC GUIDELINES

2.1 Underwater Acoustic Criteria

Under the Marine Mammal Protection Act (MMPA), the National Oceanic and Atmospheric Administration (NOAA) Fisheries is allowed, upon request, to authorize the incidental, but not intentional, "taking" of small numbers of marine mammals by U.S. citizens or agencies who engage in a specified activity (other than commercial fishing) within a specified geographical region. The term "take," as defined in Section 3 (16 U.S. Code [U.S.C.] section 1362 (13)) of the MMPA, means "to harass, hunt, capture, or kill, or attempt to harass, hunt, capture, or kill any marine mammal." "Harassment" was further defined in the 1994 amendments to the MMPA, with two levels of harassment: Level A and Level B. By definition, Level A harassment is any act of pursuit, torment, or annoyance that has the potential to injure a marine mammal or marine mammal stock, while Level B harassment is any act of pursuit, torment, or annoyance that has the potential to disturb a marine mammal or marine mammal stock in the wild by causing disruption of behavioral patterns, including, but not limited to, migration, breathing, nursing, breeding, feeding, or sheltering.

NOAA Fisheries (2018) has provided guidance for assessing the physiological impacts (Level A) of anthropogenic sound on marine mammals under their regulatory jurisdiction, which includes whales, dolphins, seals, and sea lions. The guidance specifically defines hearing groups, develops auditory weighting functions, and identifies the received levels or acoustic threshold levels, above which individual marine mammals are predicted to experience changes in their hearing sensitivity (PTS or TTS) for acute, incidental exposure to underwater sound. Southall *et al.* (2019) published consistent weighting functions and threshold levels for marine mammal species included in the NOAA Fisheries (2018) guidance but included all marine mammal species (not just those under NOAA Fisheries jurisdiction) for all noise exposures (both under water and in air), as well as updating the hearing groups. Those revised groups are defined as:

- Low-frequency (LF) Cetaceans—this group consists of the mysticetes (baleen whales) with a collective generalized hearing range of 7 Hz to 35 kilohertz (kHz).
- Mid-frequency (MF) Cetaceans—includes most of the dolphins, all toothed whales except for *Kogia* spp., and all the beaked and bottlenose whales with a generalized hearing range of approximately 150 Hz to 160 kHz (renamed high-frequency cetaceans by Southall *et al.* (2019) because their best hearing sensitivity occurs at frequencies of several tens of kHz or higher).
- High-frequency (HF) Cetaceans—incorporates all the true porpoises, the river dolphins, plus *Kogia* spp., *Cephalorhynchus* spp. (genus in the dolphin family Delphinidae), and two species of *Lagenorhynchus* (Peale's and hourglass dolphins) with a generalized hearing range estimated from 275 Hz to 160 kHz (renamed very high-frequency cetaceans by Southall *et al.* (2019) since some of these species have best hearing sensitivity at frequencies exceeding 100 kHz).
- Phocids Underwater (PW)—consists of true seals with a generalized underwater hearing range from 50 Hz to 86 kHz (renamed phocid carnivores in water by Southall *et al.* 2019).
- Otariids Underwater (OW)—includes sea lions and fur seals with a generalized underwater hearing range from 60 Hz to 39 kHz (termed other marine carnivores in water by Southall *et al.* (2019) and includes otariids, as well as walrus [Family Odobenidae], polar bear [*Ursus maritimus*], and sea and marine otters [Family Mustelidae]). It should be noted that otariids are not expected in the project area.

Within their generalized hearing ranges, the ability to hear sounds varies with frequency, as demonstrated by examining audiograms of hearing sensitivity (NOAA Fisheries 2018; Southall *et al.* 2019). To reflect higher noise sensitivities at particular frequencies, auditory weighting functions were developed for each functional hearing group that reflected the best available data on hearing ability (composite audiograms), susceptibility to noise-induced hearing loss, impacts of noise on hearing, and data on equal latency (NOAA Fisheries 2018). These weighting functions are applied to individual sound received levels to reflect the susceptibility of each hearing group to noise-induced threshold shifts, which is not the same as the range of best hearing.

NOAA Fisheries (2018) defined acoustic threshold levels at which PTS is predicted to occur for each hearing group for impulsive and non-impulsive signals. Non-impulsive signals do not have the high peak pressure with rapid rise time and decay characteristic of impulsive sounds; instead, the pressure (i.e., intensity) of non-impulsive signals is consistent throughout the signal. The acoustic threshold levels for non-impulsive sounds are defined as the cumulative sound exposure level over a 24-hr period ($L_{E,24h}$) with the appropriate frequency weighting for each hearing group (Figure ; Table 1), which is reflected in the subscript of each threshold

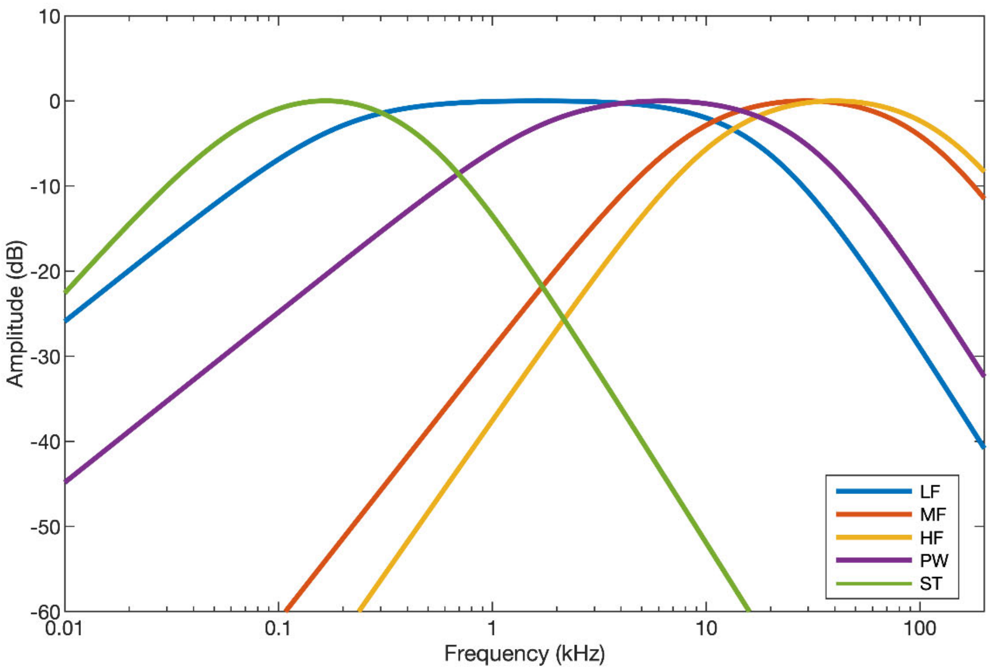

Figure 4. Auditory weighting functions for cetaceans (LF, MF, and HF species) and pinnipeds in water (PW) from NOAA Fisheries (2018). The sea turtle (ST) function is from Finneran et al. (2017).

(e.g., the LF cetacean threshold is identified as $L_{E,LF,24h}$). The cumulative SEL metric considers both received level and duration of exposure over the duration of the activity within a 24-hr period. The TTS threshold is defined as 20 dB less than the PTS threshold. A summary of the cumulative sound exposure acoustic thresholds for PTS and TTS are provided (Table 1).

Behavioral thresholds, part of MMPA Level B harassment, is defined by NOAA Fisheries as 120 dB re 1 μPa^2 (L_P) at a reference pressure of 1 microPascal squared (re 1 μPa^2) for continuous sources, such as that produced by shipping or vibratory pile driving and 160 dB re 1 μPa^2 (L_P) for impulsive sources, such as impact pile driving.

In a cooperative effort between federal and state agencies, interim criteria were developed to assess the potential for injury to fishes exposed to pile driving sounds. These noise injury thresholds have been established by the Fisheries Hydroacoustic Working Group, which was assembled by NOAA Fisheries with thresholds subsequently adopted by NOAA Fisheries. The NOAA Fisheries Greater Atlantic Regional Fisheries Office (GARFO) has applied these standards for assessing the potential effects to fish species and sea turtles listed under the Endangered Species Act (ESA) that have been exposed to elevated levels of underwater sound produced during pile driving (GARFO 2019). These noise thresholds are based on sound levels that have the potential to produce injury or illicit a behavioral response from fishes (Table 2). Separate

Table 1. Acoustic threshold levels for marine mammal physiological harassment (MMPA Level A) and NOAA Fisheries behavioral harassment (BOEM comments 2020).

Hearing Group	Impulsive Sounds			Continuous Non-Impulsive	
	SEL (dB re 1μPa^2-s)	Peak (dB re 1μPa^2)	Behavior (dB re 1μPa^2)	PTS Onset	Behavior (dB re 1μPa^2)
Low-frequency cetaceans (LFC)	183 dB ($L_{E,LF,24h}$)	219 dB ($L_{pk,0\text{-}pk,flat}$)	160 dB (L_p)	199 dB ($L_{E,LF,24h}$)	120 dB (L_p)
Mid-frequency cetaceans (MFC)	185 dB ($L_{E,MF,24h}$)	230 dB ($L_{pk,0\text{-}pk,flat}$)		198 dB ($L_{E,MF,24h}$)	
High-frequency cetaceans (HFC)	155 dB ($L_{E,HF,24h}$)	202 dB ($L_{pk,0\text{-}pk,flat}$)		173 dB ($L_{E,HF,24h}$)	
Phocid pinnipeds underwater (PW)	185 dB ($L_{E,PW,24h}$)	218 dB ($L_{pk,0\text{-}pk,flat}$)		201 dB ($L_{E,PW,24h}$)	

* Dual metric thresholds for impulsive sounds: Use whichever results in the largest isopleth for calculating PTS onset. If a non-impulsive sound has the potential of exceeding the peak sound pressure level thresholds associated with impulsive sounds, these thresholds are recommended for consideration.

Table 2. BOEM requested acoustic threshold levels for physiologic impacts to fishes.

Fish Group	Impulsive Signals			Non-Impulsive Signals	
	Injury		TTS	Injury	TTS
	SEL (dB re 1μPa^2-s) (Unweighted)	Peak (dB re 1μPa^2) (Unweighted)	SEL (dB re 1μPa^2-s) (Unweighted)	SPL (dB re 1μPa^2) (Unweighted)	SPL (dB re 1μPa^2) (Unweighted)
Fishes without swim bladders	> 216 dB ($L_{E, flat, 24h}$)	> 213 dB($L_{pk,0\text{-}pk,flat}$)	> 186 dB ($L_{E, flat, 24h}$)		
Fishes with swim bladder not involved in hearing	203 dB ($L_{E, flat, 24h}$)	> 207 dB($L_{pk,0\text{-}pk,flat}$)	> 186 dB ($L_{E, flat, 24h}$)		
Fishes with swim bladder involved in hearing	203 dB ($L_{E, flat, 24h}$)	> 207 dB ($L_{pk,0\text{-}pk,flat}$)	186 dB ($L_{E, flat, 24h}$)	170 dB ($L_{rms, flat}$)	158 dB ($L_{rms, flat}$)
All Fish (mass > 2 g)	187 dB ($L_{E, flat, 24h}$)	206 dB($L_{pk,0\text{-}pk,flat}$)			
All Fish (mass < 2g)	183 dB ($L_{E, flat, 24h}$)	206 dB($L_{pk,0\text{-}pk,flat}$)			

Table 3. BOEM requested acoustic threshold levels for physiologic impacts to sea turtles.

Species Group	***Impulsive Signals***				***Non-Impulsive Signals***	
	Injury		***TTS***		***Injury***	***TTS***
	SEL (dB re 1μPa²-s) (Weighted)	***Peak (dB re 1μPa²) (Unweighted)***	***SEL (dB re 1μPa²-s) (Weighted)***	***Peak (dB re 1μPa²) (Unweighted)***	***SEL (dB re 1μPa²-s) (Weighted)***	***SEL dB re (1μPa²-s) (Weighted)***
Sea turtles	204 dB ($L_{E,\ 24h}$)	232 dB ($L_{pk,0\text{-}pk,flat}$)	189 dB ($L_{E)}$	226 dB ($L_{pk,flat}$)	220 dB (L_E)	200 dB (L_E)

criteria are provided in GARFO (2019) for fishes weighing less than two grams and for fishes weighing more than two grams. Since fish of less than 2 grams are expected to occur in the waters of the Project for only a small percentage of the annual period, we have assessed only fish greater than 2 grams.

For sea turtles, the *Criteria and Thresholds for U.S. Navy Acoustic and Explosive Effects Analysis (Phase III)* technical report (Finneran *et al.* 2017) outlines both peak and cumulative SEL metrics to assess TTS and PTS injury (Table 3). The cumulative SEL metric is assessed with the appropriate frequency weighting for sea turtles (Figure). These injury criteria are incorporated into the guidance put forth by GARFO for sea turtles.

A Working Group organized under the American National Standards Institute-Accredited Standards Committee S3, Subcommittee 1, Animal Bioacoustics, also developed sound exposure guidelines for fish and sea turtles (Table 4; Popper et al. 2014). This working group identified three types of fishes depending on how they might be affected by underwater sound. The categories include fishes with no swim bladder or other gas chamber (e.g., dab and other flatfish); fishes with swim bladders in which hearing does not involve the swim bladder or other gas volume (e.g., salmonids); and fishes with a swim bladder that is involved in hearing (e.g., channel catfish).

Table 4. BOEM acoustic threshold levels for behavioral impacts to fishes and sea turtles

Group	***Behavioral threshold (L_{rms} dB re 1μPa², unweighted)***
Small fish (mass < 2g)	150
Large Fish (mass > 2 g)	150
Sea Turtles	175

The peak sound pressure level (L_{pk}) in these tables has a reference value of 1 μPa^2, and the cumulative sound exposure level (L_E) has a reference value of 1 μPa^{2}s. The subscript "flat" indicates sound pressures are unweighted. The subscript associated with cumulative sound exposure level thresholds indicates the designated marine mammal (LF, MF, and HF cetaceans, and PW pinnipeds) or sea turtle (ST) auditory weighting function. The accumulation period for SEL thresholds is indicated in hours in the subscript.

2.2 Weighting Used for Marine Mammal Impact Analysis

Exposure estimates over a 24-hour period were generated for all potential marine mammal species in response to potential impact pile driving of the monopile and jacket foundation structures in the Lease area. LF auditory weighting was used to model the exposure of the fin, minke, North Atlantic right, and humpback whales to the pile driving activities. MF auditory weighting was used to model the exposure of sperm, beaked, pilot, and killer whales as well as dolphins, while HF auditory weighting was used to model the exposure of the harbor porpoise and *Kogia* spp. The phocid underwater (PW) weighting was used to model the exposure of the harbor seal. The best available information on marine mammal density estimates (Roberts *et al.* 2020, Roberts *et al.* 2021) (Table 5) and behavioral patterns of the western North Atlantic Ocean species were used to model the movement of the marine mammals around the proposed pile driving locations over a 24-hour period. The modeling parameters used to represent these species are provided in Appendix A.

3 MARINE SPECIES POTENTIALLY OCCURRING IN THE PROJECT AREA

Following are descriptions of the marine species potentially occurring in the Project area that were modeled to access exposure potential.

3.1 Fin Whale (*Balaenoptera physalus*)

Fin whales are the second largest whale species, with males reaching 25 m and females reaching 26 m in length. Fin whales are a cosmopolitan species, only avoiding ice covered or tropical waters. Northern fin whales prefer to feed on krill, although they will eat other crustacean species and small fish as well. Southern hemisphere fin whales have a well-defined seasonal latitudinal migration, as is typical in many baleen whales. Migratory patterns of the fin whale in the northern hemisphere are not well understood. In the North Atlantic, some individual fin whales are known to remain at high latitudes, while others remain at low latitudes throughout the year. It may be that prey distributions are driving the movements of the whales. Other potential drivers of this difference in distributions could be due to coastal feeding in the summer and movement into deeper water in the winter.

No direct measurement of fin whale hearing sensitivity has been made. Fin whales produce a variety of LF sounds that range in frequency from 10 to 200 Hz (Edds 1988, Watkins 1981, Watkins *et al.* 1987). Fin whales produce well-known “20 Hz pulses” and most of their vocalizations are below 100 Hz (Watkins *et al.* 1987). Males can produce these pulses in a repeated pattern that functions as song, a presumed reproductive display (Morano *et al.* 2012). Fin whales are known to respond to anthropogenic noise such as shipping vessel noise, airguns, and small vessel noise (Jahoda *et al.* 2003, Castellote *et al.* 2012).

Table 5. Marine mammal (Roberts et al., 2020; 2021) and sea turtle (DoN, 2007, Barco et al. 2018) density estimates used in animat modeling.

Marine Mammal Species	*Density (animals/1 km²)*	
	April-Nov	*May-Oct*
Common minke whale	0.0019863	0.0019129
Fin whale	0.0049980	0.0053951
Humpback whale	0.0019228	0.0016660
North Atlantic right whale	0.0003601*	0.0000643*
Atlantic spotted dolphin	0.0110289	0.0116774
Blainville's beaked whale	0.0010748	0.0010748
Common bottlenose dolphin (offshore)	0.1788633	0.2113603
Common dolphin	0.1263270	0.0969471
Cuvier's beaked whale	0.0019218	0.0019218
Gervais' beaked whale	0.0010748	0.0010748
Harbor porpoise	0.0047753	0.0009466
Harbor seal	0.0037791	0.0015894
Killer whale	0.0000090	0.0000090
Kogia spp.	0.0003004	0.0003004
Pantropical spotted dolphin	0.0000152	0.0000152
Pilot whales	0.0227548	0.0227548
Risso's dolphin	0.0106719	0.0115273
Rough-toothed dolphin	0.0002112	0.0002112
Sperm whale	0.0015992	0.0018990
Striped dolphin	0.0295892	0.0295892
True's beaked whale	0.0010748	0.0010748
Green turtle/Hardshelled guild	0.059209	0.059209
Kemp’s ridley turtle	0.015028	0.015028
Leatherback turtle	0.024261	0.024261
Loggerhead turtle (DoN 2017)	0.062064	0.062064
Loggerhead turtle (Barco et al. 2018)	2.064	2.064

*2021 values

3.2 Common Minke Whale (Balaenoptera acutorostrata)

Common minke whales are smaller baleen whales that are about 11 m in length. Minke whales occur most often in tropical to polar coastal/neritic and inshore waters of the Atlantic, Pacific, and Indian oceans but infrequently also occur in pelagic waters. Common minke whales are considered rare in the northern Indian Ocean, Gulf of Mexico, and Mediterranean Sea (Jefferson *et al.* 2015). Common minke whales are thought to be migratory, at least in some areas, but migratory pathways are not well known and populations in some area remain resident year-round (Cooke 2018). Minke whales opportunistically feed on a wide variety from crustaceans, plankton, and small schooling fish.

Although the hearing sensitivity of minke whales has not been directly measured (Ketten, 2000) models of their middle ears predicts their best hearing overlaps with their vocalization frequency range (Tubelli *et al.* 2012). Minke whales produce a variety of sounds, primarily moans, clicks, downsweeps, ratchets, thump trains, grunts, and “boings” in the 80 Hz to 20 kHz range, and the signal features of their vocalizations consistently include LF, short-duration downsweeps from 250 to 50 Hz (Edds-Walton 2000, Mellinger *et al.* 2000, Risch *et al.* 2014).

3.3 Humpback Whale (*Megaptera novaeangliae*)

Humpback whales are a medium sized baleen whale, with typical adult sizes of 15 to 16 m. They are a cosmopolitan species found in all ocean basins. All populations, except that of the Arabian Sea, migrate seasonally between high latitude feeding grounds and low latitude reproductive areas, where calving is known to occur. Given their 11.5 month long reproductive cycle, mating is presumed to occur in low latitude areas as well, but it remains unobserved. Northwest Atlantic humpbacks migrate from their summer grounds off northeastern U.S. and Canada to the Caribbean in the winter. Humpbacks are catholic feeders, able to take prey ranging from krill to small fish including sandlance, herring, spot, drum, and capelin.

Hearing has not been measured in humpback whales, but they were the first whale known to produce songs. Vocalizations span from 10 Hz to more than 24 kHz (Frankel *et al.* 1995, Au *et al.* 2006, Zoidis *et al.* 2008) but most of the energy is concentrated below 2 kHz. Humpback whales are known to react to anthropogenic sound (Frankel & Clark 2000, Fristrup *et al.* 2003, Dunlop *et al.* 2018). Like some other whale species, they have shown the ability to at least partially compensate for increases in masking noise by increasing their source level (Dunlop *et al.* 2014).

3.4 North Atlantic Right Whale (*Eubalaena glacialis*)

North Atlantic Right Whales (NARW) are a large slow-moving whale that typically grows to a length of 13 to 16 m. They are migratory between high latitude waters in the summer and lower latitude waters in the winter. Historically, NARW ranged between Florida, northwest Africa, Labrador, south Greenland, Iceland, and Norway. Commercial whaling decimated their numbers, and a remnant population now migrates between the southeast United States (U.S) (primarily eastern Florida and Georgia) and Canada.

Right whales are obligate predators on zooplankton, notably calanoid copepods, feeding in the spring, summer, and fall on their high latitude summer grounds. Feeding can occur at the surface and at depth, making them vulnerable to ship strikes and entanglement in fishing gear. They have been found to shift their feeding grounds in response to changing sea surface temperatures (Keller *et al.* 2006), likely a response to shifts in the distribution of their prey (Meyer-Gutbrod & Greene 2014).

NARWs migrate to calve in the southeast U.S. waters in the winter. They show strong preferences for waters that are 13 to 19 m in depth and between 13 to 16°C (Winn *et al.* 1986, Kraus & Rolland 2007). The breeding grounds are unknown and NARW typically have a three-year reproductive cycle.

NARW are low-frequency hearing specialists. Their predicted hearing ranges from 10 to 22,000 Hz (Parks *et al.* 2007). Their vocalizations have most of their energy below 2,000 Hz (Parks *et al.*, 2011). The characteristics of NARW vocalizations have been shown to change in response to increased noise (Parks *et al.* 2011, Parks *et al.* 2007a).

3.5 Atlantic Spotted Dolphin (*Stenella frontalis*)

Atlantic spotted dolphins are about 1.5 to 2.3 m in length and are found only in the tropical and warm-temperate waters of the Atlantic Ocean and associated seas and occur commonly along the southeastern U.S. and the Gulf coasts, in the Caribbean, and off West Africa. They inhabit waters usually about 200 m in depth but may occasionally swim closer to shore to feed. These dolphins eat small fish, invertebrates, and cephalopods (such as squid and octopi).

There are no current hearing data on Atlantic spotted dolphins. Atlantic spotted dolphins produce a variety of sounds, including whistles, whistle-squawks, buzzes, burst-pulses, synch pulses, barks, screams, squawks, tail slaps, and echolocation clicks. Like other odontocetes, they produce broadband, short duration echolocation signals. Their broadband clicks have peak frequencies between 60 and 120 kHz. Dolphins produce whistles with a frequency range of 1 to 23 kHz.

3.6 Blainville's Beaked Whale (*Mesoplodon densirostris*)

Blainville's beaked whale is the most cosmopolitan of the *Mesoplodon* beaked whales, having a continuous distribution throughout tropical, sub-tropical, and warm-temperate waters of the world's oceans (MacLeod *et al.* 2006).

The hearing sensitivity of a stranded Blainville's beaked whale was reported between 5.6 and 160 kHz, with the best hearing response between 40 and 50 kHz and thresholds less than 50 dB re 1 μPa (Pacini *et al.* 2011). Johnson *et al.* (2006) investigated the clicks of Blainville's beaked whales and discovered they have a distinct search click with an FM upsweep with a minus 10 dB bandwidth from 26 to 51 kHz; they also produce a buzz click that is used during the final stage of prey capture.

3.7 Common Bottlenose Dolphin (*Tursiops truncatus*)

The common bottlenose dolphin is typically 2 *to* 3.9 m in length. Common bottlenose dolphins are distributed worldwide in temperate to tropical waters. In North American waters, this species inhabits waters with temperatures ranging from 50 to 89°F (10 to 32°C) (Wells & Scott 2009). Common bottlenose dolphins are primarily found in coastal or shallower waters, but they also occur in diverse habitats ranging from rivers and protected bays to oceanic islands and the open ocean (Scott & Chivers 1990, Sudara & Mahakunayanakul 1998, Wells & Scott 2009). Common bottlenose dolphins in the U.S. Atlantic waters are divided into multiple offshore, estuarine, and coastal stocks. Seasonal movements vary between inshore and offshore locations and year-round home ranges (Croll *et al.* 1999, Wells & Scott 2009).

Bottlenose dolphins can thrive in many environments and feed on a variety of prey, such as fish, squid, and crustaceans (e.g., crabs and shrimp). They use different techniques to pursue and capture prey, searching for food individually or cooperatively.

Bottlenose dolphins hear underwater sounds in the range of 150 Hz to 135 kHz (Johnson 1967, Ljungblad *et al.* 1982). Their best underwater hearing occurs between 15 and 110 kHz, with the threshold level range is 42 to 52 dB RL (Au 1993). Nachtigall *et al.* (2000) more recently measured the range of highest sensitivity as between 25 and 70 kHz, with peaks in sensitivity at 25 and 50 kHz. Bottlenose dolphins produce a variety of whistles, echolocation clicks, low-frequency narrow, “bray” and burst-pulse sounds with frequencies as low as 50 Hz and as high as 150 kHz with dominant frequencies at 0.3 to 14.5 kHz, 25 to 30 kHz, and 95 to 130 kHz (Janik 2000).

3.8 Common Dolphin (*Delphinus delphis*)

The common dolphin is one of the most abundant dolphins in the world. It reaches lengths of about 1.8 m. Common dolphins are distributed worldwide in temperate, tropical, and subtropical oceans, primarily along continental shelf and steep bank regions where upwelling occurs (Jefferson et al. 2015). They seem to be most common north of 50°N in the Atlantic Ocean (Croll et al., 1999). Common dolphins usually rest during the day and feed at night. They typically dive to about 30 m to feed on schooling fish and cephalopods (e.g., squid) that migrate towards the surface at night.

Little is known about hearing in the common dolphin. The hearing threshold of a common dolphin was measured with an auditory range from 10 to 150 kHz, with greatest sensitivity between 60 and 70 kHz. Common dolphins produce sounds as low as 0.2 kHz and as high as 150 kHz, with dominant frequencies at 0.5 to 18 kHz and 30 to 60 kHz (Au 1993, Moore & Ridgway 1995). Signal types consist of clicks, squeals, whistles, and creaks (Evans, 1994). Whistles of common dolphins range between 3.5 and 23.5 kHz (Ansmann *et al*. 2007). Most of the energy of echolocation clicks is concentrated between 15 and 100 kHz (Croll *et al*. 1999). In the North Atlantic, the mean SL of common dolphin whistles was approximately 143 dB with a maximum of 154 (Croll *et al*. 1999).

3.9 Cuvier’s Beaked Whale (*Ziphius cavirostris*)

Cuvier’s beaked whale can reach lengths of 4.6 to 7 m. They are the most cosmopolitan of all beaked whale species, with a wide distribution in oceanic tropical to polar waters of all oceans except the high polar regions. Cuvier’s beaked whales prefer the deeper waters of the continental slope and areas around steep underwater geologic features like seamounts and submarine canyons.

The hearing sensitivity of Cuvier’s beaked whales has not been measured (Ketten 2000). Cuvier’s beaked whales have been recorded producing clicks between about 12 to 40 kHz with associated SLs of 200 to 220 dB re 1 $\mu Pa^2 m^2$ (pk-to-pk). Johnson *et al.* (2004) also found that

Cuvier's beaked whales do not vocalize when within 200 m of the surface and only started clicking at an average depth of 475 m and stopped clicking on the ascent at an average depth of 850 m.

3.10 Gervais' Beaked Whale (*Mesoplodon europaeus*)

Gervais' beaked whales are about the same size as Cuvier's beaked whale, with lengths ranging from 4.7 to 5 m. Gervais' beaked whales occur in deep tropical, subtropical, and warm temperate waters of the Atlantic Ocean, ranging from Ireland to Brazil and the Gulf of Mexico, but are occasionally found in colder temperate seas. While diving, they use suction to feed mainly on cephalopods (e.g., squid), mysid shrimp, and small fish in deep water.

Few data are available on the auditory abilities of *Mesoplodon* beaked whales. A stranded Gervais' beaked whale had an upper limit for effective hearing at 80 to 90 kHz (Finneran *et al.* 2009).

3.11 Killer Whale (*Orcinus orca*)

Killer whales range from 8.5 to nearly 10 m in length, for females and males, respectively. This largest member of the dolphin family has a distinctive and easily identifiable appearance and is perhaps the most cosmopolitan of all marine mammals. Killer whales occur in all the world's oceans from about 80°N to 77°S and are especially common in high productivity and high-latitude (cold-temperate to subpolar) neritic waters (Ford 2009, Forney & Wade 2006, Leatherwood & Dahlheim 1978). Killer whales have a widely varied diet, feeding on nearly every group of large marine animals and even some marine birds. Killer whales can be divided into ecotypes depending upon their geography and the prey type upon which they feed. In the Atlantic Ocean, killer whales have been generally categorized as two ecotypes, Type 1, which are smaller and fish-eating, and Type 2, larger whales that feed on cetaceans (Jefferson et al. 2015).

Killer whales hear underwater sounds in the range of <500 Hz to 120 kHz (Bain *et al.* 1993, Szymanski *et al.* 1999). Their best underwater hearing occurs between 15 and 42 kHz (Hall & Johnson 1972, Szymanski et al. 1999). Killer whales produce sounds as low as 80 Hz and as high as 85 kHz with dominant frequencies at 1 to 20 kHz (Awbrey 1982, Ford & Fisher 1982, Miller & Bain 2000, Schevill & Watkins 1966). An average of 12 different call types (range 7 to 17)—mostly repetitive discrete calls—exist for some pods of killer whales (Ford 2009). Vocalizations include pulsed calls, whistles, and echolocation clicks. While the basic structure of killer whale vocalizations is similar within all populations, geographic variation between populations does exist (Samarra *et al.* 2015).

3.12 Dwarf and Pygmy Sperm Whales (*Kogia* spp).

The two *Kogia* species, pygmy and dwarf sperm whales, are very difficult to differentiate at sea due to their small body size and cryptic nature, so most records of these species are only identified to genus (*Kogia* spp.). Thus, little detailed information is available for either species.

Pygmy and dwarf sperm whales are distributed worldwide, primarily in temperate to tropical deep waters, and are especially common in waters along continental shelf breaks (Evans 1987, Jefferson et al. 2015). Dwarf sperm whales appear to prefer warmer water than the pygmy sperm whale (Caldwell & Caldwell 1989). Little evidence exists for seasonal movements in either species (Mcalpine 2009). Both *Kogia* species feed on deep water cephalopods but also feed on fishes and shrimps (Jefferson et al. 2015).

Sparse data exist on the hearing sensitivity of pygmy sperm whales and no data are known on the hearing sensitivity of the dwarf sperm whale have been measured. The hearing of a rehabilitating pygmy sperm whale was measured, with greatest hearing sensitivity between 90 and 150 kHz (Carder *et al.* 1995, Ridgway & Carder 2001). Recordings of captive pygmy sperm whales show they produce sounds between 60 and 200 kHz with peak frequencies at 120 to 130 kHz (Carder et al. 1995, Ridgway & Carder 2001, Santoro *et al.* 1989). Echolocation pulses of pygmy sperm whales were documented with peak frequencies at 125 to 130 kHz (Ridgway and Carder 2001). Merkens *et al.* (2018) recently reported that the sounds produced by captive and free-ranging dwarf sperm whales were very similar to those of pygmy sperm whales, and were characterized as narrow-band, HF clicks with mean frequencies from 127 to 129 kHz.

3.13 Pantropical Spotted Dolphin (*Stenella attenuata*)

Pantropical dolphins are relatively small dolphins that range in size from 1.8 to 2.1 m. These dolphins occur throughout tropical and sub-tropical waters of the world from roughly 40°N to 40°S (Jefferson *et al*. 2015). Typically, oceanic, pantropical spotted dolphins can be found close to shore in areas where deep water approaches the coast. Pantropical spotted dolphins spend most of daylight hours in waters between 91 and 305 m deep, but at night, they dive into deeper waters to search for prey and feed primarily on mesopelagic cephalopods and fishes.

There are no direct hearing measurements for the pantropical spotted dolphin. Pantropical spotted dolphins produce whistles with a frequency range of 3.1 to 21.4 kHz (Richardson *et al.* 1995). They also produce click sounds that are typically bimodal in frequency with peaks at 40 to 60 kHz and 120 to 140 kHz with source levels up to 220 dB re 1 µPa at 1m (Schotten *et al.* 2004).

3.14 Pilot Whales (*Globicephala* spp.)

Both species, the short- and long-finned, pilot whales occur in the North Atlantic Ocean. Adult pilot whales reach lengths of about 6.5 m. Sightings of pilot whales in the western North Atlantic occur primarily near the continental shelf break from Florida to the Nova Scotian Shelf (Mullin & Fulling 2003). Pilot whales tend to concentrate in areas of high bathymetric relief or strong thermal fronts and are typically found almost exclusively along the continental shelf edge and slope regions (Waring *et al.* 2010). Short-finned pilot whales have a tropical and subtropical distribution (Olson 2009), while long-finned pilot whales occur off shelf edges in deep pelagic waters in temperate and subpolar zones excluding the North Pacific (Nelson & Lien 1996). Pilot whales feed mainly on squid, but they may also feed on octopuses and fish, all from moderately deep water of 305 m or more.

The best hearing sensitivity for a captive pilot whale was measured between 40 and 56 kHz with the upper limit of functional hearing between 80 and 100 kHz. Pilot whales echolocate with a precision similar to bottlenose dolphins. Short-finned pilot whales produce sounds as low as 280 Hz and as high as 100 kHz, with dominant frequencies between 2 to 14 kHz and 30 to 60 kHz (Caldwell & Caldwell 1969, Fish & Turl 1976, Scheer *et al.* 1998). The mean frequency of calls produced by short-finned pilot whales is 7,870 Hz, much higher than the mean frequency of calls produced by long-finned pilot whales (Rendell *et al.* 1999). Echolocation abilities have been demonstrated during click production (Evans 1973). SLs of clicks have been measured as high as 180 dB (Fish and Turl 1976).

3.15 Risso's Dolphin (*Grampus griseus*)

Risso's dolphin's range in length from 2.6 to 3.9 m. These dolphins inhabit deep oceanic and continental slope waters worldwide, from tropical to temperate waters of both hemispheres (Leatherwood *et al.* 1980, Baird 2009). They appear, however, to have a strong preference for temperate waters between 30° and 45° in latitude (Jefferson et al., 2015). Little to nothing is known about movement or migration patterns of Risso's dolphins. Although Risso's dolphins consume cephalopods and crustaceans, they prefer squid and octopus (Jefferson et al. 2015).

Audiograms for Risso's dolphins indicate that their hearing ranges in frequency from 1.6 to 110 kHz, with optimal hearing occurring between 4 and 80 kHz (Nachtigall *et al.* 1995). Risso's dolphins produce sounds as low as 0.1 kHz and as high as 65 kHz. Their dominant vocalizing frequencies are between 2 to 5 kHz and 65 kHz (Corkeron & Van Parijs 2001, Watkins 1967, Au 1993). Risso's dolphins produce tonal whistles, burst-pulse sounds, echolocation clicks, and a hybrid burst-pulse tonal signal (Corkeron and Van Parijs 2001).

3.16 Rough-toothed Dolphin (*Steno bredanensis*)

Rough-toothed dolphins reach lengths of about 2.6 m and occur in oceanic tropical and warm-temperate waters around the world. Although they appear to be relatively abundant in certain areas; these dolphins are typically found in continental shelf waters in some locations, such as Brazil. In the western Atlantic Ocean, they are found from the southeastern U.S. to southern Brazil, including the Gulf of Mexico and Caribbean Sea. Prey that rough-toothed dolphins feed upon include squids and different types of fish.

Very little information is available on the hearing sensitivity of rough-toothed dolphins. Rough-toothed dolphins are likely capable of detecting frequencies much higher than 80 kHz and as low as 5 kHz (Cook *et al.* 2005). Rough-toothed dolphins produce clicks and whistles ranging from 0.1 kHz to 200 kHz (Miyazaki & Perrin 1994, Popper 1980, Thomson & Richardson 1995).

3.17 Sperm Whale (*Physeter macrocephalus*)

The sperm whale is the largest toothed whale, with males averaging 16 m and females only about 12 m in length. Sperm whales are primarily found in deeper (1000 m) ocean waters and distributed in polar, temperate, and tropical waters of the world's oceans. In the waters of the U.S. Atlantic, sperm whales are distributed from the continental shelf edge and slope to open ocean waters and are often associated with the Gulf Stream and its features. Sperm whales dive deeply for their prey, which consists of species such as squid, sharks, skates, and fishes. The measured hearing of a sperm whale calf suggested an auditory range of 2.5 to 60 kHz, with best hearing sensitivity between 5 and 20 kHz (Ridgway & Carder 2001). Ketten (2000) predicted a lower limit of hearing, near 100 Hz. Sperm whales produce broadband clicks with energy from less than 100 Hz to 30 kHz. Regular click trains and creaks have been recorded from foraging sperm whales and may be produced as a function of echolocation. A series of short clicks, termed "codas," have been associated with social interactions and are thought to play a role in communication.

3.18 Striped Dolphin (*Stenella coeruleoalba*)

Striped dolphins are one of the most abundant and commonly occurring dolphins in the world. They reach about 2.7 m in length and are common in tropical and warm-temperate oceanic waters of the Atlantic, Pacific, and Indian oceans and adjacent seas between roughly 50° N and 40° S (Jefferson et al. 2015) and are often linked to upwelling areas and convergence zones.

The behavioral audiogram developed by Kastelein *et al.* (2003) for the striped dolphin shows hearing capabilities from 0.5 to 160 kHz. The best underwater hearing of the species appears to be at from 29 to 123 kHz (Kastelein *et al*. 2003). Striped dolphins produce whistle vocalizations lasting up to three seconds, with frequencies ranging from 1.5 to >24 kHz, with peak frequencies ranging from 8 to 12.5 kHz.

3.19 True's Beaked Whale (*Mesoplodon mirus*)

True's beaked whales are medium sized beaked whales, ranging from 4.7 to 5.3 m in length. This beaked whale species occurs in the deep, warm, temperate waters of the North Atlantic Ocean as well as at least two other areas in the Southern Hemisphere. In the western North Atlantic Ocean, True's beaked whales range from Nova Scotia to Brazil. While diving, these beaked whale use suction to feed on small fish and cephalopods (e.g., squid) in deep waters, normally about 870 m in depth.

Few data are available on the auditory abilities of *Mesoplodon* beaked whales. Scientists recently discovered that True's beaked whales emit ultrasonic[1] vocalizations, such as clicks, during foraging dives. DeAngelis *et al.* (2018) described the frequency modulated clicks of True's beaked whales as similar to those of Gervais's beaked whales. The median peak frequencies of True's beaked whale clicks recorded in 2016 and 2017 were 43.1 and 43.5 kHz, respectively. Median inter-click intervals were 0.17s and 0.19 s.

1 Ultrasonic=frequencies >20 kHz

3.20 Harbor Porpoise (*Phocoena phocoena*)

Harbor porpoises are small, coastal odontocetes that are common in the waters of the northern hemisphere. They reach a maximum size of about 1.5 m and are typically difficult to spot at the sea surface due to their small size and very short surface durations. Harbor porpoise feed primarily on small fish.

Harbor porpoises are classified as HF hearing specialists and produce narrowband high-frequency echolocation clicks (Madsen *et al.* 2005). Despite their HF hearing, harbor porpoises are well known for sometimes strong behavioral reactions to LF sound (Tougaard *et al.* 2009, Kastelein 2013, Kastelein *et al.* 2017, Graham *et al.* 2019, Graham *et al.* 2017).

3.21 Green Turtle (*Chelonia mydas*)

Eleven worldwide distinct population segments (DPSs) for the green turtle have been designated as either threatened or endangered under the ESA (NOAA 2016). Green turtles potentially occurring in the project area are part of the North Atlantic DPS, which is listed as threatened. The ESA critical habitat in the coastal waters around Culebra Island, Puerto Rico and its outlying keys established in 1998 remains in effect for the North Atlantic DPS. The global population of the green turtle is estimated as 570,926 turtles while the North Atlantic DPS has an estimated population of 167,424 individuals (NOAA 2016).

Green turtles are widespread throughout tropical, subtropical, and warm-temperate waters of the Atlantic, Pacific, and Indian oceans and Mediterranean Sea between 30° N and 30°S (Lazell, 1980). Except during the juvenile lifestage and adult migrations when green turtles are found in the oceanic environment, green turtles principally inhabit the neritic zone, typically occurring in nearshore and inshore waters where they forage primarily on sea grasses and algae (Mortimer, 1982). Nesting of green turtles occurs on nearly 1,800 nesting beaches worldwide in over 80 countries (Hirth 1997, Pike 2013).

Green turtles typically make shallow and short-duration dives to no more than 98 ft (30 m) for <23 min but dives more than 453 ft (138 m) and for durations of 307 min have been recorded, with these deeper dives usually occurring during winter (Blanco et al. 2013, Hays et al. 2000, Hochscheid et al. 1999, Rice and Balazs 2008). Godley et al. (2002) reported travel speeds for green turtles ranging from 0.3 to 1.5 kt (0.6 to 2.8 kph), with faster swim speeds associated with traverse across deeper, open waters. Song et al. (2002) reported average swimming speeds ranging from 0.8 to 1.6 kt (1.4 to 3 kph) for migrating green turtles.

3.22 Kemp's Ridley Turtle (*Lepidochelys kempii*)

The Kemp's ridley turtle is the rarest sea turtle worldwide and has the most restricted distribution. The Kemp's ridley is listed as endangered throughout their range under the ESA with no designated critical habitat. Although abundance information for the Kemp's ridley turtle is sparse, the 2012 estimated population of female Kemp's ridley turtles 2 years and older was 248,307 turtles with 10,987 nests reported in 2014 (NMFS and USFWS 2015).

Kemp's ridley turtles are found primarily in the neritic waters along the U.S. and Mexico coasts of the Gulf of Mexico and western North Atlantic Ocean (Byles and Plotkin 1994, Marquez-M. 1994, Plotkin 2003). Adult females make relatively short annual migrations from their feeding grounds in the western Atlantic and Gulf of Mexico to their principal nesting beach at Rancho Nuevo, Mexico. Unique among sea turtles, adult males are non-migratory, remaining resident in coastal waters near Rancho Nuevo year-round. In contrast, juvenile Kemp's ridleys make longer migrations between their winter feeding grounds in the Gulf of Mexico and Florida to their summer feeding grounds in coastal waters and embayments of the U.S. East Coast. Kemp's ridley turtles participate in arribada nesting, with the major arribada nesting site at Rancho Nuevo; however, solitary nesting has been recorded at 10 beaches along 120 mi (193 km) of Mexican shoreline in Tamaulipas and another 20 mi (32 km) in Veracruz, Mexico.

Kemp's ridleys make shallow dives (<164 ft [<50 m]) of short duration (12 to 18 min) (Lutcavage and Lutz 1997). Renaud (1995) reported the mean dive duration as 33.7 min, with 84 percent of the submergences <60 min. Mean swimming speeds were reported to range from 0.4 to 0.7 kt (0.7 to 1.3 kph), with over 95 percent of the actual velocity values <2.7 kt (<5 kph) (Renaud 1995).

3.23 Leatherback Turtle (*Dermochelys coriacea*)

The leatherback turtle is the largest turtle in the world and one of the largest living reptiles. As a species, the leatherback is listed endangered throughout its range under the ESA. Critical habitat for the leatherback turtle has been designated in the Caribbean Sea waters adjacent to Sandy Point Beach, St. Croix, U.S. Virgin Islands, as well as in the northeast Pacific Ocean waters from California to Washington (NOAA 1979b, 2012b). Nel (2012) reported the worldwide leatherback abundance as 57,147 to 61,256 nests annually. The subpopulation of leatherback turtles in the northwest Atlantic Ocean is the largest in the world, with an estimated 34,000 to 94,000 individuals (The Turtle Expert Working Group 2007) and 50,842 nests per year (Wallace et al. 2013).

Leatherbacks are the most pelagic and most widely distributed of any sea turtle and can be found circumglobally in temperate and tropical oceans (Spotila 2004). The largest Atlantic nesting sites are located in Gabon, Africa and Trinidad, Caribbean Sea (Wallace et al. 2013). Highly migratory, leatherbacks in the western Atlantic travel north in the spring, following the Gulf Stream and feeding opportunistically, arriving in continental shelf and coastal waters off New England and Atlantic Canada where they remain through October. In the fall, some leatherbacks head south essentially retracing their offshore migratory route while others cross the Atlantic to Great Britain and migrate south along the eastern Atlantic (James et al. 2005).

Leatherback turtles make the deepest dives of any sea turtle, with the deepest dive recorded at 4,198 ft (1,280 m) (Doyle et al. 2008). Their longest duration dive was 86.5 min, but most dives are no more than 40 min (Byrne et al. 2009, López-Mendilaharsua et al. 2009, Sale et al. 2006). Hougthon et al. (2008) found that 99.6 percent of leatherback dives were to water depths less than 984 ft (300 m) while only a 0.4 percent were to deeper water depths, with the dives to waters >984 ft (300 m) occurring principally during the day and during migrational transit. In the Atlantic, Hays et al. (2004) determined that migrating and foraging adult leatherbacks spent 71 to 94 percent of their diving time at depths from 230 to 361 ft (70 to 110 m). The modal speeds of swimming leatherback turtles ranged between 1.1 to 1.6 kt (2 to 3 kph) with absolute maximum speeds in the range of 3.5 to 5.4 kt (6.5 to 10 kph) (Eckert 2002). Inter-nesting leatherback turtles swam at speeds ranging from 0.7 to 1.4 kt (1.25 to 2.5 kph) (Byrne et al. 2009).

3.24 Loggerhead Turtle (*Caretta caretta*)

Five loggerhead DPS are listed as endangered under the ESA while four DPS are listed as threatened (NOAA and USFWS 2011). Only members of the threatened Northwest Atlantic Ocean DPS occur in the project area. In 2014, critical habitat was designated for the Northwest Atlantic Ocean DPS in the northwestern Atlantic Ocean and the Gulf of Mexico that includes nearshore reproductive habitat, winter habitat, breeding areas, constricted migratory corridors, and *Sargassum* habitat (NOAA 2014). Critical habitat for the Northwest Atlantic Ocean DPS additionally includes 38 marine areas along the coastlines and offshore of North Carolina, South Carolina, Georgia, Florida, Alabama, Louisiana, and Texas (DoI 2014). Casale and Tucker (2017) estimated the minimum global population of loggerhead turtles as 200,246 individuals. One of the two major global populations occurs in southeastern U.S. and northern Gulf of Mexico waters, with the number of U.S. nests estimated at approximately 68,000 to 90,000 nests per year. The largest concentration of loggerhead female turtles in the Northwest Atlantic DPS nest along the coast of Florida, where in 2016, 65,807 nesting females were reported (FFWCC 2018).

Loggerhead turtles are found in coastal to oceanic temperate, tropical, and subtropical waters of the Atlantic, Pacific, and Indian oceans and the Mediterranean Sea (Dodd 1988). Although loggerhead turtles are highly migratory, no migrational movements north-south across the equator are known, and loggerheads migrate hundreds to thousands of miles between feeding and nesting grounds.

Howell et al. (2010) found that more than 80 percent the time, loggerheads in the North Pacific Ocean dove to water depths <16 ft (5 m), but 90 percent of their time was spent diving to depths <49 ft (15 m). Even as larger juveniles and adults, loggerheads' routine dives are only to 30 to 72 ft (9 to 22 m) (Lutcavage and Lutz 1997). Migrating male loggerheads along the U.S. East Coast dove to water depths of 66 to 131 ft (20 to 40 m) (Arendt et al. 2012). An adult loggerhead made the deepest recorded dive to 764 ft (233 m), staying submerged for 8 min (Sakamoto et al. 1990). The longest duration dive by a loggerhead turtle was 614 min during deep-bottom resting dives (Broderick et al. 2007). Sakamoto et al. (1990) reported loggerhead diving speeds ranging from 0.4 to 1.89 kt (0.75 to 3.5 kph), while migrating females swam at minimum speeds of 0.7 to 0.9 kt (0.75 to 1.7 kph) (Godley et al. 2003).

4 ACOUSTIC MODELING SCENARIOS

Three modeling scenarios were selected to represent the scope of the pile driving operations for the Project (Table). A single representative location (38.3°N, 74.7°W) was selected for the underwater acoustic modeling analysis. This site has a depth of 27 m, which is an intermediate depth over the range (12 to 42 m) of the Project area. The physical characteristics of the site are provided in section 4.1. Two foundation types were evaluated. The first was an 11 m diameter monopile being impact driven at a maximum strike energy of 4,400 kJ for a 2-hour duration. The second was of a 3.0-m pin pile as part of a jacket foundation with a maximum strike energy of 1,500 kJ. The third modeling scenario was vibratory pile driving of a 1.8-m diameter monopile.

Table** 6. **Overview of modeling scenarios.

Modeling Scenario	*Description*
1	11 m Monopile Foundation Impact Pile Driving – 4,400 kJ Hammer – Two-hour duration
2	3.0 m Pin Pile Jacket Foundation Pin Pile Impact Pile Driving – 1,500 kJ Hammer – Three-hour duration
3	1.8 m pile installed with vibratory driving – One-hour duration

4.1 Impulsive Source Scenarios – Impact Pile Driving

Installation of two foundation types was considered in the underwater acoustic analysis and are indicated as Scenarios 1 and 2 (Table). The installation of one monopile per day (24-hour period) was considered. The jacket foundation is comprised of four legs that are secured at the four corners with a 3.0-m diameter pin pile. Each leg requires a single pin pile. The installation of one and two pin piles per day (24-hour period) were considered. In the modeling of the pin piles, no correction for post-pile driving was applied as no determination regarding pre- or post-piling has yet been made; the modeling analysis is applicable regardless.

4.1.1 Acoustic Environment

4.1.1.1 Ambient Noise

A dedicated passive acoustic study (Bailey *et al.* 2018) in the Project area described the ambient noise environment. Bailey *et al.* (2018) deployed acoustic recorders throughout the Maryland Wind Energy Area (WEA) as well as offshore and inshore of the WEA (**Error! Reference source not found.**) to monitor baleen whales. The deployed series of long-term recorders monitored LF noise (1 to 1,000 Hz). The measured ambient noise levels were affected by the proximity of the shipping lanes into the Philadelphia area (white rectangles in **Error! Reference source not found.**). Ambient noise levels were increased at sites A-4M, A-7M and T-2M that adjoin or are in line with the shipping lanes (Table 7). Although these elevated ambient noise levels have no impact on the definition of regulatory

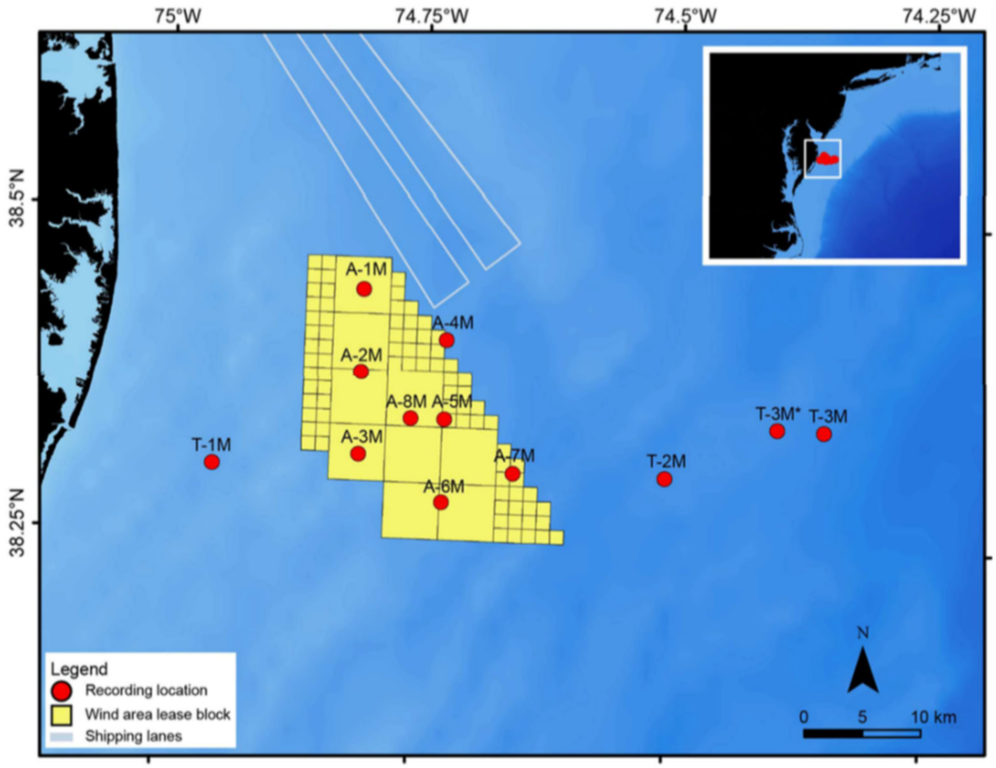

Figure 5. Location of recorders in the Bailey et al (2018) passive acoustic study with the shipping lanes into the Philadelphia area shown as white lines.

acoustic exposures, the raised ambient noise level reduce the signal excess of any pile driving sound.

4.1.1.2 Bathymetry

Bathymetric data for the Project area were obtained from the Coastal Relief Model (NOAA-NGDC 2013) with a spatial resolution of 3 arc-seconds (approximately 90 m). The bathymetry was extracted along radials in 10° increments emanating from the source location to the maximum modeled range. The data were extracted in range intervals of 25 m.

4.1.1.3 Geoacoustic Model

The geoacoustic model (Table) was based on the geological description presented in Fugro USA Marine (2020). This document provided measurements of compressional and shear wave speeds and densities for the different sediment layers in the Project area. Compressional and shear wave attenuation values were calculated using the model presented in Buckingham (2005).

Table 7. Summary broadband (1-1,000 Hz) ambient noise levels reported by Bailey et al. (2018) in the Project area.

Site	*Average dB Year 1*	*Average dB Year 2*	*Average dB Year 3*	*Median dB*
T-1M	109.8	108.7	108.2	107.2
A-1M	111.7	110.7	111.3	110.5
A-2M	110.1	109.8	109.8	108.5
A-3M	110.7	109.1	109	108.1
A-4M	116.3	116	116.1	115.6
A-5M	114.9	113.5	114.4	113.8
A-6M	113.2	113.3	112.4	112.1
A-7M	116.9	116.3	116.7	116.1
A-8M	112.4	113	NA	111.4
T-2M	115.4	115.8	115	115.3
T-3*M	NA	118.3	114.2	113.8
T-3M	113.8	112	NA	112

NA=not applicable

4.1.1.4 Sound Velocity Profile

Sound velocity profiles for the region and the modeling site were extracted from the GDEM-V 3.0 database (Carnes 2009) (). Profiles for April and May were extracted for the relevant modeling runs.

4.1.1.5 Beam Pattern Generation

The directivity of the pile sources was represented with frequency-dependent beam patterns. That is, the amplitude of the source is a function of the vertical angle, with the greatest amplitude propagated horizontally. A linear array of virtual omnidirectional sources spaced at one meter from the water's surface to the seafloor was used to generate a beam pattern for each modeled frequency. A simple array beam pattern generation formula (e.g., Kuperman & Roux 2007) was used. The beam pattern was applied to a single source placed in the middle of the water column.

4.1.2 Impulsive Source Characterization

4.1.2.1 Monopile (Scenario 1)

Direct predictions of the spectrum of the 11-m monopile were not available. However, the spectrum for a 11-m diameter monopile was predicted in (Denes *et al.* 2018),which was used as a surrogate source signature in the modeling of the 11-m monopile (Figure). The broadband source level of this source is 224 dB re 1µPa^2-s-m^2.

Table 8. Geoacoustic model used to represent the modeling locations in the Project area (Buckingham 2005, Fugro USA Marine 2020).

Depth below Seafloor (m)	Substrate Material	Density (g/cc)	Compressional Wave		Shear Wave	
			Speed (m/s)	Attenuation (dB/λ)	Speed (m/s)	Attenuation (dB/λ)
0 to 12.5	Dense to very dense silty fine to medium sand with few stratifications of gravel	2.18	2,112	1.20	609	3.65
12.5 to 20.2	Dense to very dense silty fine to medium sand	1.58	1,831	1.28	467	
20.2 to 23.3	Very loose to loose sandy silt	1.14	1,638	0.59	178	
23.3 to 26.5	Very stiff to hard clay with fine sand	1.12	1,627	0.53	158	
26.5 to 44.0	Very stiff to hard sandy clay	1.12	1,607	0.46	134	
44.0 to 50.8	Dense to very dense silty fine sand	1.24	1,784	1.14	376	
50.8 to 64.9	Dense clayey fine to medium sand	1.21	1,770	1.08	353	

4.1.2.2 Pin Piles (Scenario 2)

Pin pile source spectra were based on the measured spectra of a 6-m pile reported by Bruns *et al.* (2014) and the 3.5-m FINO2 pile reported by Matuschek and Betke (2009). The 6-m pile reported by Bruns *et al.* (2014) was recorded at a distance of 15 m, and a hybrid spherical/cylindrical spreading model (i.e., 15 x $\log_{10}$ (range)) was used to adjust the received level to a source level. The levels were further reduced by 3 dB to account for the smaller pile diameter. The FINO2 pile was recorded at a distance of 500 m, and the same hybrid propagation loss model was used to adjust the received levels to source levels. The mean of the two pin pile spectra from these sources (Figure) was taken as the source level of 3-m pin pile for the Project. The broadband SEL source level of this signature is 210 dB re 1µPa^2-s-m^2. This value is comparable to the measured values of ~209 dB re 1µPa^2-s-m^2 for a 96” (2.4 m) steel pile driven by a 1700 kJ Menck Hammer (Molnar *et al.* 2020; Table I-2-1a).

4.1.3 Acoustic Propagation Modeling

The primary source of underwater sound due to impact pile driving is a result of the compression of the pile during each hammer strike. The hammer strike produces a compressional wave in the pile that results in the pile wall deforming. The pile is compressed in the vertical and expands in the horizontal. This deformation or “bulge” travels down the pile at the speed close to the compressional wave speed in steel and behaves as the sound source.

Since the pile is surrounded by water, and the speed of sound in water is less than that in steel, the resulting acoustic field is in the shape of a Mach cone.

In the modeling described in this report, the pile is represented as a vertical line array. The pile beampattern was created from a vertical line array of elements with one meter spacing from the surface to the seafloor. This representative array was used to create a frequency-specific beampattern that was applied to a point source at mid-water column and propagated using the RAM PE model (Collins 1993).

This process was followed for each third octave center frequency in the bands from 10 Hz to 16 kHz. Radials were run at 10° intervals to a range of 50 km. The third-octave band source levels were added to each transmission loss value to produce a received level value at each range, depth, and bearing point.

Finally, the combined sound fields for each frequency were summed to generate a representative broadband sound field. This process was followed for each radial around the source to produce an N x 2-D grid of received sound levels in range, depth and bearing. The resulting predicted acoustic SEL field was weighted using the LF, MF, HF, PW, and ST weighting functions (NOAA Fisheries 2018). Assuming a signal length of 100 milliseconds (ms), the broadband L_p source field was calculated from the broadband unweighted L_E(ss) field using the following equation, where T = 0.1 s (100 ms). This resulted in 10 dB being added to the unweighted L_E(ss) field to represent the L_p field:

$$L_{\mathrm{p}} = L_E(\mathrm{ss}) - 10 \log10\ T$$

The L_p field was generated from the unweighted L_E sound field using the semi-empirical method described in Lippert *et al.* (2015). This method reflects range-dependent effects on the waveform structure to estimate the peak level from the SEL value using the equation:

$$\mathrm{SPL}_{\mathrm{peak}} = A\ \mathrm{SEL} + B + C$$

The term *A* SEL represents how peak amplitude changes with range. The *B* term represents the initial relationship between $\mathrm{SPL}_{\mathrm{peak}}$ and SEL. The C term includes scaling factors between the pile being considered and previously measured piles. This calculation used values for Young's modulus of 210 GPa, an axial velocity of 5,000 m/s, and ram masses of 200 and 70 tons for the monopile and pin piles, respectively.

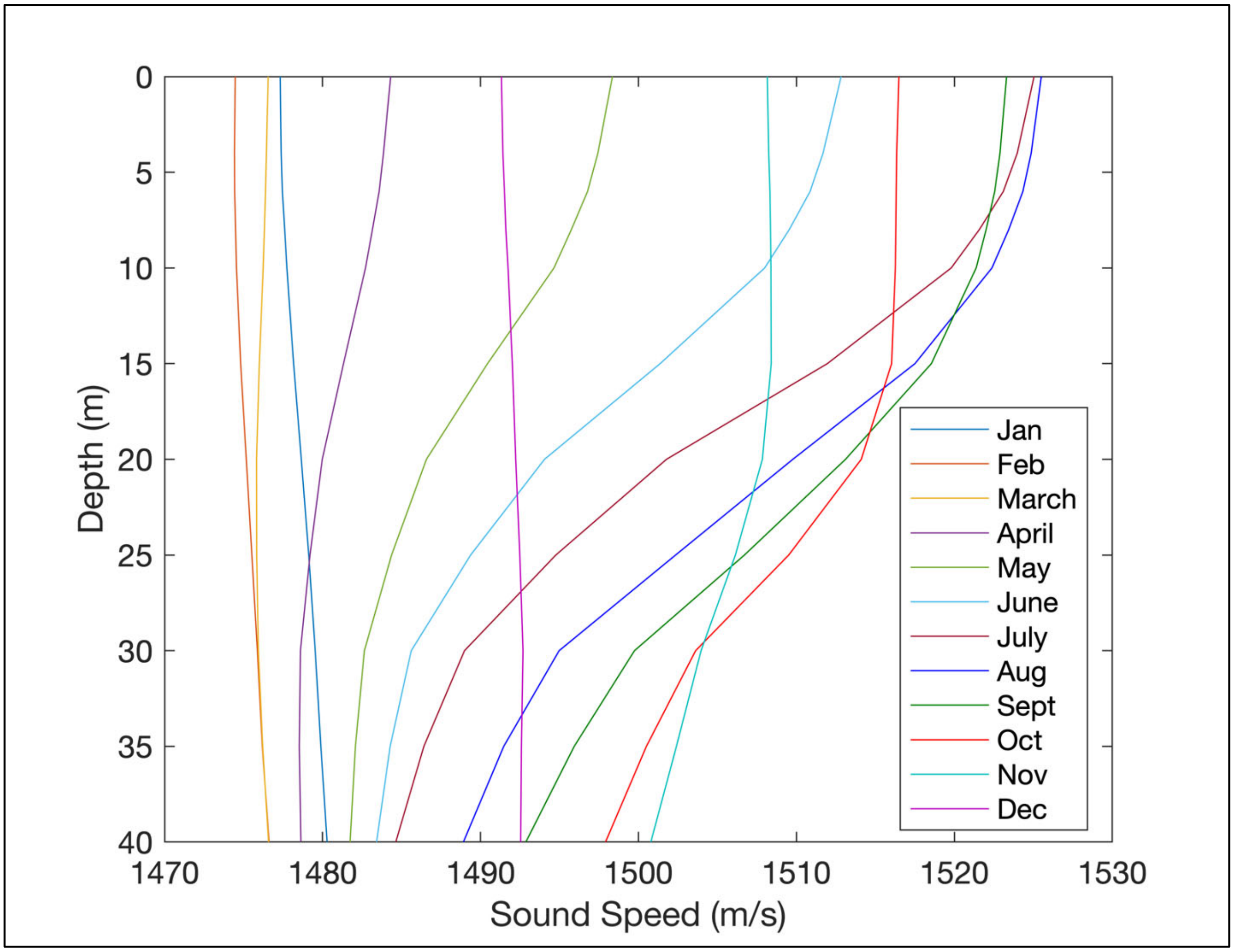

Figure 6. Modeling site monthly sound velocity profiles extracted from the GDEM-V 3.0 database (Carnes 2009).

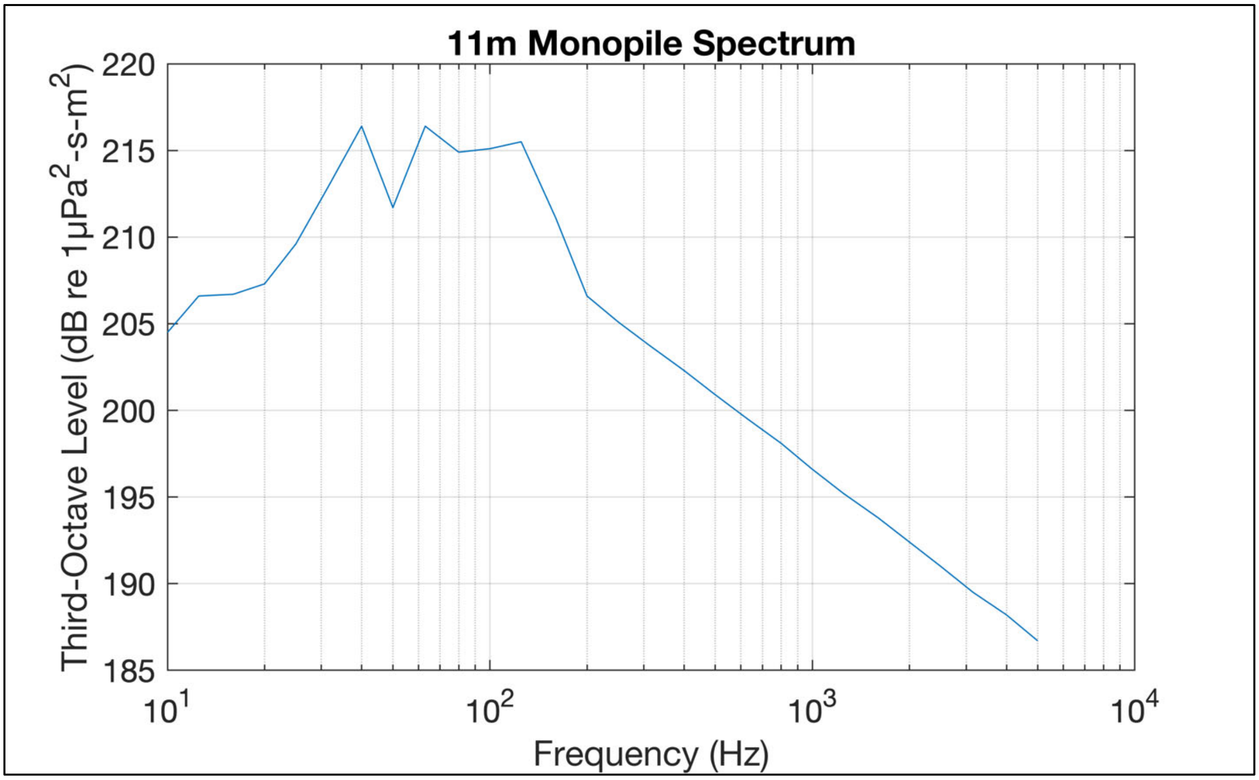

Figure 7. Predicted third-octave band spectrum for an 11-m monopile.

4.1.4 Effect of Depth on Propagation Predictions

The effect of varying the depth from the minimum of 12 m to the maximum of 42 m was explored by running additional propagation predictions for an 11-m pile at the shallowest and deepest location within the project bounds. Propagation modeling at these locations were intended to explore the effects of the minimum and maximum water depth for the project area. These were intended to capture the "best" and "worst" propagation conditions.

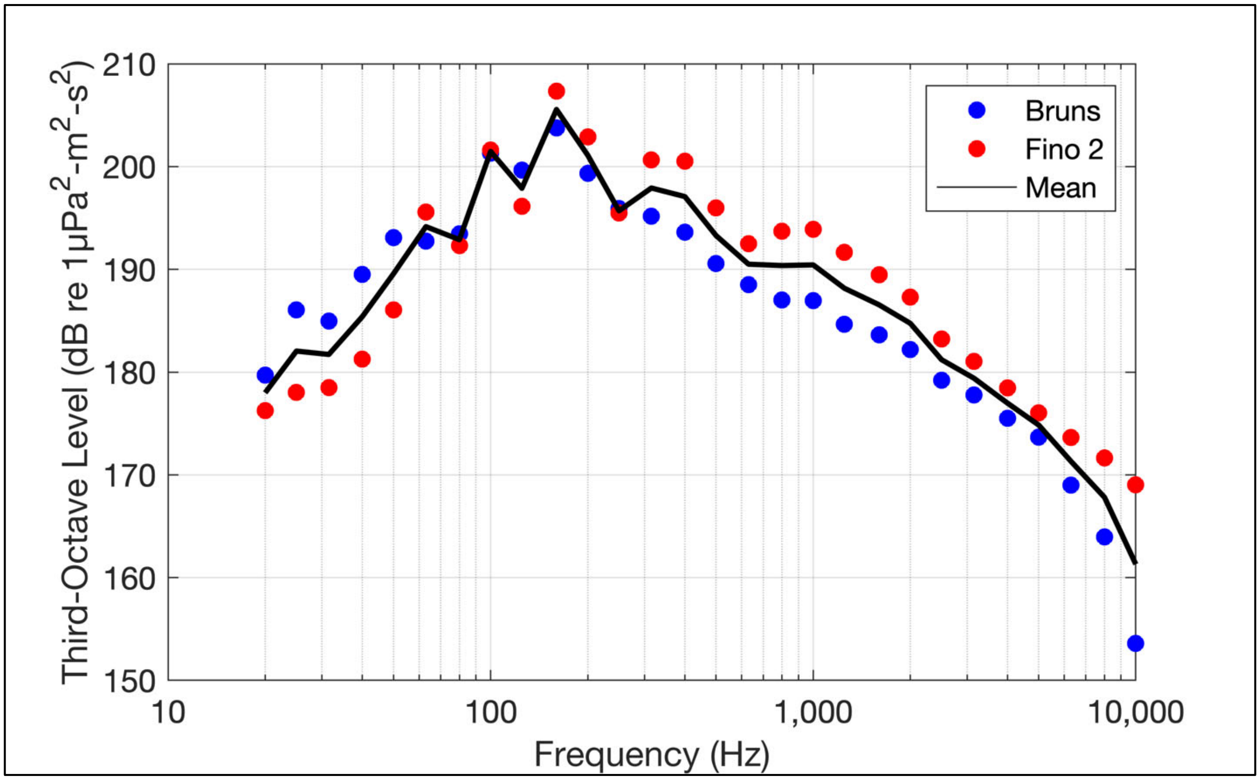

Figure 8. Spectra for pin piles (Bruns et al. (2014).

4.1.5 Implementation of Pile Schedule

Fugro Marine (2020) included a summary of the predicted number of strikes necessary as a function of depth for the monopile case. This model was conservatively based on the IHC hammer operating at 4,400 kJ for every strike. Predictions were made for both the lower and upper boring coring case (Figure 4). The lower bound case predicts a total of 2,248 strikes, while the upper bound has a predicted total of 3,742. Thus, the difference between single strike and cumulative SELs are 33.5 and 35.7 dB respectively. The mean of these two estimates (34.6 dB) was used to calculate the cumulative SEL for the range to threshold calculations. The IHC S-4000 hammer has a specified blow rate of 28-36 blows/minute. The maximum projected duration was 117 minutes using the mean blow rate of 32 blows/minute. This duration was rounded to 120 minutes to calculate the animal exposure metrics for monopile driving.

US Wind projected that each 3-m pin pile will require 4,000 to 7,000 blows using a 1,500 kJ hammer. These blow counts would produce a cumulative SEL that is 36.0 to 38.4 dB greater that a single strike SEL. The mean value of 37.7 dB will be used for estimating ranges for cumulative SEL criteria. Using a nominal 30 blows/minute value, the total time to drive a pin pile ranges from 133 to 233 minutes. The mean interval of 183 minutes was rounded to 180 minutes to calculate animal exposure metrics. Based on these durations, and the mitigation measure proposed by US Wind in the Construction and Operations Plan to not conduct pile driving at night, it is predicted that two pin piles could be driven in a 24-hour period.

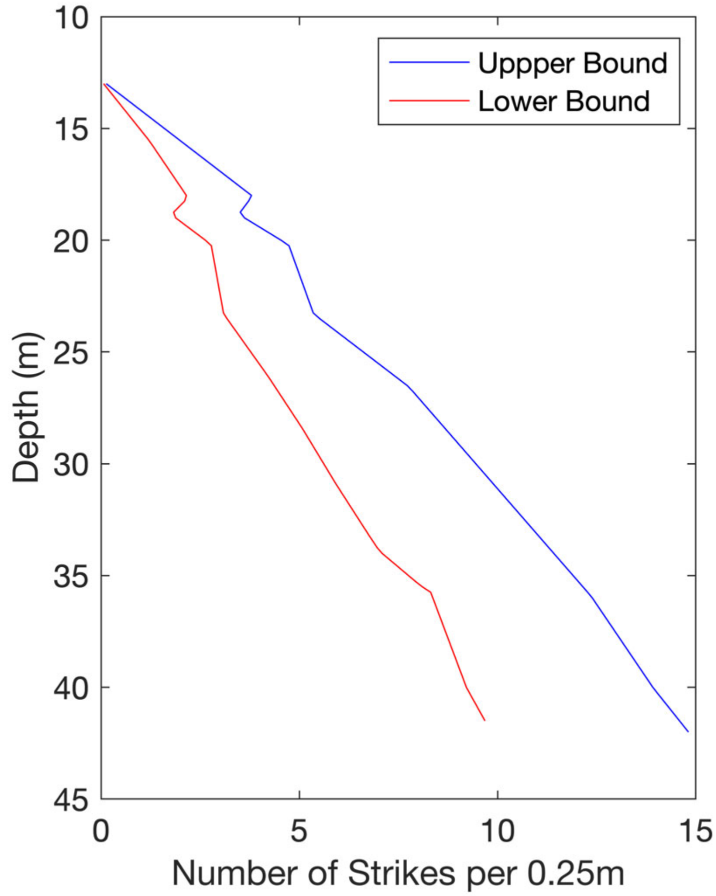

Figure 4. Predicted monopile strike progression.

Propagation modeling was conducted using the maximum projected blow energy of 4,400 kJ for the monopile and 1500 kJ for the pin piles. The durations to drive one monopile and one or two pin piles were used to derive the L_E(cum) sound fields and associated ranges to regulatory thresholds for the different scenarios.

4.1.6 Animat Modeling

A separate AIM simulation was created and run for each combination of location and marine mammal species. Marine mammals were simulated by creating animats that were programmed with behavioral values describing dive depth, surfacing and dive durations, swimming speed, and course change relevant to each marine mammal species. A minimum and maximum value for each of these parameters was specified. These data were extracted from scientific literature. The simulation area was delineated by four boundaries composed of latitude and longitude lines. These boundaries extended one degree of latitude or longitude beyond each modeling site to ensure 1) the region in which substantial behavioral reactions that might be anticipated was captured and 2) an adequate number of animats would be modeled in all directions.

Animats were randomly distributed over the model simulation area. The modeled marine mammal animats were set to populate the simulation area with densities often higher than those estimated in the marine environment. This “over population” of the modeling environment ensures that the result of the simulation is not unduly influenced by the chance placement of a few simulated marine mammals. To obtain final exposure estimates, the modeled results are normalized by the ratio of the modeled animat density to the real-world marine mammal density estimate (Roberts *et al*. 2020, 2021). This allows for greater statistical power without overestimating exposure.

Modeling included a number of conservative assumptions. During AIM modeling, the animats were programmed to “reflect” off the boundaries of the area to remain within the simulation area. This reflection maintains the appropriate density of animats since no animats are allowed to diffuse out of the simulation area. It is also a conservative factor in the modeling results since it keeps animats within the simulation area and available for additional acoustic exposure during the 24-hr simulation period. In reality, an animat that reflects off the simulation boundary would actually leave the simulation area, whereas the animat reflecting into the simulation boundary would actually be a new animal with no acoustic exposure entering the simulation area. Since acoustic exposure accumulates over the 24-hr modeling period, the reflected animat may have a higher acoustic exposure than if it were considered as two separate animals.

An AIM simulation consists of a user-specified number of steps forward in time at which the received sound level and 3D position of the animat were recorded to calculate exposure estimates. For each time step, each animat is moved according to the rules describing its behavior. At the end of each time step, each animat “evaluates” its environment, potentially including its 3D location and water depth. If an environmental variable has exceeded the user-specified boundary value (e.g., water too shallow), then the animat will alter its course to react to the environment. These responses to the environment are entitled “aversions.” There are several potential aversion variables that can be used to build an animat’s behavioral pattern.

4.1.7 Calculation of Exposure Estimates

To maximize sample size, AIM simulations are run with the source operating continuously for the entire modeling period. These results are then sampled to reflect the actual operating characteristics of the source. For example, to predict the exposures created by driving a monopile (nominally 2 hours), a 24-hour exposure history would be produced. Then multiple 2-hour time periods would be sequentially extracted from that simulation output (e.g., 0 to 2 hours, 2 to 4 hours). Thus, multiple sequential estimates were produced for each scenario, and the mean value of exposure levels were reported.

Furthermore, each simulation is populated with a far greater animat density than the real-world animal densities to increase sample size. The modeled animat density value was determined through a sensitivity analysis that examined the stability of the predicted estimate of exposure levels as a function of animat density. Therefore, the modeled density was determined to accurately capture the full distributional range of probabilities of exposure for the proposed activity. The potential impacts were normalized back to actual predicted density estimates for each species. The daily exposure estimates should be multiplied by the planned number of piles to determine the total number of exposures for the entire construction period.

The L_E(cum) for each animat in the AIM output was calculated. The distribution of exposures is presented as histograms, showing the number of animats in each 3 dB L_E(cum) bin. The number of exposures were scaled by the ratio of local animal density and AIM model density. Therefore, for species with low local animal densities, the values on the y-axis could all be less than one. Summing the number of exposures above the relevant L_E(cum) threshold would provide an estimate of the number of regulatory exposures.

4.1.8 Calculation of Ranges to Regulatory Thresholds

The maximum received level-over-depth was calculated at each range step and along each radial. The maximum and 95th percentile range to each of the regulatory thresholds were then calculated. The maximum value represents the greatest distance along any one single radial and is in general higher than the 95th percentile because of different bathymetry and transmission paths along each radial. The 95th percentile range is an improved representation of the range to the threshold as it eliminates major outliers and better represents all the modeled radials. All ranges presented to regulatory threshold are the 95th percentile range. Because these values are taken from static sound fields, the SEL ranges reflect the ranges to stationary virtual receivers.

4.2 Non-Impulsive Source Scenarios

This section describes the approach unique to modeling Scenario 3 (Table), which is vibratory pile driving. The same physical environmental inputs used in the impulsive modeling were also used here.

4.2.1 Source Characterization

4.2.1.1 Vibratory Driving of a 1.8-m Monopile (Scenario 3)

No sound level predictions were available for vibratory driving of a 1.8-m monopile. Therefore, the spectral measurements from (Dahl *et al.* 2015) were used. The Dahl et al. (2015) received levels were first adjusted to account for transmission loss using a 15 log R model. The difference in sound level due to pile diameter was approximated using a 10 $\log_{10}$ (pile diameter ratio) model. The underlying assumption is that sound level will scale with pile diameter. Indeed, the measured sound level of vibratory driven piles was greater for 48” piles than 36” piles (Illingworth and Rodkin, 2017). These two resulting values were added to the received level to produce an estimated source spectrum for monopile vibratory driving for this project (**Error! Reference source not found.**). Third octave band center frequencies from 63 Hz up to 2 kHz were used in the modeling. The broadband source level was 187 dB re 1 µPa^{2}m^2.

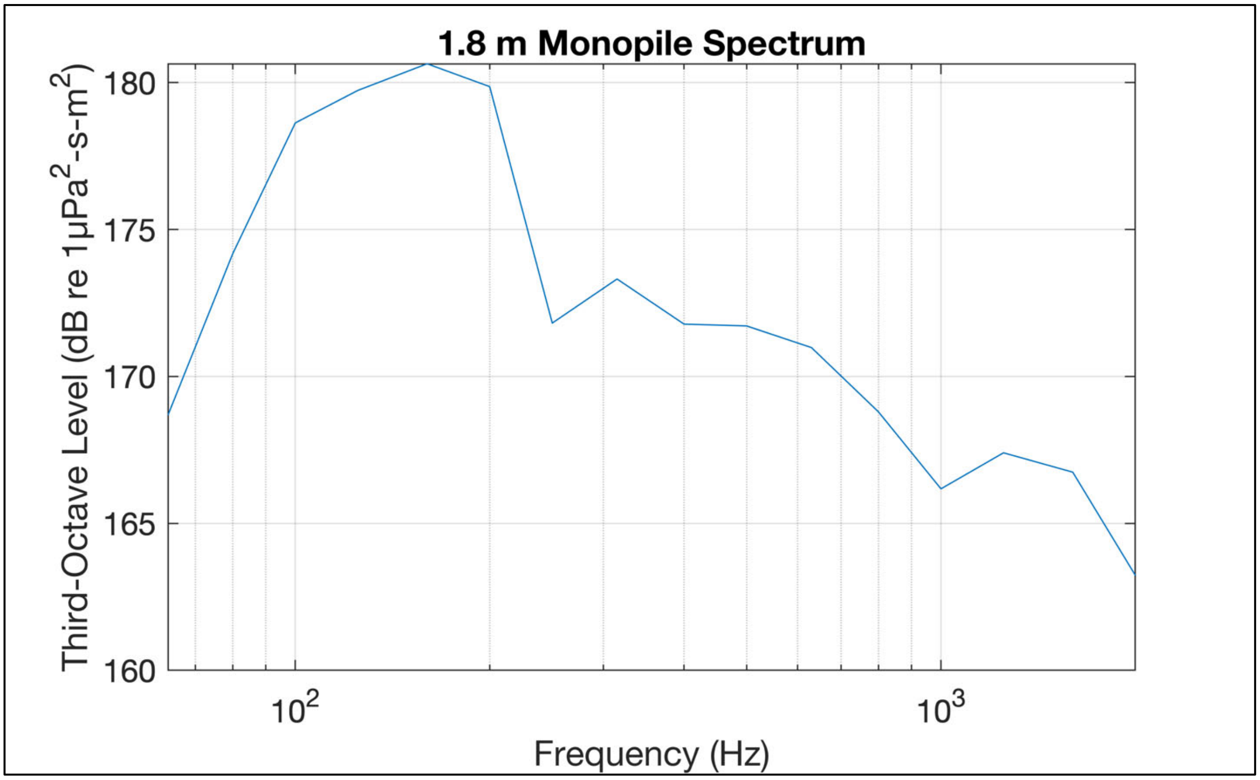

Figure 5. Predicted spectrum for vibratory driving of a 1.8-m monopile.

4.2.2 Acoustic Propagation Modeling

To model vibratory pile driving operations, an omnidirectional source was placed at a depth of five meters. Propagation predictions were calculated using the RAM PE model (Collins 1993). This process was followed for each third-octave center frequency in the bands from 10 Hz to 5 kHz. Radials were run at 10° intervals out to a range of 50 km.

The representative sound fields for the monopile driving were generated in the same manner as the impact pile driving analysis. The sound fields for each frequency were summed to generate a representative broadband sound field. This process was followed for each radial around the source to yield a transmission loss grid in range, depth, and bearing. The resulting predicted acoustic SEL field was weighted using the LF, MF, HF, PW, and ST weighting functions (NOAA Fisheries 2018).

4.2.3 Calculation of Ranges to Regulatory Thresholds

The ranges to the regulatory threshold for vibratory pile driving were calculated in the same manner as for the impulsive scenarios described in Section 4.1.8.

4.3 Modeling Assumptions

The following modeling assumptions were made for the impulsive and non-impulsive scenarios:

1) Single modeling location is representative of conditions throughout the WEA. The small changes in absolute water depth suggest that this is a reasonable assumption. This assumption was tested with acoustic propagation model runs at the deepest and shallowest locations within the WEA (see section 4.1.4).
2) The propagation modeling effort used sound velocity profiles from April and May. These are likely to represent the 'best' propagation environment for the construction period. Thus, the range to isopleths and exposure predictions will likely be overestimates of varying degrees. Estimates for summer months are most likely to be highly overestimated due to summertime sound velocity profiles causing downward refracting propagation instead of a slight surface ducting effect in winter. April was chosen to evaluate the potential impact of beginning construction in April instead of waiting until May.
3) Species presence and densities are taken from Roberts et al. (2020, 2021), which represents the best available science.
4) Monopile diameter was assumed to be 11-m with a maximum strike energy of 4,400 kJ. Only one monopile would be driven in any given day.
5) Pin pile diameter was assumed to be 3.0-m with a maximum strike energy of 1500 kJ. Installation of one or four pin piles per day was considered. No adjustment for post-piling was incorporated because the final decision on this topic had not been made.
6) Vibratory pile driving spectra was obtained from others published in the literature. The time needed to drive a 1.8-m pile was assumed to be one hour, based on the statement that vibratory driving is faster than impact driving (Saleem 2011). The one scaled experiment indicated that a pile could be driven a meter in about a minute with vibratory methods (Remspecher *et al.* 2019).
7) Seabed structure described by Fugro USA Marine (2020) was assumed to be valid for the entire WEA.
8) Monthly mean sound velocity profiles were used to represent average conditions. On any given day, the SVP may differ from the modeled SVP, altering the acoustic propagation.
9) Source characteristics for both monopiles and pin piles were derived from predictions and measurements made at other locations. The actual source spectrum produced may differ from the modeled source spectrum.
10) The maximum strike energy (4,400 or 1,500 kJ) was assumed for each strike during the pile driving progression. The number and rate of strikes were derived from pile driving progression predictions.
11) Animats (virtual representations of animals) were assumed to remain in the vicinity of the pile driving location (1.75° longitude x 1.5° latitude box centered on the modeling location).
12) Two animal density ranges were used. The April modeling results used a mean of the April to November values, while the May results were convolved with mean marine mammal densities from May to October.

5 RESULTS

5.1 Impulsive Scenarios

5.1.1 Monopile Foundation Installation (11-m Pile)

5.1.1.1 Ranges to Regulatory Thresholds

The ranges to the regulatory behavior thresholds for the unmitigated pile driving of an 11 m monopile were 16,800 m, 36,700 m, and 3,500 for marine mammals, fishes, and sea turtles, respectively (Tables 9 and 10). The range to the thresholds for injury to marine mammals was greatest for the LF cetaceans, with the range for the SEL threshold from 10,700 m (Table 9). The range to the injury thresholds (L_E *(cum)*) for fish and sea turtles ranged from 300 m to 19,400 m (Table 11). The regulatory thresholds recommended by Popper et al. (2014) resulted in far different ranges than those recommended by GARFO (2019) (Tables 10 and 11). It is important to note the ranges to SEL thresholds assume that animals remain in the area for the total duration of the driving of a pile, and therefore can be considered conservative estimates.

Table 9. Ranges (m) to regulatory threshold levels for marine mammals (NOAA Fisheries 2018, Southall et al. 2019) during two hours of unmitigated pile driving of an 11-m monopile in April.

Marine Mammal Hearing Group	*Range to Injury Thresholds (m)*		*NMFS Behavioral Threshold (160 dB re 1µPa^2, flat)*
	SEL (dB re 1µPa^2-s, 24hr)	*Peak SPL (dB re 1µPa^2, flat)*	
Low-frequency (LF) cetaceans	10,700	100	16,800
Mid-frequency (MF) cetaceans	< 50	< 50	
High-frequency (HF) cetaceans	350	700	
Phocid pinnipeds underwater	800	100	

5.1.1.2 Sound Maps

➢ **11-m Monopile**

Plan views of the sound fields predicted for an unmitigated single strike on an 11-m monopile are shown for April (Figure 11) and May (**Error! Reference source not found.**) with the maximum value in the water column shown. Sounds fields are shown in 10 dB steps by different colors, and the color scale changes as needed. All predicted isopleths show evidence of bearing dependence. While there is variation, most isopleths show better propagation (greater distance to isopleths) in the

Table 10. Ranges (m) to behavioral threshold levels for fishes and sea turtles (GARFO 2019) during unmitigated pile driving of an 11-m monopile in April.

Group	Behavioral Threshold (L_{rms} dB re 1μPa^2, flat)
Fishes (< 2g)	36,700
Fishes (> 2g)	
Sea Turtles	3,500

Table 3. Ranges (m) to injury threshold levels for fishes and sea turtles (Popper et al. 2014) during unmitigated pile driving of an 11-m monopile in April.

Group	Injury		TTS
	SEL (dB re 1μPa^2-s)	Peak SPL (dB re 1μPa^2, flat)	SEL (dB re 1μPa^2-s)
Fishes without swim bladders	300	200	14,700
Fishes with swim bladder not involved in hearing	2,300	400	14,700
Fishes with swim bladder involved in hearing	2,300	400	14,700
Fishes (> 2g)	13,300	450	--
Fishes (< 2g)	19,400	450	--
Sea Turtles	1,600	< 50	9,750

offshore direction compared to cross shore and inshore propagation paths. For example, the flat 160 dB RMS isopleth (green-blue) in Figure 11 subplot a extends ~10 km inshore, ~10 km to the north and south and ~15 km in the offshore direction.

5.1.1.3 Effect of Depth on Propagation Predictions.

Propagation models were run for the shallowest and deepest locations within the Project bounds (Figure 1). Somewhat surprisingly, the R95 ranges to the behavioral thresholds, were lower at both the deep (15,700 m) and shallow location (10,700 m), compared to the modeling location (19,350 m). Furthermore, all of the R95 ranges to metrics were lower for both shallow

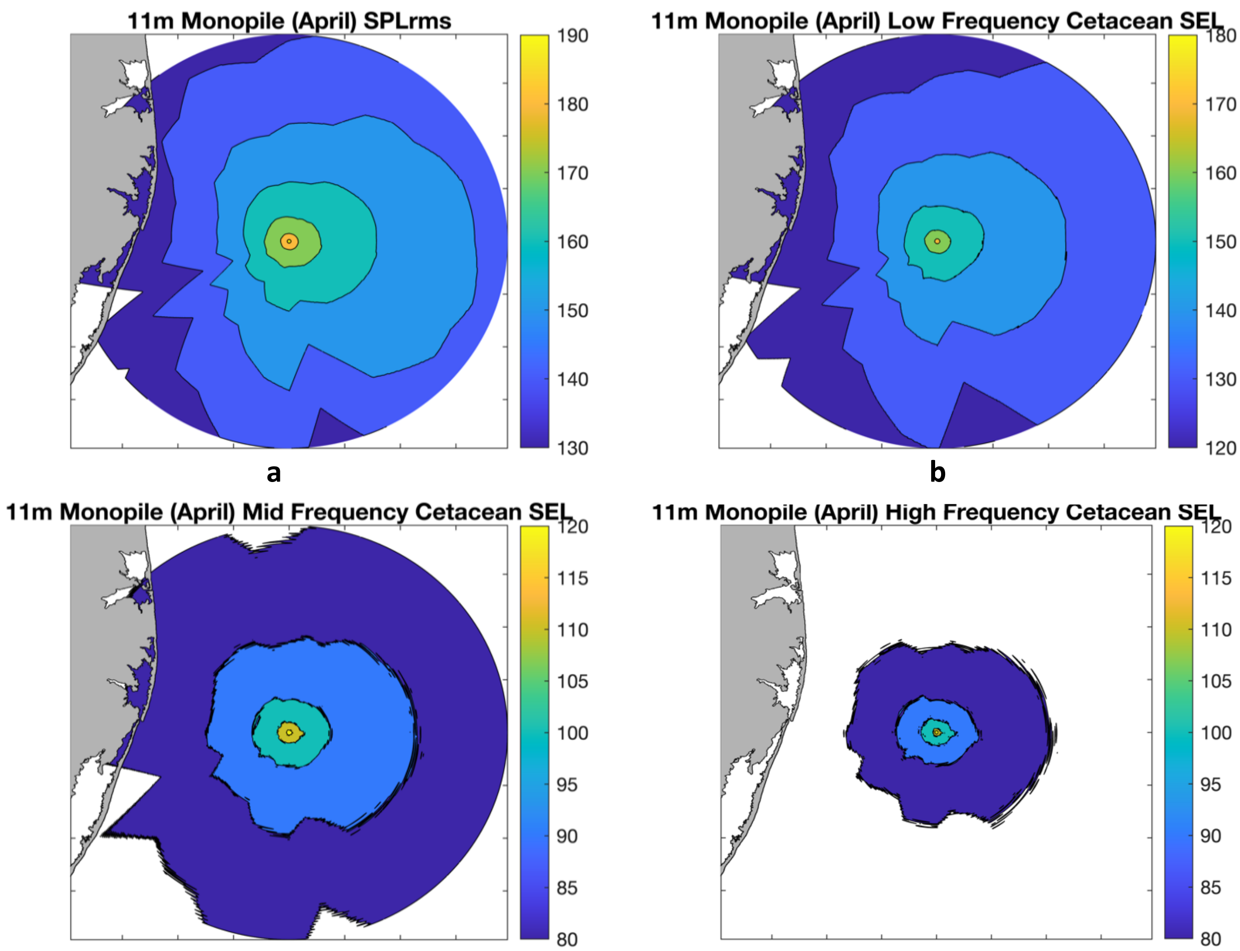

Figure 6. Sound maps of an 11-m monopile single strike for April show the maximum over depth a) unweighted SPL and frequency-weighted single strike SEL (L_E (ss)) for the b) low frequency cetaceans, c) mid-frequency cetaceans, and d) high frequency cetaceans for the unmitigated pile driving of the 11-m monopile. The SEL sound fields have been weighted using the NOAA Fisheries (2018) auditory weighting functions. The SPL sound levels are in dB re 1µPa^2 while SEL values are in dB re 1µPa^{2}s. Map area is 100 km x 100 km.

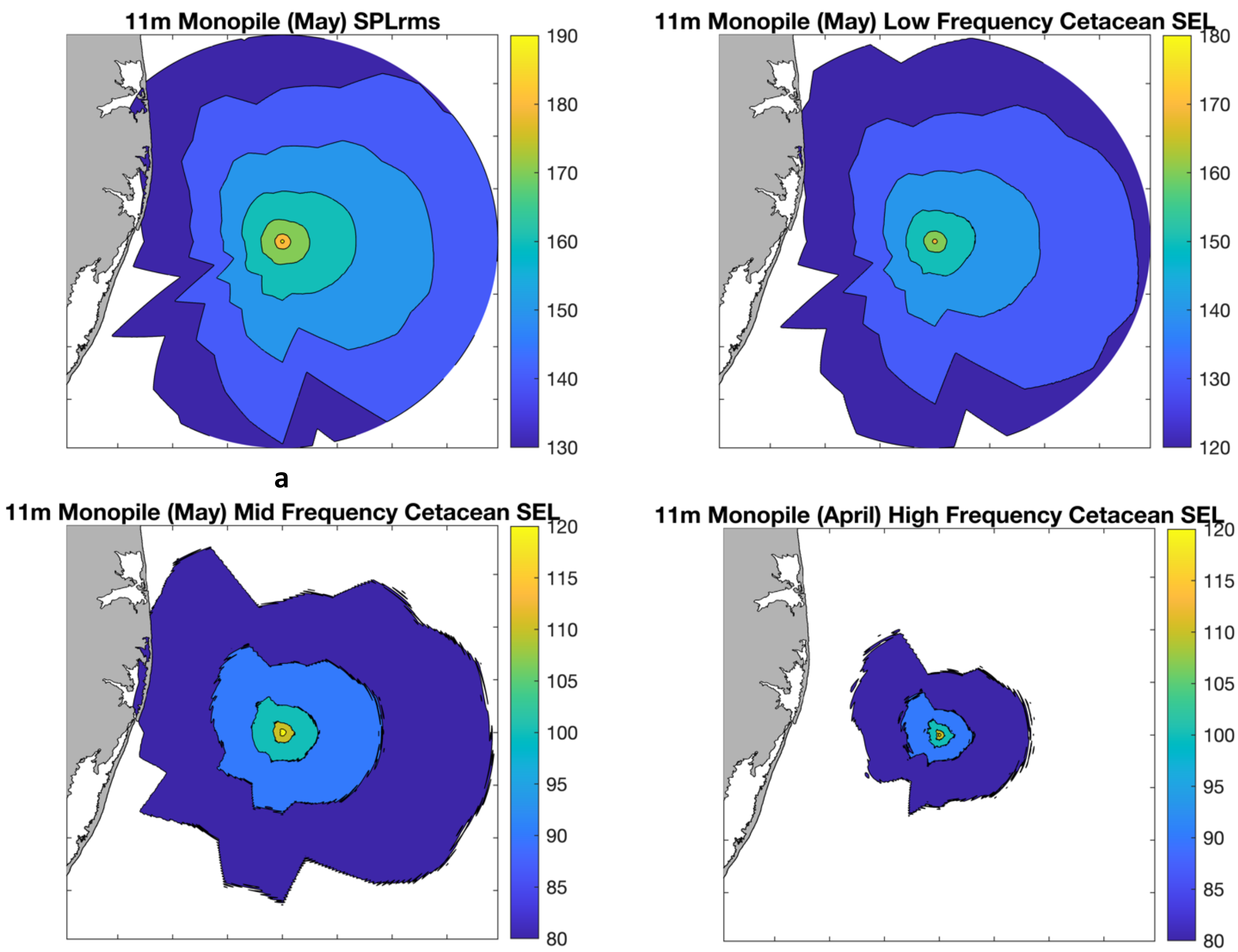

Figure 12. Sound maps for of an 11-m monopile single strike May show the maximum over depth a) unweighted SPL and frequency-weighted single strike SEL (L_E (ss)) for the b) low frequency cetaceans, c) mid-frequency cetaceans, and d) high frequency cetaceans for the unmitigated pile driving of the 11-m monopile. The SEL sound fields have been weighted usin the NOAA Fisheries (2018) auditory weighting functions. The SPL sound levels are in dB re 1µPa^2 while SEL values are in dB re 1µPa^{2}s. Map area is 100 km x 100 km.

and deep with the exception of the HF SEL metric. PTS SEL HF was 450 m at the deep location, 400 m at the modeling location, and 700 m at the shallow location.

5.1.1.4 Exposure Tables

The outputs of the animat modeling for marine mammals and sea turtles are presented in tables of the predicted numbers of animals exposed to levels exceeding regulatory thresholds (Table 12). Note that it is possible for low-frequency cetaceans to be exposed to cumulative SEL injury values at greater ranges than the range to the behavioral threshold. Such animals would be reported as SEL exposures and not as behavioral exposures, to prevent "double counting" animals. The values in Table are for a single 11-m monopile being driven without mitigation. The animat exposure estimates are the product of the number of modeled exposures multiplied by the ratio of real-world density and model densities. Separate estimates are provided for the April through November and May through October timeframes, and the densities that were applied represent the mean density value across those timeframes. Additional modeling result tables (Appendix B) present the numbers of marine mammal exposures with various levels of sound source reduction as possible mitigation.

5.1.1.5 Potential Effect of Sound Source Mitigation for 11-M Monopile

The potential effect of sound source mitigation (e.g., bubble curtain) on distances to regulatory isopleths were evaluated. No determination has been made regarding application of mitigation methods or which methods might be employed. Therefore, a parametric evaluation predicted the range to regulatory isopleths for a uniform broadband reduction of 0, 6, 9, 12, 15, 18, and 20 dB using the existing monopole model outputs. The predicted number of regulatory exposures of marine mammals using these sound source level reductions are presented in Appendix B. The ranges to regulatory isopleths for marine mammals, sea turtles, and marine fishes under different mitigation scenarios are presented in Appendix C.

The effect of different levels of mitigation sound source reductions on the range to the behavioral and LF cetacean PTS SEL isopleth thresholds (**Error! Reference source not found.**) show that a source level reduction of 10 dB decreased the range to the behavioral response isopleth threshold from 16,800 m to 6,000 m. A 20 dB reduction in the source level further decreased the range to the behavioral response isopleth to a range of about 2,000 m. The effect of mitigation on the number of behavioral exposures for common bottlenose dolphins, the species with the largest number of exposures (**Error! Reference source not found.**), shows that even moderate levels of source level reduction accomplished by implementing mitigation measures such as bubble curtain can produce a strong reduction in the impact to the biological environment.

An additional mitigation scenario, temporal mitigation, was examined by considering two time periods for installation of monopiles, either during April to November or May to October. While small differences were expected for the acoustic fields between April and May, both sound fields were modeled separately. Additional AIM runs were conducted for North Atlantic right whales in these time periods. The major contribution to the effectiveness of such a temporal mitigation effort is the seasonal reduction in right whale density (**Error! Reference source not found.**). The number of potential injury exposures of North Atlantic right whales is also reduced by a factor of 7.8 by beginning monopile driving in May instead of April.

Table 4. Exposure estimates of marine mammals and sea turtles for unmitigated pile driving of a single 11-m monopile for two time periods. Individuals are only reported once; animals receiving injury exposures are not reported as behavioral exposures.

Marine Species	*Behavioral Exposures*		*Cumulative SEL Injury Exposures*		*Peak SEL Injury Exposures*	
	April-Nov	*May-Oct*	*April-Nov*	*May-Oct*	*April-Nov*	*May-Oct*
Risso's dolphin	0.00	0.00	0.00000	0.00000	0.00000	0.00000
Common dolphin	110.87	85.09	0.00000	0.00000	0.00000	0.00000
Fin whale	0.00	0.00	1.27949	1.38116	0.01000	0.01079
Harbor porpoise	3.97	0.79	0.00000	0.00000	0.04616	0.00915
Harbor seal	2.93	1.23	0.00630	0.00265	0.00126	0.00053
Killer whale	0.01	0.01	0.00000	0.00000	0.00000	0.00000
Rough-toothed dolphin	0.13	0.13	0.00000	0.00000	0.00000	0.00000
Common minke whale	0.00	0.00	0.52306	0.50374	0.00265	0.00255
Humpback whale	0.00	0.00	0.50633	0.43871	0.00256	0.00222
Kogia spp.	0.00	0.00	0.00000	0.00000	0.00000	0.00000
Pilot whales	0.00	0.00	0.00000	0.00000	0.00000	0.00000
North Atlantic right whale	0.00	0.00	0.09747	0.01239	0.00012	0.00000
Blainville's beaked whale	0.00	0.00	0.00000	0.00000	0.00000	0.00000
Cuvier's beaked whale	0.00	0.00	0.00000	0.00000	0.00000	0.00000
Gervais' beaked whale	0.00	0.00	0.00000	0.00000	0.00000	0.00000
True's beaked whale	0.00	0.00	0.00000	0.00000	0.00000	0.00000
Sperm whale	0.10	0.12	0.00000	0.00000	0.00000	0.00000
Atlantic spotted dolphin	10.05	10.64	0.00000	0.00000	0.00000	0.00000
Pantropical spotted dolphin	0.01	0.01	0.00000	0.00000	0.00000	0.00000
Striped dolphin	26.97	26.97	0.00000	0.00000	0.00000	0.00000
Common bottlenose dolphin	194.13	229.40	0.00000	0.00000	0.00000	0.00000
Leatherback turtle	1.28	1.28	0.02	0.02	0.00	0.00
Kemp’s ridley turtle	0.79	0.79	0.01	0.01	0.00	0.00
Green turtle (Hardshelled guild)	3.12	3.12	0.04	0.04	0.00	0.00
Loggerhead turtle (DoN 2017)	3.27	3.27	0.05	0.05	0.00	0.00
Loggerhead turtle (Barco *et al*. 2018)	108.70	108.70	1.51	1.51	0.00	0.00

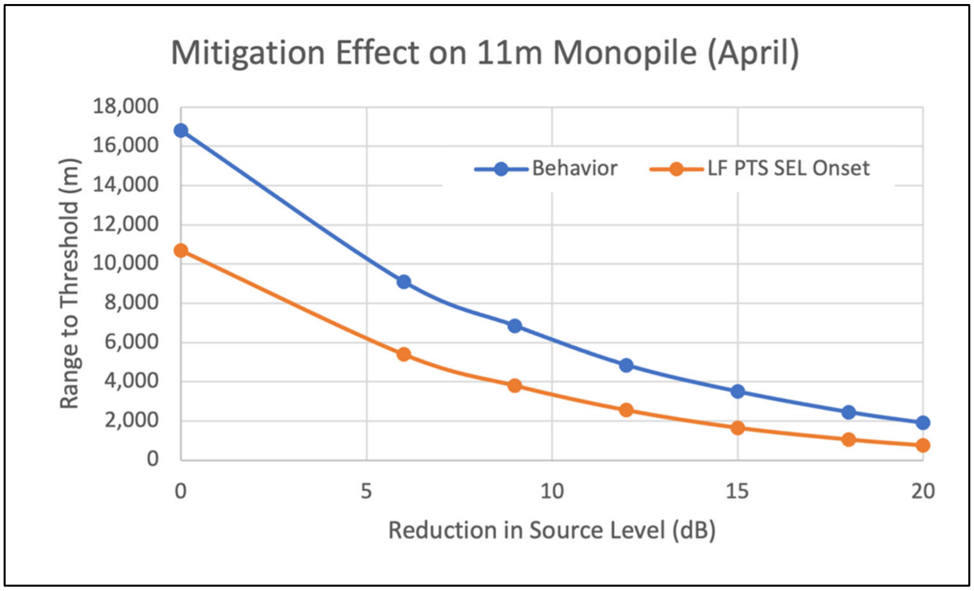

Figure 13. Effect of different levels of sound-source mitigation on the range to behavioral and PTS isopleths for LF cetaceans.

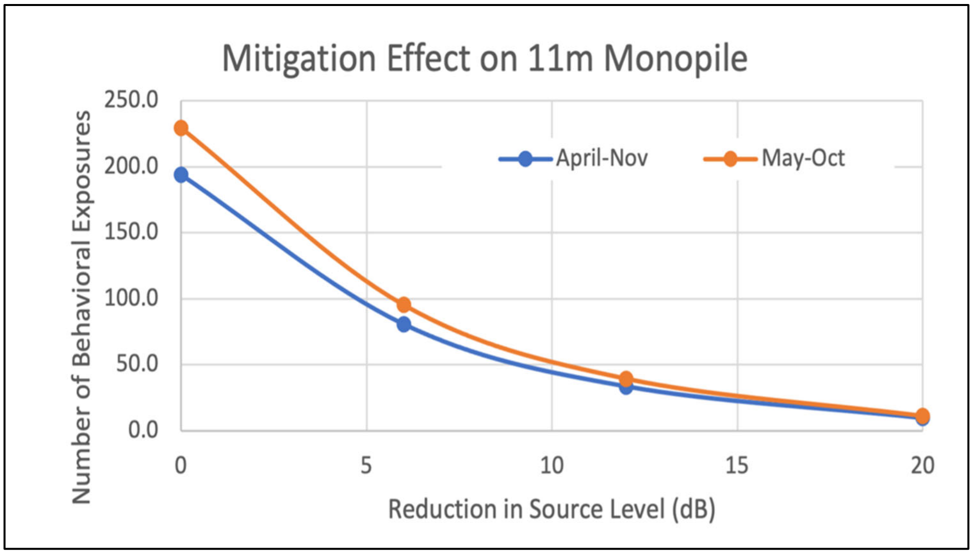

Figure 7. Mitigation effects of reduction in sound-source levels on the number of behavioral exposures of common dolphins.

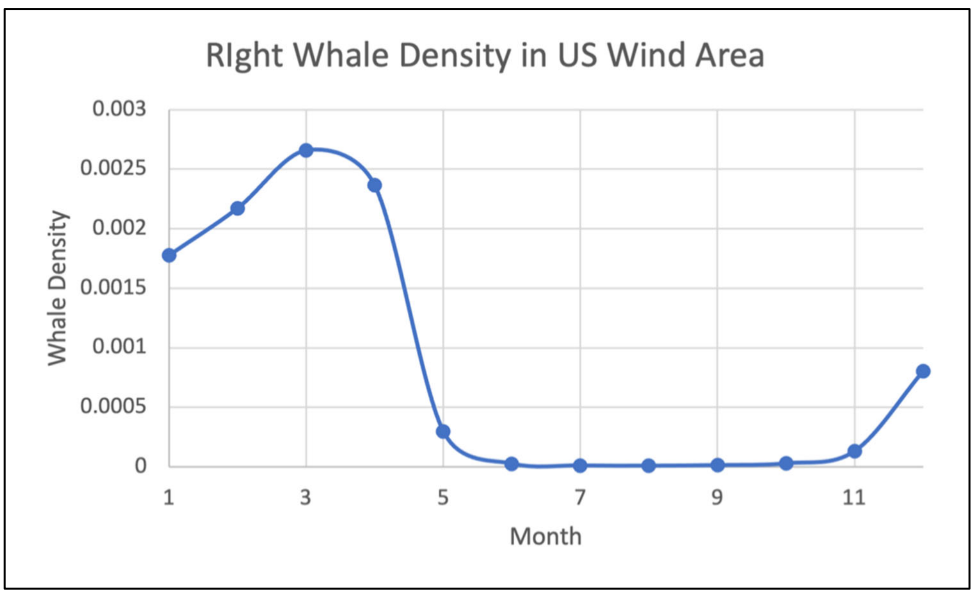

Figure 8. North Atlantic right whale density for the US Wind project area by month. Data extracted from Roberts et al. (2021). There is a marked decrease in right whale density between April and May that manifests itself as a reduced number of exposures that would result from delaying impact driving until May.

5.1.2 Pin Pile Jacket Foundation Installation

5.1.2.1 Ranges to Regulatory Thresholds

The ranges to the regulatory behavior thresholds for the pile driving of a 3-m pin pile without mitigation were 6,550 m, 21,450 m, and 800 for marine mammals, fishes, and sea turtles, respectively (Tables 13 and 14). The range to the PTS marine mammal thresholds were greatest for the LF cetaceans, with ranges for the PTS SEL threshold from of 7,950 m and 10,950 m for one and two piles per day (Table 13). The range to the injury thresholds (L_E *(cum)*) for fish and sea turtles ranged from 600 m to 15,700 m (Table 15). The regulatory thresholds recommended by Popper et al. (2014) resulted in far different ranges than those recommended by GARFO (2019) (Tables 14 and 15). It is important to note the ranges to SEL thresholds assume that animals remain in the area for the total duration of the driving of one or two piles, and therefore, can be considered conservative estimates.

5.1.2.2 Sound Maps

The plan views of the sound fields predicted for a single unmitigated strike on a 3-m pin pile were derived for April (**Error! Reference source not found.**) and May (Figure), which show the maximum value in the water column and sounds fields are shown in 10 dB steps by different colors, with the color scale changing as needed. All predicted isopleths show evidence of bearing dependence. The 160 dB SPL_{rms} isopleth (green-blue) has a radius of about 6 km.

Table 5. Ranges (m) to regulatory threshold levels for marine mammals (NOAA Fisheries 2018, Southall et al. 2019) during pile driving of 3-m pin piles in April.

Marine Mammal Hearing Group	Impulsive Signals—Injury			NMFS Behavioral Threshold (160 dB re 1µPa^2, flat)
	Peak SPL (dB re 1µPa^2, flat)	SEL (dB re 1µPa^2-s, 24hr)		
		1 Pin Pile	2 Pin Piles	
Low-frequency (LF) cetaceans	50	7,950	10,950	6,550
Mid-frequency (MF) cetaceans	< 50	< 50	< 50	
High-frequency (HF) cetaceans	450	1,250	1,700	
Phocid pinnipeds underwater	50	900	1,550	

Table 6. Ranges (m) to regulatory behavioral threshold levels for fishes and sea turtles (GARFO 2019) during pile driving of 3-m pin piles.

Group	Behavioral Threshold (L_{rms} dB re 1µPa^2, flat)
Fishes (< 2g)	21,450
Fishes (> 2g)	
Sea Turtles	800

5.1.2.3 Exposure Tables

The outputs of the animat modeling are presented as tables of predicted numbers of marine mammal and sea turtle exposures exceeding regulatory thresholds (Table 1) for a single 3-m pin pile strike and two time periods (April through November and May through October) with no mitigation applied (Table 16). The animat exposure estimates are the product of the number of modeled exposures multiplied by the ratio of real-world density and model density.

5.1.2.4 Potential Effect of Sound Source Mitigation for Pinpiles

The effect of source level mitigation methods (e.g., bubble curtains) was also examined for impact pile driving of the pin piles. A reduction in the sound level by 10 dB lowered the range to the LF cetacean injury threshold from 8,000 m to 2,000 m, while a 20 dB sound level reduction further decreased the range to the injury threshold to only 350 m (Figure).

Table 7. Ranges (m) to regulatory injury threshold levels for fishes and sea turtles during pile driving of 3-m pin piles (Popper et al. 2014).

Group	Injury			TTS	
	Peak SPL (dB re 1µPa^2, flat)	SEL (dB re 1µPa^2-s, 24hr)		SEL (dB re 1µPa^2-s)	
		1 Pin Pile	2 Pin Piles	1 Pin Pile	2 Pin Piles
Fishes without swim bladders	100	50	100	8,000	10,950
Fishes with swim bladder not involved in hearing	250	700	1,100	8,000	10,950
Fishes with swim bladder involved in hearing	250	700	1,100	8,000	10,950
Fishes (> 2g)	300	7,200	9,550	--	--
Fishes (< 2g)	300	11,600	15,700	--	--
Sea Turtles	< 50	600	850	5,050	7,050

5.2 Non-Impulsive Scenarios

5.2.1 Vibratory Pile Driving of a 1.8-m Monopile

Substations will be placed on 1.8-m diameter monopiles and installed using vibratory pile driving methods. The predicted affected areas and exposure estimates are presented here.

5.2.1.1 Ranges to Regulatory Thresholds

The ranges to the regulatory behavior thresholds for vibratory pile driving are 23,700 m for marine mammals, 1,400 m for fishes, and less than 50 m for sea turtles (Tables 17 through 19). The large disparity in the ranges to regulatory thresholds is due to the 120 dB re 1µPa^2 SPL_{rms} threshold that NOAA Fisheries specifies for marine mammals and the fish behavioral threshold of 150 dB. The range to injury isopleths for marine mammals were all under 50 m (Table). The range to the injury thresholds (L_E *(cum)*) for fish and sea turtles were all less than 50 m (Table 19). It is important to note the ranges to SEL thresholds assume that animals remain in the area for the total duration of the driving of a pile, and therefore can be considered conservative estimates.

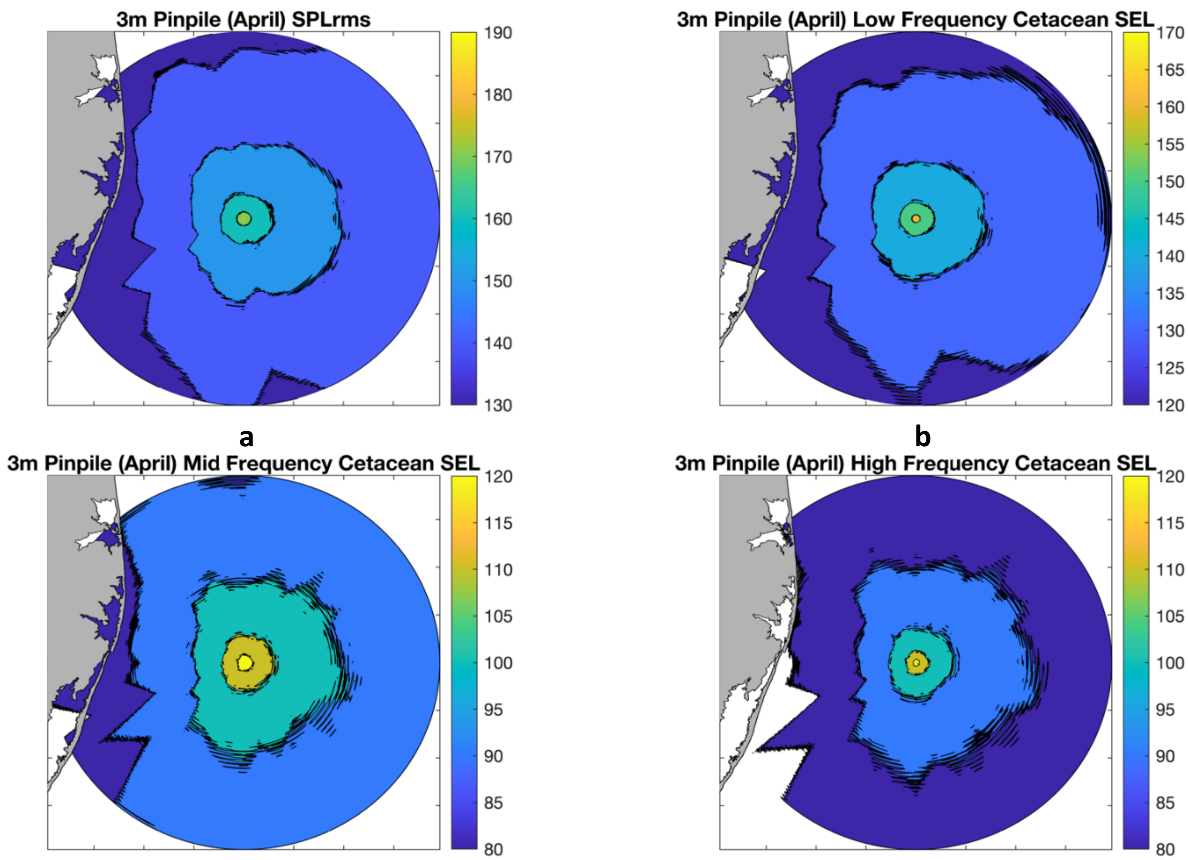

Figure 16. Sound maps for a single strike of a 3-m pinpile in April without mitigation show the maximum over depth a) unweighted SPL, and frequency-weighted single strike SEL (L_E (ss)) for the b) low frequency cetaceans, c) mid-frequency cetaceans, and d) high frequency cetaceans at the modeling site for the pile driving of one pin pile. The sound fields have been weighted using the NOAA Fisheries (2018) auditory weighting functions. The SPL sound levels are in dB re $1\mu Pa^2$ while SEL values are in dB re $1\mu Pa^2 s$. Map area is 100 km x 100 km.

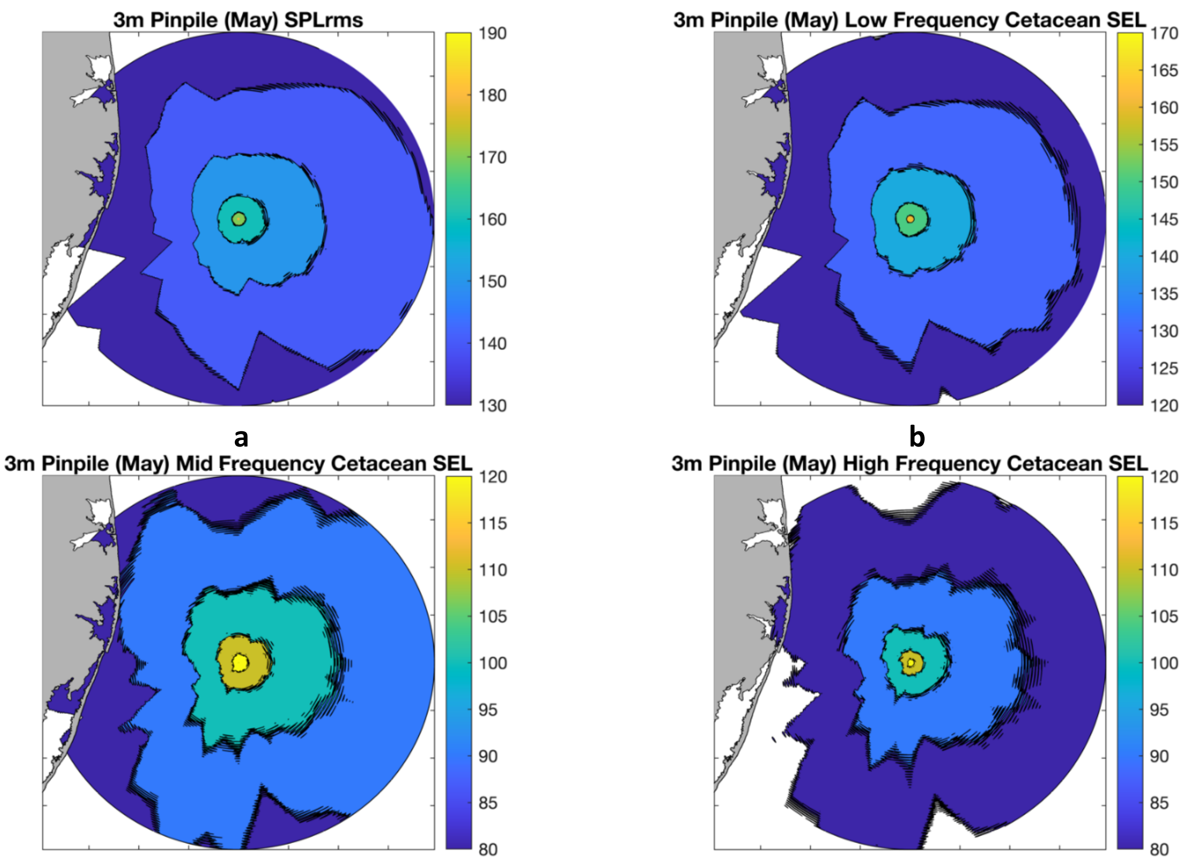

Figure 17. Sound maps for a single strike of a 3-m pin pile in May without mitigation show the maximum over depth a) unweighted SPL, and frequency-weighted single strike SEL (L_E (ss)) for the b) low frequency cetaceans, c) mid-frequency cetaceans, and d) high frequency cetaceans at the modeling site for the pile driving of one pin pile. The sound fields have been weighted using the NOAA Fisheries (2018) auditory weighting functions. The SPL sound levels are in dB re 1µPa^2 while SEL values are in dB re 1µPa^{2}s.. Map area is 100 km x 100 km.

Table 8. Exposure estimates of marine mammals and sea turtles for a single 3-m pin pile strike in two time periods with no mitigation applied. Individuals are only reported once; animals receiving injury exposures are not reported as behavioral exposures.

Marine Mammal Species	Behavioral Exposures		Cumulative SEL Injury Exposures		Peak SEL Injury Exposures	
	April-Nov	May-Oct	April-Nov	May-Oct	April-Nov	May-Oct
Risso's dolphin	0.00	0.00	0.00000	0.00000	0.00000	0.00000
Common dolphin	0.00	0.00	6.94798	5.33209	0.00000	0.00000
Fin whale	0.00	0.00	0.55228	0.59616	0.00500	0.00540
Harbor porpoise	0.85	0.17	0.00955	0.00189	0.05014	0.00994
Harbor seal	0.67	0.28	0.00000	0.00000	0.00189	0.00079
Killer whale	0.00	0.00	0.00063	0.00063	0.00000	0.00000
Rough-toothed dolphin	0.00	0.00	0.00042	0.00042	0.00000	0.00000
Common minke whale	0.00	0.00	0.21949	0.21138	0.00596	0.00574
Humpback whale	0.00	0.00	0.21247	0.18409	0.00577	0.00500
Kogia spp.	0.00	0.00	0.00000	0.00000	0.00000	0.00000
Pilot whales	0.00	0.00	0.00000	0.00000	0.00000	0.00000
North Atlantic right whale	0.00	0.00	0.03529	0.00540	0.00018	0.00013
Blainville's beaked whale	0.00	0.00	0.00000	0.00000	0.00000	0.00000
Cuvier's beaked whale	0.00	0.00	0.00000	0.00000	0.00000	0.00000
Gervais' beaked whale	0.00	0.00	0.00000	0.00000	0.00000	0.00000
True's beaked whale	0.00	0.00	0.00000	0.00000	0.00000	0.00000
Sperm whale	0.00	0.00	0.00000	0.00000	0.00000	0.00000
Atlantic spotted dolphin	0.00	0.00	0.72240	0.76487	0.00000	0.00000
Pantropical spotted dolphin	0.00	0.00	0.00099	0.00099	0.00000	0.00000
Striped dolphin	0.00	0.00	1.93810	1.93810	0.00000	0.00000
Common bottlenose dolphin	0.00	0.00	8.94316	10.56801	0.00000	0.00000
Leatherback turtle	0.24	0.24	0.01	0.01	0.00	0.00
Kemp’s ridley turtle	0.15	0.15	0.01	0.01	0.00	0.00
Green turtle (Hardshelled guild)	0.59	0.59	0.03	0.03	0.00	0.00
Loggerhead turtle (DoN 2007)	0.62	0.62	0.03	0.03	0.00	0.00
Loggerhead turtle (Barco et al. 2018)	20.64	20.64	1.03	1.03	0.00	0.00

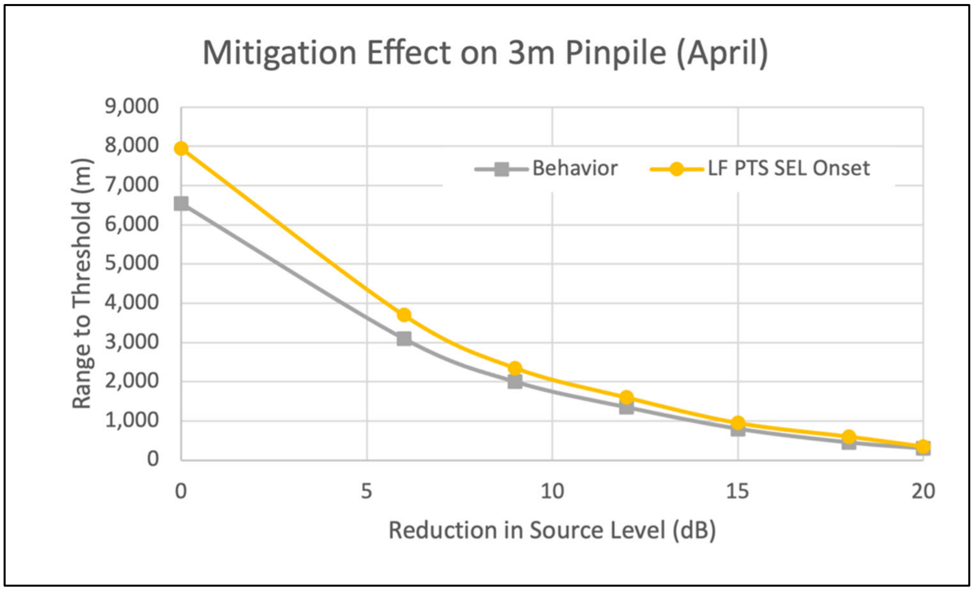

Figure 18. Mitigation effects for pinpiles.

Table 9. Ranges (m) to regulatory threshold levels for marine mammals (NOAA Fisheries 2018, Southall et al. 2019) during vibratory pile driving. Cumulative SELs (L_E(cum)) were determined assuming a one-hour period.

Marine Mammal Hearing Group	***Non-impulsive Signals—Injury*** ***SEL (dB re 1µPa^2-s, 24hr)***	***NMFS Behavioral Threshold (120 dB re 1µPa^2, flat)***
Low-frequency (LF) cetaceans	< 50	23,700
Mid-frequency (MF) cetaceans	< 50	
High-frequency (HF) cetaceans	< 50	
Phocid pinnipeds underwater	< 50	

5.2.1.2 Sound Maps

Plan views of the sound fields predicted for vibratory pile driving are shown for April (Figure) and May (

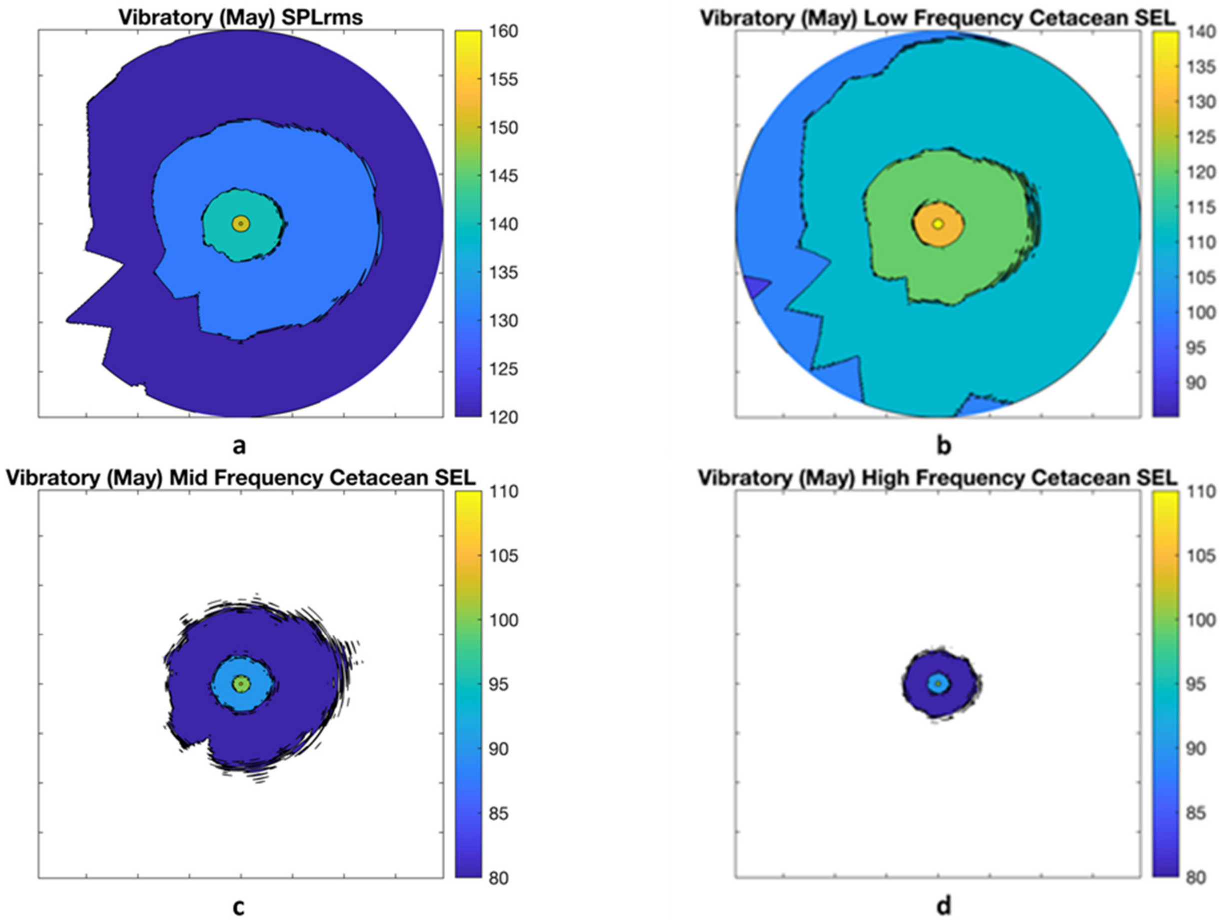

Figure). The maximum value in the water column is shown. Sound fields are shown in 10 dB steps by different colors. The color scales are far lower than the impact pile driving figures, reflecting the lower source level of vibratory pile drivers. Sub-plots a-d show the unweighted SPL_{rms} field and the three frequency-weighted

Table 10. Ranges (m) to regulatory behavioral threshold levels for fishes (Statler and Woodbury 2009, GARFO 2016) and sea turtles (GARFO 2019) during vibratory pile driving. Cumulative SELs (L_E(cum)) were determined assuming a one-hour period.

Group	*Behavioral Threshold (L_{rms} dB re 1μPa^2, flat)*
Fishes (< 2g)	1,400
Fishes (> 2g)	
Sea Turtles	< 50

Table 11. Ranges (m) to regulatory injury threshold levels for fishes and sea turtles (Popper et al. 2014) during vibratory pile driving.

Group	*Injury*	*TTS*
Fishes without swim bladders	--	--
Fishes with swim bladder not involved in hearing	--	--
Fishes with swim bladder involved in hearing	< 50	300
Fishes (> 2g)	--	--
Fishes (< 2g)	--	--
Sea Turtles	< 50	< 50

SEL sound fields. All predicted isopleths show evidence of bearing dependence. While there is variation, most isopleths show better propagation (greater distance to isopleths) in the offshore direction compared to cross shore and inshore propagation paths.

5.2.1.3 Exposure Tables

The outputs of the animat modeling for marine mammals and sea turtles are presented as tables of the predicted numbers of exposures of animals to the regulatory thresholds for each species (20). These values are for a single 1.8 m monopile. The animat exposure estimates are the product of the number of modeled exposures multiplied by the ratio of real-world density and model density. Separate estimates are provided for the April to November and May to October timeframes; the densities used in the modeling represent the mean density value across those timeframes. The values shown in Table Table are for a single 1.8-m monopile driven without mitigation.

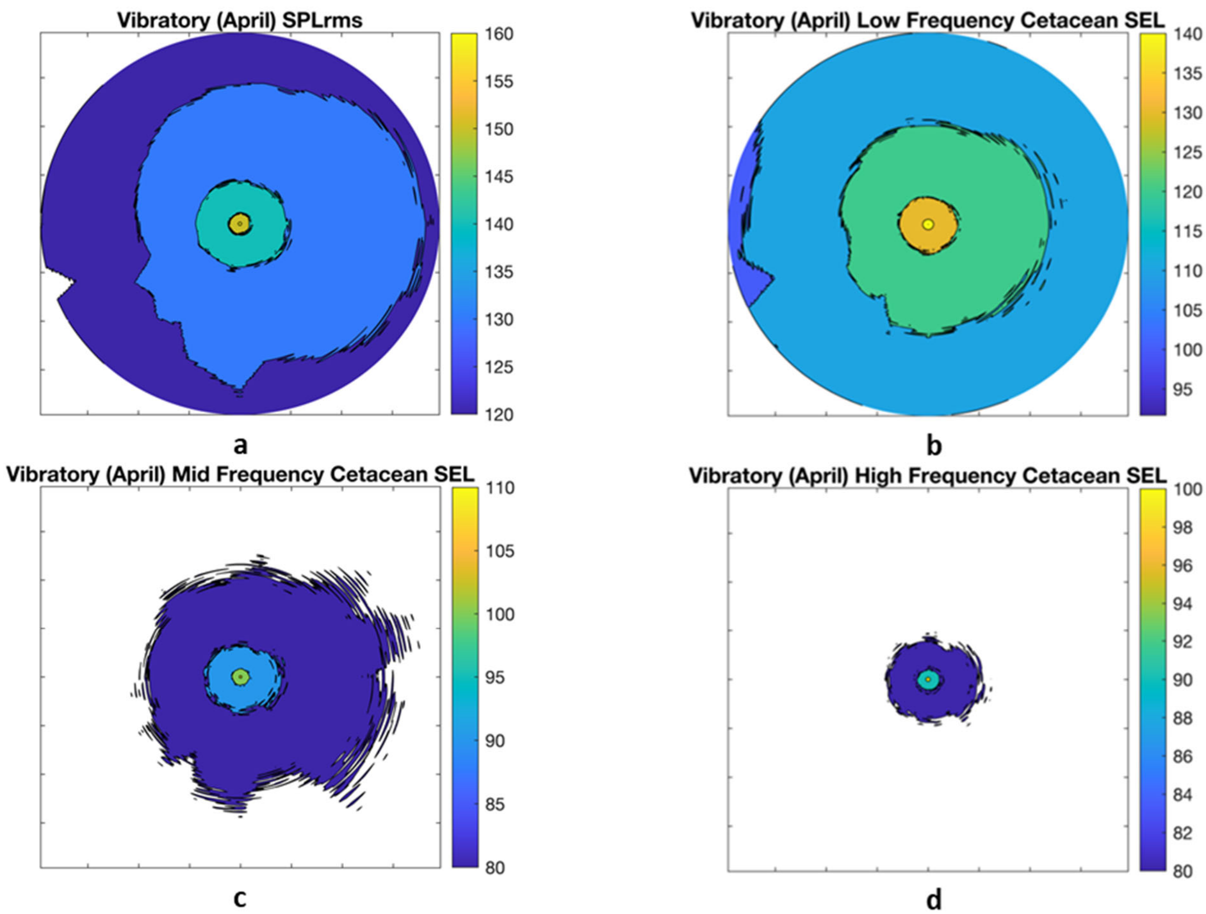

Figure 19. Sound maps for April showing the maximum over depth a) unweighted SPL, and frequency-weighted single strike SEL (L_E (ss)) for the b) low frequency cetaceans, c) mid-frequency cetaceans, and d) high frequency cetaceans for vibratory pile driving. Note the change of scale between a and b, and c and d. The sound fields have been weighted using the NOAA Fisheries (2018) auditory weighting functions. The SPL sound levels are in dB re 1μPa^2 while SEL values are in dB re 1μPa^{2}s.. Map area is 50 km x 50 km.

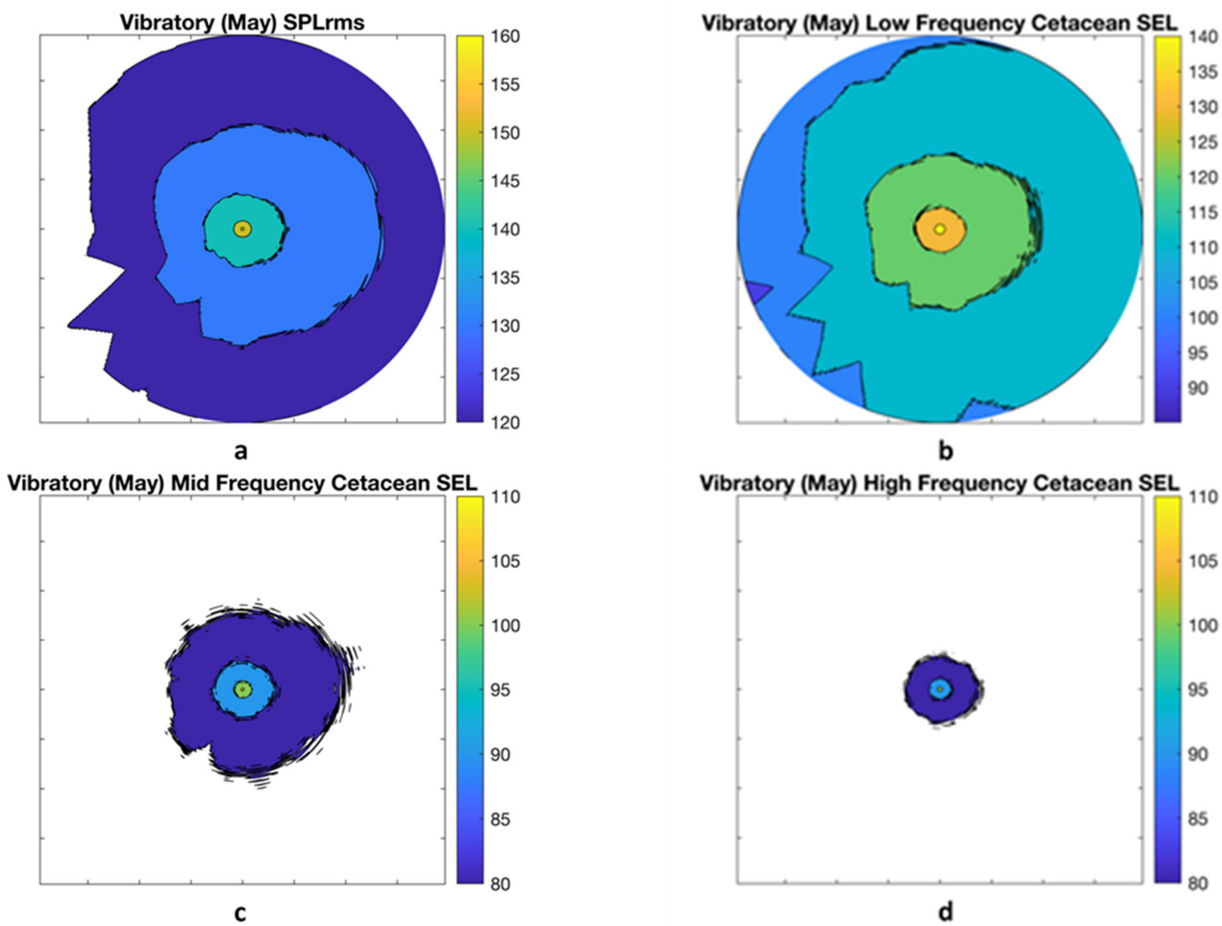

Figure 9. Sound maps for May showing the maximum over depth a) unweighted SPL, and frequency-weighted single strike SEL (L_E (ss)) for the b) low frequency cetaceans, c) mid-frequency cetaceans, and d) high frequency cetaceans for vibratory pile driving. Note the change of scale between a and b, and c and d. The sound fields have been weighted using the NOAA Fisheries (2018) auditory weighting functions. The SPL sound levels are in dB re 1µPa^2 while SEL values are in dB re 1µPa^{2}s. Map area is 50 km x 50 km.

Table 20. Marine mammal and sea turtle exposure estimates for vibratory driving of a 1.8m diameter monopile and two periods.

	Behavioral Exposures		Cumulative SEL Injury Exposures	
Marine Mammal Species	***April-Nov***	***May-Oct***	***April-Nov***	***May-Oct***
Risso's dolphin	0.00	0.00	0.00	0.00
Common dolphin	0.00	0.00	0.00	0.00
Fin whale	30.65	33.08	0.00	0.00
Harbor porpoise	0.00	0.00	0.024672	0.0048906
Harbor seal	3.28	1.38	0.00	0.000
Killer whale	0.00	0.00	0.00	0.00
Rough-toothed dolphin	0.00	0.00	0.00	0.00
Common minke whale	8.06	7.77	0.00	0.00
Humpback whale	7.81	6.76	0.00	0.00
Kogia spp.	0.00	0.00	0.00	0.00
Pilot whales	0.00	0.00	0.00	0.00
North Atlantic right whale	0.78	0.13	0.00	0.00
Blainville's beaked whale	0.00	0.00	0.00	0.00
Cuvier's beaked whale	0.00	0.00	0.00	0.00
Gervais' beaked whale	0.00	0.00	0.00	0.00
True's beaked whale	0.00	0.00	0.00	0.00
Sperm whale	0.00	0.00	0.00	0.00
Atlantic spotted dolphin	0.49	0.51	0.00	0.00
Pantropical spotted dolphin	0.00	0.00	0.00	0.00
Striped dolphin	1.30	1.30	0.00	0.00
Common bottlenose dolphin	0.00	0.00	0.00	0.00
Leatherback turtle	0.00	0.00	0.00	0.00
Kemp’s ridley turtle	0.00	0.00	0.00	0.00
Green turtle (Hardshelled guild)	0.00	0.00	0.00	0.00
Loggerhead turtle (DoN 2007)	0.00	0.00	0.00	0.00
Loggerhead turtle (Barco et al. 2018)	0.00	0.00	0.00	0.00

5.3 Sources of Uncertainty

This section discusses the major uncertainties inherent in the modeling scenarios. These include animal densities, animal movement, and the pile driving spectrum.

5.3.1 Animal Density

Animal density estimates are a source of uncertainty in modeling and analysis that can have a large effect on the calculated number of exposed animals. The fidelity of modeled animal density values improves as additional data are collected and both collection and analysis methodologies are refined. Marine mammal density estimates used in this analysis were taken from Roberts *et al*. (2020; 2021), which are the most recent data available for the Project area. Densities of sea turtles are much scarcer, particularly at-sea densities, as abundance and density estimations for sea turtles are frequently based on the number of nesting females counted when they come ashore or the number nests laid on nesting beaches. Even these land-based density estimates are not accurate as they underestimate the number of sea turtles since they only include the number of nesting female turtles, and female turtles can lay more than one nest in a season. For the Project analysis, two sources provided the best available at-sea density estimates for potentially occurring sea turtles: DoN (2007) and Barco *et al*. (2018). Barco et al. (2018) only was used for updated loggerhead turtle density estimates for the Project area. However, the densities and resulting exposure estimates based on both DoN (2007) and Barco *et al*. (2018) have been provided for the loggerhead turtle. The more recent Barco *et al*. (2018) densities are much higher than the older DoN (2007) estimates and include an availability correction factor.

Last, although green turtles may occur seasonally in the Project area, no at-sea density estimates are available for this more rarely occurring species. Since available occurrence data for the green turtle were included in the “Hardshelled Guild” in the DoN (2007) density dataset, the seasonal density estimates from this guild were used as surrogate densities for the green turtle. These represent the best available data for green turtle densities for the Project area. The U.S. Navy set a precedent for use of this turtle guild’s density estimates to represent the green turtle (DoN 2017).

5.3.2 Animal Movement

The movement parameters used to create the animat paths are based on the most recent and most complete reported values of real animal behavior (Appendix A). However, the recorded range of behavior may not be complete and other behaviors may exist (such as diving to depths greater than previously observed). This uncertainty is considered to have a small potential to affect the number of exposed animals.

5.3.3 Source Spectra

There were no exact spectra available for the impact and vibratory drivers that will be used for the monopile or pin piles. Therefore, representative spectra were extracted from the literature.

5.3.4 Acoustic Propagation Modeling

The Project will span multiple years. A single set of propagation models was run to reduce complexity of the modeling procedure. To make the results applicable to all possible months, the environmental conditions of April were utilized (). Additional propagation and modelling results were conducted for North Atlantic right whales in May.

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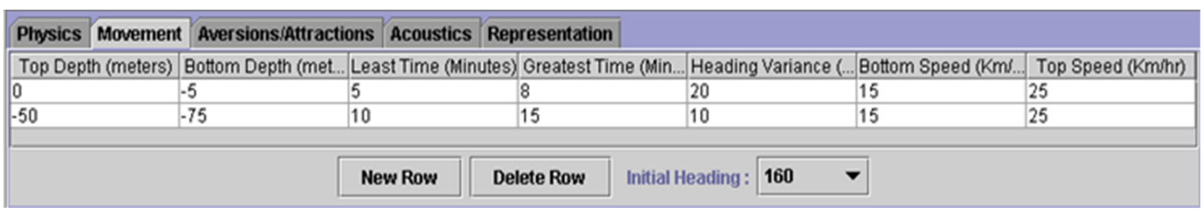
APPENDIX A: ANIMAT MODELING PARAMETERS

Parameters that Define Animat Movement in AIM

Animals move through four dimensions: 3D space and time. Several parameters are used in AIM to produce simulated movements that accurately represent expected real animal movement patterns. This section provides short descriptions of the various parameters, with nominal values as examples of how the parameters are implemented in AIM. The actual values used in the modeling of the US Wind Project pile driving operations and the literature from which that information was obtained are detailed in this appendix.

Marine Mammal Diving Patterns

Diving parameters, such as time limits, depth limits, heading variance, and speed, are specified for each animat in the AIM model (Figure A-1). As an example, a dive pattern is presented that consists of a shallow, respiratory sequence (Figure A-1) followed by a deeper, longer dive (bottom row of Figure A-1). The horizontal component of the dive is handled with the "heading variance" term, which allows the animal to change course up to a certain number of degrees at each movement step. For this example, the animal can change course 20° during a shallow dive and 10° during a deep dive (Figure A-1). Using the defined diving parameters, AIM generates realistic dive patterns (Figure A-2).



Top Depth (meters)	Bottom Depth (met...	Least Time (Minutes)	Greatest Time (Min...	Heading Variance (...	Bottom Speed (Km/...	Top Speed (Km/hr)
0	-5	5	8	20	15	25
-50	-75	10	15	10	15	25

Figure A-1. Example of AIM marine mammal movement parameters, with the top row showing the parameters of a shallow, respiratory dive (diving from surface to 5 m for 5 to 8 min) and the bottom row showing a deeper, longer dive (diving between 50 and 75 m for 10 to 15 min).

Aversions

In addition to movement patterns, animats can be programmed to avoid certain environmental characteristics (Figure A-3). For example, aversions can be used to constrain an animal to a particular depth regime. (e.g., an animat can be constrained to waters between 2,000 and 5,000 m deep). An animat will continue to turn until the aversion is satisfied. In this example, animat makes 20° turns in water depths shallower than 2,000 m or deeper than 5,000 m to remain within that depth range.

Heading Variance

There is little data that summarizes movement in terms of heading variance, or the amount the course of the animal changes per unit time. Therefore, the default value used in the modeling is

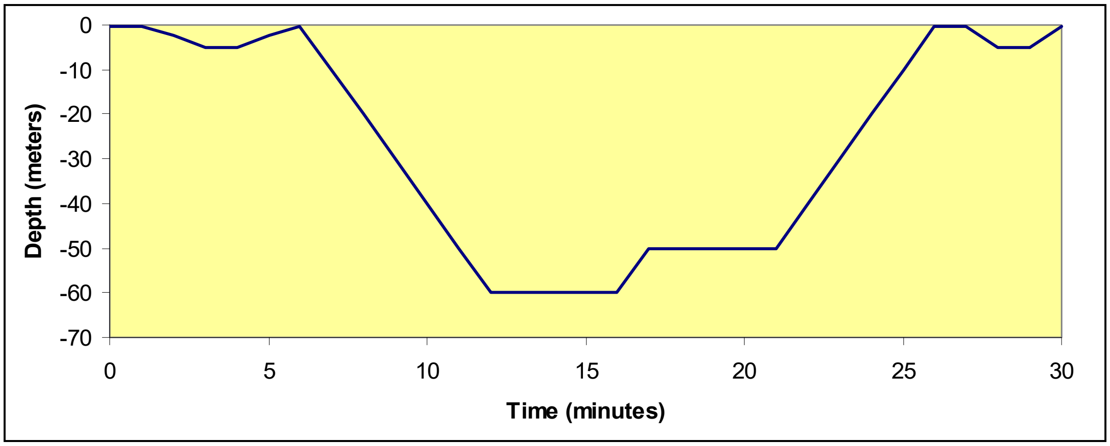
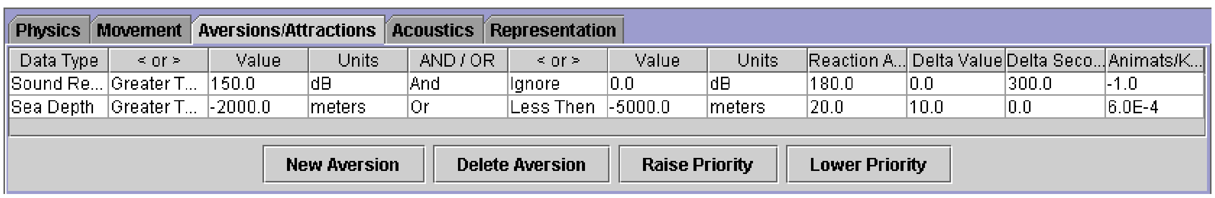


Figure A-2. Marine mammal dive pattern based on animat data in Figure A-1. The animat makes a shallow dive from the surface to 5 m for approximately 6 min, surfaces, and then makes a deep dive to 60 m for about 5 min, changes depth to 50 m for another 5 min, and then surfaces.



Data Type	< or >	Value	Units	AND / OR	< or >	Value	Units	Reaction A...	Delta Value	Delta Seco...	Animats/K...
Sound Re...	Greater T...	150.0	dB	And	Ignore	0.0	dB	180.0	0.0	300.0	-1.0
Sea Depth	Greater T...	-2000.0	meters	Or	Less Then	-5000.0	meters	20.0	10.0	0.0	6.0E-4

Figure A-3. Example of depth aversion parameters for modeling of marine mammal movements.

30 degrees. Exceptions are made for migratory animals, which tend to have more linear travel; therefore, these animals typically are assigned a value of 10 degrees. Foraging animals tend to have less linear travel, as they may be trying to remain within a food patch. Therefore, foraging animals are assigned a higher heading variance value, typically 45 to 60 degrees.

These types of data have been reported in the literature as “linearity”, “tortuosity” and “meander” (Soule and Wilcock, 2013). “Meander” is defined as the ratio of the total distance along the smoothed path to the net distance traveled; a value of 1 would indicate a straight path.

Residency
The amount of time that an animal spends in an area can have a tremendous influence on how the animal samples an acoustic field. Individuals displaying high residency in the area of a localized noise source will experience higher exposures than animals that transit the area once.

Parameters of Marine Mammal Movement Behaviors Used in Impact Analysis
Dive and swim speed information for each marine mammal or marine mammal group is a critical component of accurately and realistically modeling marine mammal movements when assessing potential exposure to underwater acoustic sound. All parameters except speed use a

uniform distribution between the minimum and maximum values. Speed parameters include the minimum and maximum as well as the statistical distribution used to select speed values. Options include a normal distribution and a gamma distribution. When gamma distributions are specified, they are typically the result of fitting to an existing dataset. The mean of the normal distribution is the mean of the minimum and maximum speed. The minimum and maximum values are four standard deviations below or above the distribution mean. Dive and swim parameters for marine mammals potentially occurring in the US Wind Project modeled area are summarized in Table A-1.

Table A-1. Dive and swim parameters of all the marine mammal species of interest in the US Wind Project modeling area. Multiple entries in a single cell represent multiple modeled diving states of the species. The underlying statistic distribution is uniform for all parameters except speed, which uses either a normal or user-specified gamma distribution

Modeled Species	*Min/Max Surface Time (Min)*	*Surface/ Dive Angle (°)*	*Dive Depth in Meters Min/Max (Percentage)*	*Min/Max Dive Time (Min)*	*Heading Variance (Angle/Time)*	*Min/ Max Speed (kph)*	*Speed Distribution*	*Depth Limit (m)/ Reaction Angle*
Fin Whale	2/4	64/54	20/40 (25) 20/40 (25) 50/150 (22) 50/150 (22) 150/527 (6)	2/4 2/4 5/8 5/8 10/18	30/300 90/300 30/300 90/300 90/300	1/8	Normal	30/ reflect
Humpback Whale	1/3	75	10/60 (20) 40/100 (75) 100/150 (5)	7/10 7/10 7/15	90/300 90/90 90/90	1/8	Normal	100/ reflect
North Atlantic Foraging Minke	1/3	75	75/150 (14) 25/45 (29) 5/25 (57)	2/7 1/5 0.5/1.5	90/90 90/300 10/300	1/11	Gamma (3,1.5)	10 / reflect
Right Whale	4/5	75	113/130 (50) 113/130 (50)	11/13 11/13	90/90 30/90	1/4	Normal	
Atlantic Spotted Dolphin, Pantropical Spotted Dolphin, Striped Dolphin (*Stenella* spp).	1/1	75	Day: 5/25 (50) Night: 10/400 (10) Night: 10/100(40)	1/4	30	2/15	Normal	10/ reflect
Beaked Whales	1/6	75	2000/3000(5) 1000/2000 (25) 200/500 (70)	100/140 48/74 12/30	30/300 (50) 90/300 (50)	2/7	Normal	100/ reflect

Table A-1. Dive and swim parameters of all the marine mammal species of interest in the US Wind Project modeling area. Multiple entries in a single cell represent multiple modeled diving states of the species. The underlying statistic distribution is uniform for all parameters except speed, which uses either a normal or user-specified gamma distribution

Modeled Species	Min/Max Surface Time (Min)	Surface/ Dive Angle (°)	Dive Depth in Meters Min/Max (Percentage)	Min/Max Dive Time (Min)	Heading Variance (Angle/Time)	Min/ Max Speed (kph)	Speed Distribution	Depth Limit (m)/ Reaction Angle
Bottlenose Dolphin	1/1	75	15/98	1/3	90/300 (50) 90/90 (50)	2/16	Normal	10/ reflect
Common Dolphin	1/1	75	50/200	1/5	30	2/9	Normal	100-1000/ reflect
Harbor Porpoise	1/1	17/31	1/10 (35) 10/40 (45) 40/100 (15) 100/230 (5)	1/4	43/30	2/8	Normal	1/4
Killer Whale	1/1	75	10/180	1/10	30/300 (50) 90/150 (50)	3/12	Normal	25/ reflect
Kogia spp.	1/2	75	200/1000	2/43	30	1/11	Normal	117/ reflect
Pilot Whales	1/1	75	5/100 (80) 10/1000 (20)	1/10 5/21	30	2/12	Normal	100/ reflect
Risso's Dolphin	1/3	75	150/1000	2/12	30/300 (50) 90/300 (50)	2/12	Normal	100/ reflect

Table A-1. Dive and swim parameters of all the marine mammal species of interest in the US Wind Project modeling area. Multiple entries in a single cell represent multiple modeled diving states of the species. The underlying statistic distribution is uniform for all parameters except speed, which uses either a normal or user-specified gamma distribution

Modeled Species	*Min/Max Surface Time (Min)*	*Surface/ Dive Angle (°)*	*Dive Depth in Meters Min/Max (Percentage)*	*Min/Max Dive Time (Min)*	*Heading Variance (Angle/Time)*	*Min/ Max Speed (kph)*	*Speed Distribution*	*Depth Limit (m)/ Reaction Angle*
Rough-toothed Dolphin	1/3	75	50/600	1/7	30/300 (50) 90/300 (50)	5/16	Normal	194/ reflect
Sperm Whale	5/9	90/75	600/1000 (100)	35/65	30/300 (50) 90/300 (50)	1/8	Normal	100/reflect

APPENDIX B: MARINE MAMMAL ACOUSTIC EXPOSURE TABLES FOR VARIOUS MITIGATION SCENARIOS

Table B-1: Scenario Source Levels

Source Scenario	SEL	SPL	Peak
11-m Monopile	224	234	282
3-m Pinpile	210	220	262
1.8-m pile	187	187	n/a

Table B-2: 11-m monopile exposure estimates with no mitigation applied.

	Behavioral Exposures		*Cumulative SEL Injury Exposures*		*Peak SPL Injury Exposures*	
Marine Mammal Species	***April-Nov***	***May-Oct***	***April-Nov***	***May-Oct***	***April-Nov***	***May-Oct***
Risso's dolphin	0.00	0.00	0.00000	0.00000	0.00000	0.00000
Common dolphin	110.87	85.09	0.00000	0.00000	0.00000	0.00000
Fin whale	0.00	0.00	1.27949	1.38116	0.01000	0.01079
Harbor porpoise	3.97	0.79	0.00000	0.00000	0.04616	0.00915
Harbor seal	2.93	1.23	0.00630	0.00265	0.00126	0.00053
Killer whale	0.01	0.01	0.00000	0.00000	0.00000	0.00000
Rough-toothed dolphin	0.13	0.13	0.00000	0.00000	0.00000	0.00000
Common minke whale	0.00	0.00	0.52306	0.50374	0.00265	0.00255
Humpback whale	0.00	0.00	0.50633	0.43871	0.00256	0.00222
Kogia spp.	0.00	0.00	0.00000	0.00000	0.00000	0.00000
Pilot whales	0.00	0.00	0.00000	0.00000	0.00000	0.00000
North Atlantic right whale	0.00	0.00	0.09747	0.01239	0.00012	0.00000
Blainville's beaked whale	0.00	0.00	0.00000	0.00000	0.00000	0.00000
Cuvier's beaked whale	0.00	0.00	0.00000	0.00000	0.00000	0.00000
Gervais' beaked whale	0.00	0.00	0.00000	0.00000	0.00000	0.00000
True's beaked whale	0.00	0.00	0.00000	0.00000	0.00000	0.00000
Sperm whale	0.10	0.12	0.00000	0.00000	0.00000	0.00000
Atlantic spotted dolphin	10.05	10.64	0.00000	0.00000	0.00000	0.00000
Pantropical spotted dolphin	0.01	0.01	0.00000	0.00000	0.00000	0.00000
Striped dolphin	26.97	26.97	0.00000	0.00000	0.00000	0.00000
Common bottlenose dolphin	194.13	229.40	0.00000	0.00000	0.00000	0.00000

Table B-3: 11-m monopile exposure estimates with 3 dB reduction as mitigation.

Marine Mammal Species	Behavioral Exposures		Cumulative SEL Injury Exposures		Peak SPL Injury Exposures	
	April-Nov	May-Oct	April-Nov	May-Oct	April-Nov	May-Oct
Risso's dolphin	0.00	0.00	0.00000	0.00000	0	0
Common dolphin	71.59	54.94	0.00000	0.00000	0	0
Fin whale	0.00	0.00	0.78135	0.84344	0	0
Harbor porpoise	2.48	0.49	0.00000	0.00000	0.02865	0
Harbor seal	1.77	0.74	0.00378	0.00159	0	0
Killer whale	0.00	0.00	0.00000	0.00000	0	0
Rough-toothed dolphin	0.08	0.08	0.00000	0.00000	0	0
Common minke whale	0.00	0.00	0.29199	0.28120	0	0
Humpback whale	0.00	0.00	0.28265	0.24490	0	0
Kogia spp.	0.00	0.00	0.00000	0.00000	0	0
Pilot whales	0.00	0.00	0.00000	0.00000	0	0
North Atlantic right whale	0.00	0.00	0.05354	0.00757	0	0
Blainville's beaked whale	0.00	0.00	0.00000	0.00000	0	0
Cuvier's beaked whale	0.00	0.00	0.00000	0.00000	0	0
Gervais' beaked whale	0.00	0.00	0.00000	0.00000	0	0
True's beaked whale	0.00	0.00	0.00000	0.00000	0	0
Sperm whale	0.06	0.07	0.00000	0.00000	0	0
Atlantic spotted dolphin	6.24	6.60	0.00000	0.00000	0	0
Pantropical spotted dolphin	0.01	0.01	0.00000	0.00000	0	0
Striped dolphin	16.73	16.73	0.00000	0.00000	0	0
Common bottlenose dolphin	125.03	147.74	0.00000	0.00000	0	0

Table B-4: 11-m monopile exposure estimates with 6 dB reduction as mitigation.

	Behavioral Exposures		***Cumulative SEL Injury Exposures***		***Peak SPL Injury Exposures***	
Marine Mammal Species	***April-Nov***	***May-Oct***	***April-Nov***	***May-Oct***	***April-Nov***	***May-Oct***
Risso's dolphin	0.00	0.00	0.00000	0.00000	0.00000	0.00000
Common dolphin	45.14	34.64	0.00000	0.00000	0.00000	0.00000
Fin whale	0.00	0.00	0.42483	0.45859	0.00000	0.00000
Harbor porpoise	1.53	0.30	0.00000	0.00000	0.02388	0.00473
Harbor seal	0.98	0.41	0.00000	0.00000	0.00000	0.00000
Killer whale	0.00	0.00	0.00000	0.00000	0.00000	0.00000
Rough-toothed dolphin	0.04	0.04	0.00000	0.00000	0.00000	0.00000
Common minke whale	0.00	0.00	0.16288	0.15686	0.00000	0.00000
Humpback whale	0.00	0.00	0.15767	0.13661	0.00000	0.00000
Kogia spp.	0.00	0.00	0.00000	0.00000	0.00000	0.00000
Pilot whales	0.00	0.00	0.00000	0.00000	0.00000	0.00000
North Atlantic right whale	0.00	0.00	0.02821	0.00414	0.00000	0.00000
Blainville's beaked whale	0.00	0.00	0.00000	0.00000	0.00000	0.00000
Cuvier's beaked whale	0.00	0.00	0.00000	0.00000	0.00000	0.00000
Gervais' beaked whale	0.00	0.00	0.00000	0.00000	0.00000	0.00000
True's beaked whale	0.00	0.00	0.00000	0.00000	0.00000	0.00000
Sperm whale	0.00	0.00	0.00000	0.00000	0.00000	0.00000
Atlantic spotted dolphin	3.89	4.11	0.00000	0.00000	0.00000	0.00000
Pantropical spotted dolphin	0.01	0.01	0.00000	0.00000	0.00000	0.00000
Striped dolphin	10.43	10.43	0.00000	0.00000	0.00000	0.00000
Common bottlenose dolphin	80.79	95.46	0.00000	0.00000	0.00000	0.00000

Table B-5: 11-m monopile exposure estimates with 9 dB reduction as mitigation.

	Behavioral Exposures		Cumulative SEL Injury Exposures		Peak SPL Injury Exposures	
Marine Mammal Species	**April-Nov**	**May-Oct**	**April-Nov**	**May-Oct**	**April-Nov**	**May-Oct**
Risso's dolphin	0.00	0.00	0	0	0	0
Common dolphin	28.51	21.88	0	0	0	0
Fin whale	0.00	0.00	0.17660	0.19063	0	0
Harbor porpoise	0.98	0.19	0	0	0.01592	0.00316
Harbor seal	0.57	0.24	0	0	0	0
Killer whale	0.00	0.00	0	0	0	0
Rough-toothed dolphin	0.02	0.02	0	0	0	0
Common minke whale	0.00	0.00	0.09071	0.08736	0	0
Humpback whale	0.00	0.00	0.08781	0.07608	0	0
Kogia spp.	0.00	0.00	0	0	0	0
Pilot whales	0.00	0.00	0	0	0	0
North Atlantic right whale	0.00	0.00	0.01368	0.00225	0	0
Blainville's beaked whale	0.00	0.00	0	0	0	0
Cuvier's beaked whale	0.00	0.00	0	0	0	0
Gervais' beaked whale	0.00	0.00	0	0	0	0
True's beaked whale	0.00	0.00	0	0	0	0
Sperm whale	0.00	0.00	0	0	0	0
Atlantic spotted dolphin	2.52	2.67	0	0	0	0
Pantropical spotted dolphin	0.00	0.00	0	0	0	0
Striped dolphin	6.77	6.77	0	0	0	0
Common bottlenose dolphin	55.45	65.52	0	0	0	0

Table B-6: 11-m monopile exposure estimates with 12 dB reduction as mitigation.

	Behavioral Exposures		*Cumulative SEL Injury Exposures*		*Peak SPL Injury Exposures*	
Marine Mammal Species	***April-Nov***	***May-Oct***	***April-Nov***	***May-Oct***	***April-Nov***	***May-Oct***
Risso's dolphin	0.00	0.00	0.00000	0.00000	0	0
Common dolphin	17.05	13.09	0.00000	0.00000	0	0
Fin whale	0.00	0.00	1.27949	1.38116	0	0
Harbor porpoise	0.61	0.12	0.00000	0.00000	0	0
Harbor seal	0.15	0.06	0.00630	0.00265	0	0
Killer whale	0.00	0.00	0.00000	0.00000	0	0
Rough-toothed dolphin	0.01	0.01	0.00000	0.00000	0	0
Common minke whale	0.00	0.00	0.52306	0.50374	0	0
Humpback whale	0.00	0.00	0.50633	0.43871	0	0
Kogia spp.	0.00	0.00	0.00000	0.00000	0	0
Pilot whales	0.00	0.00	0.00000	0.00000	0	0
North Atlantic right whale	0.00	0.00	0.09747	0.00114	0	0
Blainville's beaked whale	0.00	0.00	0.00000	0.00000	0	0
Cuvier's beaked whale	0.00	0.00	0.00000	0.00000	0	0
Gervais' beaked whale	0.00	0.00	0.00000	0.00000	0	0
True's beaked whale	0.00	0.00	0.00000	0.00000	0	0
Sperm whale	0.00	0.00	0.00000	0.00000	0	0
Atlantic spotted dolphin	1.56	1.65	0.00000	0.00000	0	0
Pantropical spotted dolphin	0.00	0.00	0.00000	0.00000	0	0
Striped dolphin	4.18	4.18	0.00000	0.00000	0	0
Common bottlenose dolphin	33.51	39.59	0.00000	0.00000	0	0

Table B-7: 11-m monopile exposure estimates with 15 dB reduction as mitigation.

Marine Mammal Species	Behavioral Exposures		Cumulative SEL Injury Exposures		Peak SPL Injury Exposures	
	April-Nov	May-Oct	April-Nov	May-Oct	April-Nov	May-Oct
Risso's dolphin	0.00	0.00	0	0	0	0
Common dolphin	10.40	7.98	0	0	0	0
Fin whale	0.00	0.00	0.01833	0.01978	0	0
Harbor porpoise	0.37	0.07	0	0	0	0
Harbor seal	0.19	0.08	0.00000	0	0	0
Killer whale	0.00	0.00	0	0	0	0
Rough-toothed dolphin	0.00	0.00	0	0	0	0
Common minke whale	0.00	0.00	0.01589	0.01530	0	0
Humpback whale	0.00	0.00	0.01538	0.01333	0	0
Kogia spp.	0.00	0.00	0	0	0	0
Pilot whales	0.00	0.00	0	0	0	0
North Atlantic right whale	0.00	0.00	0.00312	0.00041	0	0
Blainville's beaked whale	0.00	0.00	0	0	0	0
Cuvier's beaked whale	0.00	0.00	0	0	0	0
Gervais' beaked whale	0.00	0.00	0	0	0	0
True's beaked whale	0.00	0.00	0	0	0	0
Sperm whale	0.00	0.00	0	0	0	0
Atlantic spotted dolphin	0.94	0.99	0	0	0	0
Pantropical spotted dolphin	0.00	0.00	0	0	0	0
Striped dolphin	2.52	2.52	0	0	0	0
Common bottlenose dolphin	21.23	25.08	0	0	0	0

Table B-8: 11-m monopile exposure estimates with 18 dB reduction as mitigation.

Marine Mammal Species	Behavioral Exposures		Cumulative SEL Injury Exposures		Peak SPL Injury Exposures	
	April-Nov	May-Oct	April-Nov	May-Oct	April-Nov	May-Oct
Risso's dolphin	0.00	0.00	0	0	0	0
Common dolphin	6.74	5.17	0	0	0	0
Fin whale	0.00	0.00	0.00167	0.00180	0	0
Harbor porpoise	0.21	0.04	0	0	0	0
Harbor seal	0.11	0.04	0	0	0	0
Killer whale	0.00	0.00	0	0	0	0
Rough-toothed dolphin	0.00	0.00	0	0	0	0
Common minke whale	0.00	0.00	0.00331	0.00319	0	0
Humpback whale	0.00	0.00	0.00320	0.00278	0	0
Kogia spp.	0.00	0.00	0	0	0	0
Pilot whales	0.00	0.00	0	0	0	0
North Atlantic right whale	0.00	0.00	0.00084	0.00019	0	0
Blainville's beaked whale	0.00	0.00	0	0	0	0
Cuvier's beaked whale	0.00	0.00	0	0	0	0
Gervais' beaked whale	0.00	0.00	0	0	0	0
True's beaked whale	0.00	0.00	0	0	0	0
Sperm whale	0.00	0.00	0	0	0	0
Atlantic spotted dolphin	0.61	0.65	0	0	0	0
Pantropical spotted dolphin	0.00	0.00	0	0	0	0
Striped dolphin	1.64	1.64	0	0	0	0
Common bottlenose dolphin	13.41	15.85	0	0	0	0

Table B-9: 11-m monopile exposure estimates with 20 dB reduction as mitigation.

Marine Mammal Species	Behavioral Exposures		Cumulative SEL Injury Exposures		Peak SPL Injury Exposures	
	April-Nov	May-Oct	April-Nov	May-Oct	April-Nov	May-Oct
Risso's dolphin	0.00	0.00	0.00000	0.00000	0	0
Common dolphin	4.84	3.72	0.00000	0.00000	0	0
Fin whale	0.00	0.00	0.00000	0.57009	0	0
Harbor porpoise	0.14	0.03	0.00000	0.00000	0	0
Harbor seal	0.07	0.03	0.00000	0.00000	0	0
Killer whale	0.00	0.00	0.00000	0.00000	0	0
Rough-toothed dolphin	0.00	0.00	0.00000	0.00000	0	0
Common minke whale	0.00	0.00	0.00000	0.19129	0	0
Humpback whale	0.00	0.00	0.00000	0.16660	0	0
Kogia spp.	0.00	0.00	0.00000	0.00000	0	0
Pilot whales	0.00	0.00	0.00000	0.00000	0	0
North Atlantic right whale	0.00	0.00	0.00024	0.00009	0	0
Blainville's beaked whale	0.00	0.00	0.00000	0.00000	0	0
Cuvier's beaked whale	0.00	0.00	0.00000	0.00000	0	0
Gervais' beaked whale	0.00	0.00	0.00000	0.00000	0	0
True's beaked whale	0.00	0.00	0.00000	0.00000	0	0
Sperm whale	0.00	0.00	0.00000	0.00000	0	0
Atlantic spotted dolphin	0.43	0.46	0.00000	0.00000	0	0
Pantropical spotted dolphin	0.00	0.00	0.00000	0.00000	0	0
Striped dolphin	1.16	1.16	0.00000	0.00000	0	0
Common bottlenose dolphin	9.54	11.27	0.00000	0.00000	0	0

Table B-10: 3-m pinpile exposure estimates with no mitigation applied.

Marine Mammal Species	Behavioral Exposures		Cumulative SEL Injury Exposures		Peak SPL Injury Exposures	
	April-Nov	May-Oct	April-Nov	May-Oct	April-Nov	May-Oct
Risso's dolphin	0.00	0.00	0.00000	0.00000	0.00000	0.00000
Common dolphin	0.00	0.00	6.94798	5.33209	0.00000	0.00000
Fin whale	0.00	0.00	0.55228	0.59616	0.00500	0.00540
Harbor porpoise	0.85	0.17	0.00955	0.00189	0.05014	0.00994
Harbor seal	0.67	0.28	0.00000	0.00000	0.00189	0.00079
Killer whale	0.00	0.00	0.00063	0.00063	0.00000	0.00000
Rough-toothed dolphin	0.00	0.00	0.00042	0.00042	0.00000	0.00000
Common minke whale	0.00	0.00	0.21949	0.21138	0.00596	0.00574
Humpback whale	0.00	0.00	0.21247	0.18409	0.00577	0.00500
Kogia spp.	0.00	0.00	0.00000	0.00000	0.00000	0.00000
Pilot whales	0.00	0.00	0.00000	0.00000	0.00000	0.00000
North Atlantic right whale	0.00	0.00	0.03529	0.00540	0.00018	0.00013
Blainville's beaked whale	0.00	0.00	0.00000	0.00000	0.00000	0.00000
Cuvier's beaked whale	0.00	0.00	0.00000	0.00000	0.00000	0.00000
Gervais' beaked whale	0.00	0.00	0.00000	0.00000	0.00000	0.00000
True's beaked whale	0.00	0.00	0.00000	0.00000	0.00000	0.00000
Sperm whale	0.00	0.00	0.00000	0.00000	0.00000	0.00000
Atlantic spotted dolphin	0.00	0.00	0.72240	0.76487	0.00000	0.00000
Pantropical spotted dolphin	0.00	0.00	0.00099	0.00099	0.00000	0.00000
Striped dolphin	0.00	0.00	1.93810	1.93810	0.00000	0.00000
Common bottlenose dolphin	0.00	0.00	8.94316	10.56801	0.00000	0.00000

Table B-11: 3-m pinpile exposure estimates with 3 dB reduction as mitigation.

Marine Mammal Species	Behavioral Exposures		Cumulative SEL Injury Exposures		Peak SPL Injury Exposures	
	April-Nov	May-Oct	April-Nov	May-Oct	April-Nov	May-Oct
Risso's dolphin	0	0	0	0	0	0
Common dolphin	0	0	3.03185	2.32673	0	0
Fin whale	0	0	0.23491	0.25357	0	0
Harbor porpoise	0.52	0.10	0	0	0.02626	0.00521
Harbor seal	0.36	0.15	0	0	0	0
Killer whale	0	0	0.00028	0.00028	0	0
Rough-toothed dolphin	0	0	0	0	0	0
Common minke whale	0	0	0.10825	0.10425	0	0
Humpback whale	0	0	0.10479	0.09080	0	0
Kogia spp.	0	0	0	0	0	0
Pilot whales	0	0	0	0	0	0
North Atlantic right whale	0	0	0.01585	0.0026	0	0
Blainville's beaked whale	0	0	0	0	0	0
Cuvier's beaked whale	0	0	0	0	0	0
Gervais' beaked whale	0	0	0	0	0	0
True's beaked whale	0	0	0	0	0	0
Sperm whale	0	0	0	0	0	0
Atlantic spotted dolphin	0	0	0.27021	0.28610	0	0
Pantropical spotted dolphin	0	0	0.00037	0.00037	0	0
Striped dolphin	0	0	0.72494	0.72494	0	0
Common bottlenose dolphin	0	0	3.66670	4.33289	0	0

Table B-12: 3-m pinpile exposure estimates with 6 dB reduction as mitigation.

Marine Mammal Species	Behavioral Exposures		Cumulative SEL Injury Exposures		Peak SPL Injury Exposures	
	April-Nov	May-Oct	April-Nov	May-Oct	April-Nov	May-Oct
Risso's dolphin	0	0	0.00000	0.00000	0	0
Common dolphin	0	0	1.32643	1.01794	0	0
Fin whale	0	0	0.08996	0.09711	0	0
Harbor porpoise	0.33	0.07	0.00000	0.00000	0.01433	0.00284
Harbor seal	0.22	0.09	0.00000	0.00000	0	0
Killer whale	0	0	0.00009	0.00009	0	0
Rough-toothed dolphin	0	0	0.00000	0.00000	0	0
Common minke whale	0	0	0.04866	0.04687	0	0
Humpback whale	0	0	0.04711	0.04082	0	0
Kogia spp.	0	0	0.00000	0.00000	0	0
Pilot whales	0	0	0.00000	0.00000	0	0
North Atlantic right whale	0	0	0.00684	0.00122	0	0
Blainville's beaked whale	0	0	0.00000	0.00000	0	0
Cuvier's beaked whale	0	0	0.00000	0.00000	0	0
Gervais' beaked whale	0	0	0.00000	0.00000	0	0
True's beaked whale	0	0	0.00000	0.00000	0	0
Sperm whale	0	0	0.00000	0.00000	0	0
Atlantic spotted dolphin	0	0	0.11029	0.11677	0	0
Pantropical spotted dolphin	0	0	0.00015	0.00015	0	0
Striped dolphin	0	0	0.29589	0.29589	0	0
Common bottlenose dolphin	0	0	0.89432	1.05680	0	0

Table B-13: 3-m pinpile exposure estimates with 9 dB reduction as mitigation.

Marine Mammal Species	Behavioral Exposures		Cumulative SEL Injury Exposures		Peak SPL Injury Exposures	
	April-Nov	May-Oct	April-Nov	May-Oct	April-Nov	May-Oct
Risso's dolphin	0	0	0	0	0	0
Common dolphin	0	0	0.31582	0.24237	0	0
Fin whale	0	0	0.01250	0.01349	0	0
Harbor porpoise	0.20	0.04	0	0	0.01433	0.00284
Harbor seal	0.12	0.05	0	0	0	0
Killer whale	0	0	0.00002	0.00002	0	0
Rough-toothed dolphin	0	0	0	0	0	0
Common minke whale	0	0	0.01688	0.01626	0	0
Humpback whale	0	0	0.01634	0.01416	0	0
Kogia spp.	0	0	0	0	0	0
Pilot whales	0	0	0	0	0	0
North Atlantic right whale	0	0	0.00270	0.00039	0	0
Blainville's beaked whale	0	0	0	0	0	0
Cuvier's beaked whale	0	0	0	0	0	0
Gervais' beaked whale	0	0	0	0	0	0
True's beaked whale	0	0	0	0	0	0
Sperm whale	0	0	0	0	0	0
Atlantic spotted dolphin	0	0	0.02206	0.02335	0	0
Pantropical spotted dolphin	0	0	0.00003	0.00003	0	0
Striped dolphin	0	0	0.05918	0.05918	0	0
Common bottlenose dolphin	0	0	0.26829	0.31704	0	0

Table B-14: 3-m pinpile exposure estimates with 12 dB reduction as mitigation.

Marine Mammal Species	***Behavioral Exposures***		***Cumulative SEL Injury Exposures***		***Peak SPL Injury Exposures***	
	April-Nov	***May-Oct***	***April-Nov***	***May-Oct***	***April-Nov***	***May-Oct***
Risso's dolphin	0	0	0.00000	0.00000	0	0
Common dolphin	0	0	0.00000	0.00000	0	0
Fin whale	0	0	0.00250	0.00270	0	0
Harbor porpoise	0.11	0.02	0.00000	0.00000	0.00478	0.00095
Harbor seal	0.06	0.02	0.00000	0.00000	0	0
Killer whale	0	0	0.00000	0.00000	0	0
Rough-toothed dolphin	0	0	0.00000	0.00000	0	0
Common minke whale	0	0	0.00298	0.00287	0	0
Humpback whale	0	0	0.00288	0.00250	0	0
Kogia spp.	0	0	0.00000	0.00000	0	0
Pilot whales	0	0	0.00000	0.00000	0	0
North Atlantic right whale	0	0	0.00144	0.00026	0	0
Blainville's beaked whale	0	0	0.00000	0.00000	0	0
Cuvier's beaked whale	0	0	0.00000	0.00000	0	0
Gervais' beaked whale	0	0	0.00000	0.00000	0	0
True's beaked whale	0	0	0.00000	0.00000	0	0
Sperm whale	0	0	0.00000	0.00000	0	0
Atlantic spotted dolphin	0	0	0.00000	0.00000	0	0
Pantropical spotted dolphin	0	0	0.00000	0.00000	0	0
Striped dolphin	0	0	0.00000	0.00000	0	0
Common bottlenose dolphin	0	0	0.00000	0.00000	0	0

Table B-15: 3-m pinpile exposure estimates with 15 dB reduction as mitigation.

Marine Mammal Species	Behavioral Exposures		Cumulative SEL Injury Exposures		Peak SPL Injury Exposures	
	April-Nov	May-Oct	April-Nov	May-Oct	April-Nov	May-Oct
Risso's dolphin	0	0	0	0	0	0
Common dolphin	0	0	0	0	0	0
Fin whale	0	0	0	0	0	0
Harbor porpoise	0.06	0.01	0	0	0	0
Harbor seal	0.03	0.01	0	0	0	0
Killer whale	0	0	0	0	0	0
Rough-toothed dolphin	0	0	0	0	0	0
Common minke whale	0	0	0	0	0	0
Humpback whale	0	0	0	0	0	0
Kogia spp.	0	0	0	0	0	0
Pilot whales	0	0	0	0	0	0
North Atlantic right whale	0	0	0.00072	0.00013	0	0
Blainville's beaked whale	0	0	0	0	0	0
Cuvier's beaked whale	0	0	0	0	0	0
Gervais' beaked whale	0	0	0	0	0	0
True's beaked whale	0	0	0	0	0	0
Sperm whale	0	0	0	0	0	0
Atlantic spotted dolphin	0	0	0	0	0	0
Pantropical spotted dolphin	0	0	0	0	0	0
Striped dolphin	0	0	0	0	0	0
Common bottlenose dolphin	0	0	0	0	0	0

Table B-16: 3-m pinpile exposure estimates with 18 dB reduction as mitigation.

Marine Mammal Species	Behavioral Exposures		Cumulative SEL Injury Exposures		Peak SPL Injury Exposures	
	April-Nov	May-Oct	April-Nov	May-Oct	April-Nov	May-Oct
Risso's dolphin	0	0	0	0	0	0
Common dolphin	0	0	0	0	0	0
Fin whale	0	0	0	0	0	0
Harbor porpoise	0.05	0.01	0	0	0	0
Harbor seal	0.01	0.01	0	0	0	0
Killer whale	0	0	0	0	0	0
Rough-toothed dolphin	0	0	0	0	0	0
Common minke whale	0	0	0	0	0	0
Humpback whale	0	0	0	0	0	0
Kogia spp.	0	0	0	0	0	0
Pilot whales	0	0	0	0	0	0
North Atlantic right whale	0	0	0.00036	0.00010	0	0
Blainville's beaked whale	0	0	0	0	0	0
Cuvier's beaked whale	0	0	0	0	0	0
Gervais' beaked whale	0	0	0	0	0	0
True's beaked whale	0	0	0	0	0	0
Sperm whale	0	0	0	0	0	0
Atlantic spotted dolphin	0	0	0	0	0	0
Pantropical spotted dolphin	0	0	0	0	0	0
Striped dolphin	0	0	0	0	0	0
Common bottlenose dolphin	0	0	0	0	0	0

Table B-17: 3-m pinpile exposure estimates with 20 dB reduction as mitigation.

Marine Mammal Species	***Behavioral Exposures***		***Cumulative SEL Injury Exposures***		***Peak SPL Injury Exposures***	
	April-Nov	***May-Oct***	***April-Nov***	***May-Oct***	***April-Nov***	***May-Oct***
Risso's dolphin	0	0	0	0	0	0
Common dolphin	0	0	0	0	0	0
Fin whale	0	0	0	0	0	0
Harbor porpoise	0.04	0.01	0	0	0	0
Harbor seal	0.01	0.00	0	0	0	0
Killer whale	0	0	0	0	0	0
Rough-toothed dolphin	0	0	0	0	0	0
Common minke whale	0	0	0	0	0	0
Humpback whale	0	0	0	0	0	0
Kogia spp.	0	0	0	0	0	0
Pilot whales	0	0	0	0	0	0
North Atlantic right whale	0	0	0	0	0	0
Blainville's beaked whale	0	0	0	0	0	0
Cuvier's beaked whale	0	0	0	0	0	0
Gervais' beaked whale	0	0	0	0	0	0
True's beaked whale	0	0	0	0	0	0
Sperm whale	0	0	0	0	0	0
Atlantic spotted dolphin	0	0	0	0	0	0
Pantropical spotted dolphin	0	0	0	0	0	0
Striped dolphin	0	0	0	0	0	0
Common bottlenose dolphin	0.18	0.21	0	0	0	0

APPENDIX C: MARINE SPECIES' RANGES TO REGULATORY ISOPLETHS FOR VARIOUS MITIGATION SCENARIOS

Table C-1. 11-m monopile predicted ranges (m) to regulatory isopleths with no mitigation applied.

Marine Mammal Hearing Group	*Impulsive Signals—Injury*		*NMFS Behavioral Threshold (dB re 1µPa^2, flat)*
	SEL (dB re 1µPa^2-s, 24 hr)	*Peak SPL (dB re 1µPa^2, flat)*	
Low-frequency (LF) cetaceans	10,700	100	16,800
Mid-frequency (MF) cetaceans	<50	<50	
High-frequency (HF) cetaceans	350	700	
Phocid pinnipeds underwater	800	100	

Group	*Behavioral Threshold (L_{rms} dB re 1µPa^2, flat)*
Fishes (< 2g)	36,700
Fishes (> 2g)	
Sea Turtles	3,500

Fish Group	*Injury*		*TTS*
	SEL (dB re 1µPa^2-s, flat) (Unweighted)	*Peak SPL (dB re 1µPa^2, flat) (Unweighted)*	*SEL (dB re 1µPa^2-s) (Unweighted)*
Fishes without swim bladders	300	200	14,700
Fishes with swim bladder not involved in hearing	2,300	400	14,700
Fishes with swim bladder involved in hearing	2,300	400	14,700
Fishes (> 2g)	13,300	450	--
Fishes (< 2g)	19,400	450	--
Group	*Injury*		*TTS*
	SEL (dB re 1µPa^2-s) (Weighted)	*Peak (dB re 1µPa^2) (Unweighted)*	*SEL (dB re 1µPa^2-s) (Weighted)*
Sea turtles	1,600	<50	9,750

Table C-2. 11-m monopile predicted ranges to regulatory isopleths with 6 dB reduction as mitigation.

Marine Mammal Hearing Group	***Impulsive Signals—Injury***		***NMFS Behavioral Threshold (dB re 1μPa^2, flat)***
	SEL (dB re 1μPa^2-s, 24 hr)	***Peak SPL (dB re 1μPa^2, flat)***	
Low-frequency (LF) cetaceans	5,400	<50	9,100
Mid-frequency (MF) cetaceans	<50	<50	
High-frequency (HF) cetaceans	150	350	
Phocid pinnipeds underwater	250	<50	

Group	***Behavioral Threshold (L_{rms} dB re 1μPa^2, flat)***
Fishes (<2g)	23,750
Fishes (>2g)	
Sea Turtles	1,650

Fish Group	***Injury***		***TTS***
	SEL (dB re 1μPa^2-s, flat) (Unweighted)	***Peak SPL (dB re 1μPa^2, flat) (Unweighted)***	***SEL (dB re 1μPa^2-s) (Unweighted)***
Fishes without swim bladders	100	100	7,950
Fishes with swim bladder not involved in hearing	1,050	200	7,950
Fishes with swim bladder involved in hearing	1,050	200	7,950
Fishes (>2g)	7,300	200	--
Fishes (<2g)	10,800	200	--
Group	***Injury***		***TTS***
	SEL (dB re 1μPa^2-s) (Weighted)	***Peak (dB re 1μPa^2) (Unweighted)***	***SEL (dB re 1μPa^2-s) (Weighted)***
Sea Turtles	600	<50	5,050

Table C-3. 11-m monopile predicted ranges to regulatory isopleths with 9 dB reduction as mitigation.

Marine Mammal Hearing Group	***Impulsive Signals—Injury***		***NMFS Behavioral Threshold (dB re 1µPa^2, flat)***
	SEL (dB re 1µPa^2-s, 24 hr)	***Peak SPL (dB re 1µPa^2, flat)***	
Low-frequency (LF) cetaceans	3,800	<50	6,850
Mid-frequency (MF) cetaceans	<50	<50	
High-frequency (HF) cetaceans	150	200	
Phocid pinnipeds underwater	150	<50	

Group	***Behavioral Threshold (L_{rms} dB re 1µPa^2, flat)***
Fishes (<2g)	18,400
Fishes (>2g)	
Sea Turtles	1,100

Fish Group	***Injury***		***TTS***
	SEL (dB re 1µPa^2-s, flat) (Unweighted)	***Peak SPL (dB re 1µPa^2, flat) (Unweighted)***	***SEL (dB re 1µPa^2-s) (Unweighted)***
Fishes without swim bladders	50	50	5,800
Fishes with swim bladder not involved in hearing	650	100	5,800
Fishes with swim bladder involved in hearing	650	100	5,800
Fishes (>2g)	5,200	150	--
Fishes (<2g)	7,950	150	--
Group	***Injury***		***TTS***
	SEL (dB re 1µPa^2-s) (Weighted)	***Peak (dB re 1µPa^2) (Unweighted)***	***SEL (dB re 1µPa^2-s) (Weighted)***
Sea Turtles	350	<50	3,600

Table C-4. 11-m monopile predicted ranges to regulatory isopleths with 12 dB reduction as mitigation.

Marine Mammal Hearing Group	***Impulsive Signals—Injury***		***NMFS Behavioral Threshold (dB re 1μPa², flat)***
	SEL (dB re 1μPa²-s, 24 hr)	***Peak SPL (dB re 1μPa², flat)***	
Low-frequency (LF) cetaceans	2,550	<50	4,850
Mid-frequency (MF) cetaceans	<50	<50	
High-frequency (HF) cetaceans	100	150	
Phocid pinnipeds underwater	50	<50	

Group	***Behavioral Threshold (L_{rms} dB re 1μPa², flat)***
Fishes (<2g)	13,850
Fishes (>2g)	
Sea Turtles	700

Fish Group	***Injury***		***TTS***
	SEL (dB re 1μPa²-s, flat) (Unweighted)	***Peak SPL (dB re 1μPa², flat (Unweighted))***	***SEL (dB re 1μPa²-s) (Unweighted)***
Fishes without swim bladders	<50	<50	4,150
Fishes with swim bladder not involved in hearing	400	100	4,150
Fishes with swim bladder involved in hearing	400	100	4,150
Fishes (>2g)	3,700	100	--
Fishes (<2g)	5,800	100	--
Group	***Injury***		***TTS***
	SEL (dB re 1μPa²-s) (Weighted)	***Peak (dB re 1μPa²) (Unweighted)***	***SEL (dB re 1μPa²-s) (Weighted)***
Sea Turtles	200	<50	2450

Table C-5. 11-m monopile predicted ranges to regulatory isopleths with 15 dB reduction as mitigation.

Marine Mammal Hearing Group	***Impulsive Signals—Injury***		***NMFS Behavioral Threshold (dB re 1µPa^2, flat)***
	SEL (dB re 1µPa^2-s, 24 hr)	***Peak SPL (dB re 1µPa^2, flat)***	
Low-frequency (LF) cetaceans	1,650	<50	3,500
Mid-frequency (MF) cetaceans	<50	<50	
High-frequency (HF) cetaceans	50	100	
Phocid pinnipeds underwater	50	<50	

Group	***Behavioral Threshold (L_{rms} dB re 1µPa^2, flat)***
Fishes (<2g)	10,150
Fishes (>2g)	
Sea Turtles	400

Fish Group	***Injury***		***TTS***
	SEL (dB re 1µPa^2-s, flat) (Unweighted)	***Peak SPL (dB re 1µPa^2, flat (Unweighted))***	***SEL (dB re 1µPa^2-s) (Unweighted)***
Fishes without swim bladders	<50	<50	3,000
Fishes with swim bladder not involved in hearing	200	50	3,000
Fishes with swim bladder involved in hearing	200	50	3,000
Fishes (>2g)	2,650	50	--
Fishes (<2g)	4,150	50	--
Group	***Injury***		***TTS***
	SEL (dB re 1µPa^2-s) (Weighted)	***Peak (dB re 1µPa^2) (Unweighted)***	***SEL (dB re 1µPa^2-s) (Weighted)***
Sea Turtles	100	<50	1,600

Table C-6. 11-m monopile predicted ranges to regulatory isopleths with 18 dB reduction as mitigation.

Marine Mammal Hearing Group	***Impulsive Signals—Injury***		***NMFS Behavioral Threshold (dB re 1µPa^2, flat)***
	SEL (dB re 1µPa^2-s, 24 hr)	***Peak SPL (dB re 1µPa^2, flat)***	
Low-frequency (LF) cetaceans	1,050	<50	2,450
Mid-frequency (MF) cetaceans	<50	<50	
High-frequency (HF) cetaceans	50	50	
Phocid pinnipeds underwater	<50	<50	

Group	***Behavioral Threshold (L_{rms} dB re 1µPa^2, flat)***
Fishes (<2g)	7,550
Fishes (>2g)	
Sea Turtles	250

Fish Group	***Injury***		***TTS***
	SEL (dB re 1µPa^2-s, flat) (Unweighted)	***Peak SPL (dB re 1µPa^2, flat (Unweighted))***	***SEL (dB re 1µPa^2-s) (Unweighted)***
Fishes without swim bladders	<50	<50	2,050
Fishes with swim bladder not involved in hearing	150	<50	2,050
Fishes with swim bladder involved in hearing	150	<50	2,050
Fishes (>2g)	1,800	<50	--
Fishes (<2g)	3,000	<50	--
Group	***Injury***		***TTS***
	SEL (dB re 1µPa^2-s) (Weighted)	***Peak (dB re 1µPa^2) (Unweighted)***	***SEL (dB re 1µPa^2-s) (Weighted)***
Sea Turtles	50	<50	1,000

Table C-7. 11-m monopile predicted ranges to regulatory isopleths with 20 dB reduction as mitigation.

Marine Mammal Hearing Group	***Impulsive Signals—Injury***		***NMFS Behavioral Threshold (dB re 1μPa², flat)***
	SEL (dB re 1μPa²-s, 24 hr)	***Peak SPL (dB re 1μPa², flat)***	
Low-frequency (LF) cetaceans	750	<50	1,900
Mid-frequency (MF) cetaceans	<50	<50	
High-frequency (HF) cetaceans	<50	50	
Phocid pinnipeds underwater	<50	<50	

Group	***Behavioral Threshold (L_{rms} dB re 1μPa², flat)***
Fishes (<2g)	6,100
Fishes (>2g)	
Sea Turtles	150

Fish Group	***Injury***		***TTS***
	SEL (dB re 1μPa²-s, flat) (Unweighted)	***Peak SPL (dB re 1μPa², flat (Unweighted))***	***SEL (dB re 1μPa²-s) (Unweighted)***
Fishes without swim bladders	<50	<50	1,550
Fishes with swim bladder not involved in hearing	100	<50	1,550
Fishes with swim bladder involved in hearing	100	<50	1,550
Fishes (> 2g)	1,350	<50	--
Fishes (< 2g)	2,300	<50	--
Group	***Injury***		***TTS***
	SEL (dB re 1μPa²-s) (Weighted)	***Peak (dB re 1μPa²) (Unweighted)***	***SEL (dB re 1μPa²-s) (Weighted)***
Sea Turtles	<50	<50	700

Table C-8. 3-m monopile predicted ranges to regulatory isopleths with no mitigation applied.

Marine Mammal Hearing Group	Impulsive Signals—Injury			NMFS Behavioral Threshold (dB re 1µPa^2, flat)
	Peak SPL (dB re 1µPa^2, flat)	SEL (dB re 1µPa^2-s, 24 hr)		
		1 Pin Pile	2 Pin Piles	
Low-frequency (LF) cetaceans	50	7,950	10,950	6,550
Mid-frequency (MF) cetaceans	<50	<50	<50	
High-frequency (HF) cetaceans	450	1,250	1,700	
Phocid pinnipeds underwater	50	900	1,550	

Group	Behavioral Threshold (L_{rms} dB re 1µPa^2, flat)
Fishes (<2g)	21,450
Fishes (>2g)	
Sea Turtles	800

Fish Group	Injury			TTS	
	Peak SPL (dB re 1µPa^2, flat (Unweighted)	SEL (dB re 1µPa^2-s, 24 hr) (Unweighted)		SEL (dB re 1µPa^2-s) (Unweighted)	
		1 Pin Pile	2 Pin Piles	1 Pin Pile	2 Pin Piles
Fishes without swim bladders	100	50	100	8,000	10,950
Fishes with swim bladder not involved in hearing	250	700	1,100	8,000	10,950
Fishes with swim bladder involved in hearing	250	700	1,100	8,000	10,950
Fishes (>2g)	300	7,200	9,550	--	--
Fishes (<2g)	300	11,600	15,700	--	--
Group	**Injury**			**TTS**	
	Peak (dB re 1µPa^2) (Unweighted)	**SEL (dB re 1µPa^2-s, 24 hr) (Weighted)**		**SEL (dB re 1µPa^2-s) (Weighted)**	
		1 Pin Pile	**2 Pin Piles**	**1 Pin Pile**	**2 Pin Piles**
Sea Turtles	<50	600	850	5,050	7,050

Table C-9. 3-m monopile predicted ranges to regulatory isopleths with 6 dB reduction as mitigation.

Marine Mammal Hearing Group	Impulsive Signals—Injury			NMFS Behavioral Threshold (dB re 1µPa², flat)
	Peak SPL (dB re 1µPa², flat)	SEL (dB re 1µPa²-s, 24 hr)		
		1 Pin Pile	2 Pin Piles	
Low-frequency (LF) cetaceans	<50	3,700	5,050	3,100
Mid-frequency (MF) cetaceans	<50	<50	<50	
High-frequency (HF) cetaceans	200	700	800	
Phocid pinnipeds underwater	<50	300	450	

Group	Behavioral Threshold (L_{rms} dB re 1µPa², flat)
Fishes (<2g)	10,550
Fishes (>2g)	
Sea Turtles	250

Fish Group	Injury			TTS	
	Peak SPL (dB re 1µPa², flat (Unweighted)	SEL (dB re 1µPa²-s, 24 hr) (Unweighted)		SEL (dB re 1µPa²-s) (Unweighted)	
		1 Pin Pile	2 Pin Piles	1 Pin Pile	2 Pin Piles
Fishes without swim bladders	50	<50	<50	3,800	5,200
Fishes with swim bladder not involved in hearing	100	250	350	3,800	5,200
Fishes with swim bladder involved in hearing	100	250	350	3,800	5,200
Fishes (>2g)	150	3,400	4,550	--	--
Fishes (<2g)	150	5,550	7,600	--	--
Group	**Injury**			**TTS**	
	Peak (dB re 1µPa²) (Unweighted)	**SEL (dB re 1µPa²-s, 24 hr) (Weighted)**		**SEL (dB re 1µPa²-s) (Weighted)**	
		1 Pin Pile	**2 Pin Piles**	**1 Pin Pile**	**2 Pin Piles**
Sea Turtles	<50	200	300	2,300	3,400

Table C-10. 3m Monopile Predicted Ranges to regulatory isopleths with 9 dB reduction as mitigation.

Marine Mammal Hearing Group	Impulsive Signals—Injury			NMFS Behavioral Threshold (dB re 1μPa², flat)
	Peak SPL (dB re 1μPa², flat)	SEL (dB re 1μPa²-s, 24 hr)		
		1 Pin Pile	2 Pin Piles	
Low-frequency (LF) cetaceans	<50	2,350	3,500	2,000
Mid-frequency (MF) cetaceans	<50	<50	<50	
High-frequency (HF) cetaceans	150	200	300	
Phocid pinnipeds underwater	<50	150	250	

Group	Behavioral Threshold (L_{rms} dB re 1μPa², flat)
Fishes (<2g)	7,400
Fishes (>2g)	
Sea Turtles	150

Fish Group	Injury			TTS	
	Peak SPL (dB re 1μPa², flat (Unweighted	SEL (dB re 1μPa²-s, 24 hr) (Unweighted)		SEL (dB re 1μPa²-s) (Unweighted)	
		1 Pin Pile	2 Pin Piles	1 Pin Pile	2 Pin Piles
Fishes without swim bladders	<50	<50	<50	2,450	3,650
Fishes with swim bladder not involved in hearing	100	150	250	2,450	3,650
Fishes with swim bladder involved in hearing	100	150	250	2,450	3,650
Fishes (>2g)	100	2,200	3,200	--	--
Fishes (<2g)	100	3,800	5,200	--	--
Group	**Injury**			**TTS**	
	Peak (dB re 1μPa²) (Unweighted	**SEL (dB re 1μPa²-s, 24 hr) (Weighted)**		**SEL (dB re 1μPa²-s) (Weighted)**	
		1 Pin Pile	**2 Pin Piles**	**1 Pin Pile**	**2 Pin Piles**
Sea Turtles	<50	100	150	1,650	2,200

Table C-11. 3-m monopile predicted ranges to regulatory isopleths with 12 dB reduction as mitigation.

Marine Mammal Hearing Group	Impulsive Signals—Injury			NMFS Behavioral Threshold (dB re 1μPa^2, flat)
	Peak SPL (dB re 1μPa^2, flat)	SEL (dB re 1μPa^2-s, 24 hr)		
		1 Pin Pile	2 Pin Piles	
Low-frequency (LF) cetaceans	<50	1,600	2,250	1,350
Mid-frequency (MF) cetaceans	<50	<50	< 50	
High-frequency (HF) cetaceans	100	100	150	
Phocid pinnipeds underwater	<50	100	150	

Group	Behavioral Threshold (L_{rms} dB re 1μPa^2, flat)
Fishes (<2g)	5,000
Fishes (>2g)	
Sea Turtles	100

Fish Group	Injury			TTS	
	Peak SPL (dB re 1μPa^2, flat (Unweighted	SEL (dB re 1μPa^2-s, 24 hr) (Unweighted)		SEL (dB re 1μPa^2-s) (Unweighted)	
		1 Pin Pile	2 Pin Piles	1 Pin Pile	2 Pin Piles
Fishes without swim bladders	<50	<50	<50	1,700	2,350
Fishes with swim bladder not involved in hearing	50	100	150	1,700	2,350
Fishes with swim bladder involved in hearing	50	100	150	1,700	2,350
Fishes (>2g)	50	1,500	2,100	--	--
Fishes (<2g)	50	2,450	3,650	--	--
Group	**Injury**			**TTS**	
	Peak (dB re 1μPa^2) (Unweighted	**SEL (dB re 1μPa^2-s, 24 hr) (Weighted))**		**SEL (dB re 1μPa^2-s) (Weighted)**	
		1 Pin Pile	**2 Pin Piles**	**1 Pin Pile**	**2 Pin Piles**
Sea Turtles	<50	50	100	900	1,550

Table C-12. 3-m monopile predicted ranges to regulatory isopleths with 15 dB reduction as mitigation.

Marine Mammal Hearing Group	Impulsive Signals—Injury			NMFS Behavioral Threshold (dB re 1μPa², flat)
	Peak SPL (dB re 1μPa², flat)	SEL (dB re 1μPa²-s, 24 hr)		
		1 Pin Pile	2 Pin Piles	
Low-frequency (LF) cetaceans	<50	950	1,500	800
Mid-frequency (MF) cetaceans	<50	<50	<50	
High-frequency (HF) cetaceans	50	50	100	
Phocid pinnipeds underwater	<50	50	100	

Group	Behavioral Threshold (L_{rms} dB re 1μPa², flat)
Fishes (<2g)	3,550
Fishes (>2g)	
Sea Turtles	50

Fish Group	Injury			TTS	
	Peak SPL (dB re 1μPa², flat (Unweighted	SEL (dB re 1μPa²-s, 24 hr) (Unweighted)		SEL (dB re 1μPa²-s) (Unweighted)	
		1 Pin Pile	2 Pin Piles	1 Pin Pile	2 Pin Piles
Fishes without swim bladders	<50	<50	<50	1,050	1,650
Fishes with swim bladder not involved in hearing	<50	50	100	1,050	1,650
Fishes with swim bladder involved in hearing	<50	50	100	1,050	1,650
Fishes (>2g)	<50	850	1,400	--	--
Fishes (<2g)	<50	1,700	2,350	--	--
Group	**Injury**			**TTS**	
	Peak (dB re 1μPa²) (Unweighted	**SEL (dB re 1μPa²-s, 24 hr) (Weighted)**		**SEL (dB re 1μPa²-s) (Weighted)**	
		1 Pin Pile	**2 Pin Piles**	**1 Pin Pile**	**2 Pin Piles**
Sea Turtles	<50	<50	50	600	850

Table C-13. 3-m monopile predicted ranges to regulatory isopleths with 18 dB reduction as mitigation.

Marine Mammal Hearing Group	Impulsive Signals—Injury			NMFS Behavioral Threshold (dB re 1µPa^2, flat)
	Peak SPL (dB re 1µPa2, flat)	SEL (dB re 1µPa^2-s, 24 hr)		
		1 Pin Pile	2 Pin Piles	
Low-frequency (LF) cetaceans	<50	600	850	450
Mid-frequency (MF) cetaceans	<50	<50	<50	
High-frequency (HF) cetaceans	50	50	50	
Phocid pinnipeds underwater	<50	<50	50	

Group	Behavioral Threshold (L_{rms} dB re 1µPa^2, flat)
Fishes (<2g)	2,250
Fishes (>2g)	
Sea Turtles	<50

Fish Group	Injury			TTS	
	Peak SPL (dB re 1µPa^2, flat (Unweighted)	SEL (dB re 1µPa^2-s, 24 hr) (Unweighted)		SEL (dB re 1µPa^2-s) (Unweighted)	
		1 Pin Pile	2 Pin Piles	1 Pin Pile	2 Pin Piles
Fishes without swim bladders	<50	<50	<50	600	950
Fishes with swim bladder not involved in hearing	<50	<50	<50	600	950
Fishes with swim bladder involved in hearing	<50	<50	<50	600	950
Fishes (>2g)	<50	550	800	--	--
Fishes (<2g)	<50	1,050	1,650	--	--

Group	Injury			TTS	
	Peak (dB re 1µPa^2) (Unweighted	SEL (dB re 1µPa^2-s, 24 hr) (Weighted)		SEL (dB re 1µPa^2-s) (Weighted)	
		1 Pin Pile	2 Pin Piles	1 Pin Pile	2 Pin Piles
Sea Turtles	<50	<50	<50	300	550

Table C-14. 3-m monopile predicted ranges to regulatory isopleths with 20 dB reduction as mitigation.

Marine Mammal Hearing Group	Impulsive Signals—Injury			NMFS Behavioral Threshold (dB re 1μPa^2, flat)
	Peak SPL (dB re 1μPa2, flat)	SEL (dB re 1μPa^2-s, 24 hr)		
		1 Pin Pile	2 Pin Piles	
Low-frequency (LF) cetaceans	<50	350	600	300
Mid-frequency (MF) cetaceans	<50	<50	<50	
High-frequency (HF) cetaceans	200	50	50	
Phocid pinnipeds underwater	<50	<50	50	

Group	Behavioral Threshold (L_{rms} dB re 1μPa^2, flat)
Fishes (<2g)	1,800
Fishes (>2g)	
Sea Turtles	<50

Fish Group	Injury			TTS	
	Peak SPL (dB re 1μPa^2, flat (Unweighted	SEL (dB re 1μPa^2-s, 24 hr) (Unweighted)		SEL (dB re 1μPa^2-s) (Unweighted)	
		1 Pin Pile	2 Pin Piles	1 Pin Pile	2 Pin Piles
Fishes without swim bladders	<50	<50	<50	450	700
Fishes with swim bladder not involved in hearing	< 0	<50	<50	450	700
Fishes with swim bladder involved in hearing	<50	<50	<50	450	700
Fishes (>2g)	<50	300	600	--	--
Fishes (<2g)	<50	700	1100	--	--
Group	**Injury**			**TTS**	
	Peak (dB re 1μPa^2) (Unweighted	**SEL (dB re 1μPa^2-s, 24 hr) (Weighted)**		**SEL (dB re 1μPa^2-s) (Weighted)**	
		1 Pin Pile	**2 Pin Piles**	**1 Pin Pile**	**2 Pin Piles**
Sea Turtles	<50	<50	<50	250	300