Appendix U2. Underwater Acoustic Modeling of Construction Sound and Animal Exposure Estimation

Document Revision	C
Issue Date	March 2022

MAYFLOWER WIND

Prepared for:
Mayflower Wind Energy LLC

Appendix U2. Underwater Acoustic Modeling of Construction Sound and Animal Exposure Estimation

March 2022

Technical Report

Underwater Acoustic Modeling of Construction Sound and Animal Exposure Estimation for Mayflower Wind Energy LLC

Submitted to:

AECOM
Contract: 60620428

Authors:

Samuel L. Denes
Michelle J. Weirathmueller
Elizabeth T. Küsel
Katy E. Limpert
Karlee E. Zammit
Cynthia D. Pyć

03 March 2022

P001558-001
Document 02185
Version 3.0 Revision 2

JASCO Applied Sciences (USA) Inc.
8630 Fenton Street, Suite 218
Silver Spring, MD 20910 USA
Tel: +1-301-565-3500
www.jasco.com

Suggested citation:

Denes, S.L., M.J. Weirathmueller, E.T. Küsel, K.E. Limpert, K.E. Zammit, and C.D. Pyć. 2022. *Technical Report: Underwater Acoustic Modeling of Construction Sound and Animal Exposure Estimation for Mayflower Wind Energy LLC*. Document 02185, Version 3.0 Revision 2. Technical report by JASCO Applied Sciences for AECOM.

Disclaimer:

The results presented herein are relevant within the specific context described in this report. They could be misinterpreted if not considered in the light of all the information contained in this report. Accordingly, if information from this report is used in documents released to the public or to regulatory bodies, such documents must clearly cite the original report, which shall be made readily available to the recipients in integral and unedited form.

Revision History

Revision	Revision date	Details	Authorized	Name	Position
0	02/15/2021	COP Submittal	Yes	Kristen Durocher	Deputy Project Manager (AECOM)
1	08/27/2021	Minimal edits. Revised introduction to include Brayton Point. No technical edits required.	Yes	Kristen Durocher	Deputy Project Manager (AECOM)
2	03/02/2022	Responded to February 2022 BOEM comments. Minimal edits specifying number of OSPs and pin piles.	Yes	Kristen Durocher	Deputy Project Manager (AECOM)

Contents

Figures

Tables

Acronyms and Abbreviations

AMAPPS	Atlantic Marine Assessment Program for Protected Species
ANSI	American National Standards Institute
BOEM	Bureau of Ocean Energy Management
CalTrans	California Department of Transportation
COP	Construction and Operations Plan
CPA	closest point of approach
dB	decibels
DoC	Department of Commerce (US)
DoN	Department of the Navy (US)
DP	dynamic positioning
DPS	Distinct Population Segment
ECC	export cable corridor
EEZ	Exclusive Economic Zone
EGM	Earth Gravitational Model
ESA	Endangered Species Act
FD	finite difference
FHWG	Fisheries Hydroacoustic Working Group
ft	feet
FWRAM	Full Wave Range Dependent Acoustic Model
GARFO	Greater Atlantic Regional Fisheries Office
GDEM	Generalized Digital Environmental Model
h	hour
HF	high frequency (cetacean hearing group)
HVDC	High-voltage direct-current
HSD	HydroSound Dampers
Hz	Hertz
in	inch
ISO	International Organization for Standardization
JASMINE	JASCO Animal Simulation Model Including Noise Exposure
kg	kilogram
kHz	kilohertz
kJ	kilojoule
km	kilometer
LE	cumulative sound exposure level

LF	low frequency (cetacean hearing group)
Lp	sound pressure level
Lpk	peak pressure level
m	meter
MA WEA	Massachusetts Wind Energy Area
MF	mid-frequency (cetacean hearing group)
mi	mile
MMPA	Marine Mammal Protection Act
MONM	Marine Operations Noise Model
NAVO	Naval Oceanography Office (US)
NSF	National Science Foundation (US)
μPa	micro-Pascal
m/s	meters per second
MA WEA	Massachusetts Wind Energy Area
MW	megawatt
NARW	North Atlantic right whale
NAS	Noise Abatement System
NEFSC	Northeast Fisheries Science Center
NOAA	National Oceanic and Atmospheric Administration
NM	nautical mile
NMFS	National Marine Fisheries Service
NMS	Noise Mitigation System
NODE	Navy OPAREA Density Estimate
OBIS-SEAMAP	Ocean Biogeographic Information System Spatial Ecological Analysis of Megavertebrate Populations
OCS	Outer Continental Shelf
OSP	Offshore Substation Platform
PBR	Potential Biological Removal
PDF	probability distribution function
PDSM	Pile Driving Source Model
PE	parabolic equation
PK	peak pressure level
PPA	Phocid pinnipeds in air (cetacean hearing group)
PPW	Phocid pinnipeds in water (cetacean hearing group)
PSO	protected species observer
PTS	permanent threshold shift

RAM	Range-dependent Acoustic Model
SEFSC	Southeast Fisheries Science Center
SEL	sound exposure level
SERDP-SDSS	Strategic Environmental Research and Development Program Spatial Decision Support System
SL	source level
SMRU	Sea Mammal Research Unit
SRTM	Shuttle Radar Topography Mission
SPL	sound pressure level
TL	Transmission loss
TTS	temporary threshold shift
TUW	turtles in water
US	United States
USFWS	US Fish and Wildlife Service
WTG	wind turbine generator

1. Introduction

1.1. Overview of Assessed Activity

Mayflower Wind Energy LLC (Mayflower Wind) is submitting for approval to the Bureau of Ocean Energy Management (BOEM) a Construction and Operations Plan (COP) to construct, operate, and decommission offshore renewable wind energy facilities within its federal Lease Area OCS-A 0521 (referred to as the Lease Area) along with associated offshore and onshore cabling, onshore substation, high-voltage direct-current (HVDC) converter station, and onshore operations and maintenance facilities. The Lease Area is located offshore of the southern coast of Massachusetts, approximately 26 nautical miles (nm; 48 km) south of Martha's Vineyard and 20 nm (37 km) south of Nantucket. The closest wind turbine generator (WTG) position within the Lease Area to the mainland is 52 nm (96.5 km). The Lease Area is a total of 127,388 acres (BOEM 2019) in size (Figure 1).

A maximum of 147 WTGs and five offshore substation platforms (OSPs) with inter-array cables connecting the WTGs and OSPs may be installed in the Lease Area. For this report, a maximum of 146 WTGs, and up to 28 pin piles supporting three OSPs were modeled. The Mayflower Wind Project (the Project) may be constructed over one or multiple years. The foundation types under consideration within the Mayflower Wind Project Design Envelope (PDE) include monopile, piled jacket, suction-bucket jacket, or gravity-based structure (GBS).

The WTG and OSP positions have been established based on a 1 × 1 nm (1.9 × 1.9 km) grid oriented along the cardinal directions to maintain a uniform spacing of WTGs and OSPs across all the lease areas within the Massachusetts/Rhode Island Wind Energy Area. Submarine offshore export cables will be installed within offshore export cable corridors (ECCs) to carry the electricity from the OSPs within the Lease Area to the onshore transmission systems via two different ECCs. One ECC will make landfall in Falmouth, Massachusetts and the other will make landfall at Brayton Point in Somerset, Massachusetts. Up to five offshore submarine export cables will pass through Muskeget Channel and Nantucket Sound to deliver power from the OSPs to the onshore transmission system in Falmouth and up to six offshore submarine export cables will pass through the Sakonnet River and Mount Hope Bay to deliver power from the OSPs to the onshore transmission system at Brayton Point (Figure 1). The Project Area includes the WTGs, OSPs, inter-array cabling, and offshore export cabling components.

For the Project impact (impulsive) pile driving is expected to introduce the most sound to the environment and is therefore considered to be the primary sound source. Several secondary sound sources are expected to occur during construction or over the lifecycle of the Project. These may include vibratory pile driving, installation of suction and gravity-based structures, and vessel activities associated with cable-laying, dredging, and construction. Operations, maintenance, and decommissioning are also considered to be secondary sound sources. Vessels associated with any of these activities contribute non-impulsive sound to the environment via dynamic positioning (DP) thrusters and vessel propulsion. Secondary sound sources are discussed but not quantitatively modeled as part of this analysis.

For this underwater acoustic technical report, JASCO Applied Sciences (JASCO) modeled the potential underwater acoustic effects resulting from two different piling scenarios for both monopile and jacket foundations. The modeling effort assumed that piles will be installed one at a time. The realistic scenarios include the set of foundation dimensions and installation requirements that will allow for the timely development of the Project. With the preliminary engineering completed, the realistic scenarios are therefore based on the installation of either 11 m diameter monopile foundations or jacket foundations supported by three, 2.9 m diameter pin piles.

JASCO also modeled scenarios based on the potential availability of larger WTG technology. Mayflower Wind believes that this turbine technology could be commercially available in the foreseeable future and would enable greater capacity, and therefore increased clean energy production, to be installed within the Lease Area. Corresponding foundation parameters have been used to provide a preliminary basis for a set of maximum scenarios. These maximum scenarios include the installation of 16 m monopile foundations or jacket foundations supported by 4.5 m diameter pin piles. Detailed design and installation assessments will be progressed with the final wind turbine selected, which will provide refined inputs to be modeled and used as basis for the construction IHA.

The results in this report are presented as sound pressure levels (SPL), zero-to-peak pressure levels (PK), and both single-strike (i.e., per-pulse) and accumulated sound exposure levels (SEL). Section 2 details the effect criteria considered, and describes the methods used to predict sound source levels, model sound propagation, and estimation of potential exposures of marine fauna to regulatory defined threshold levels of sound. Section 2.2 describes the specifications of the impact pile driving source and all environmental parameters that were used in acoustic modeling. Section 2.6 explains the animal movement and sound exposure modeling (JASCO's Animal Simulation Model Including Noise Exposure [JASMINE]) used to determine total acoustic energy (SEL) and maximum PK and SPL received by a simulated animal (animat). Section 2.8 considers potentially affected species, and Section 3 describes the results. Additional modeling details and results can be found in the appendices.

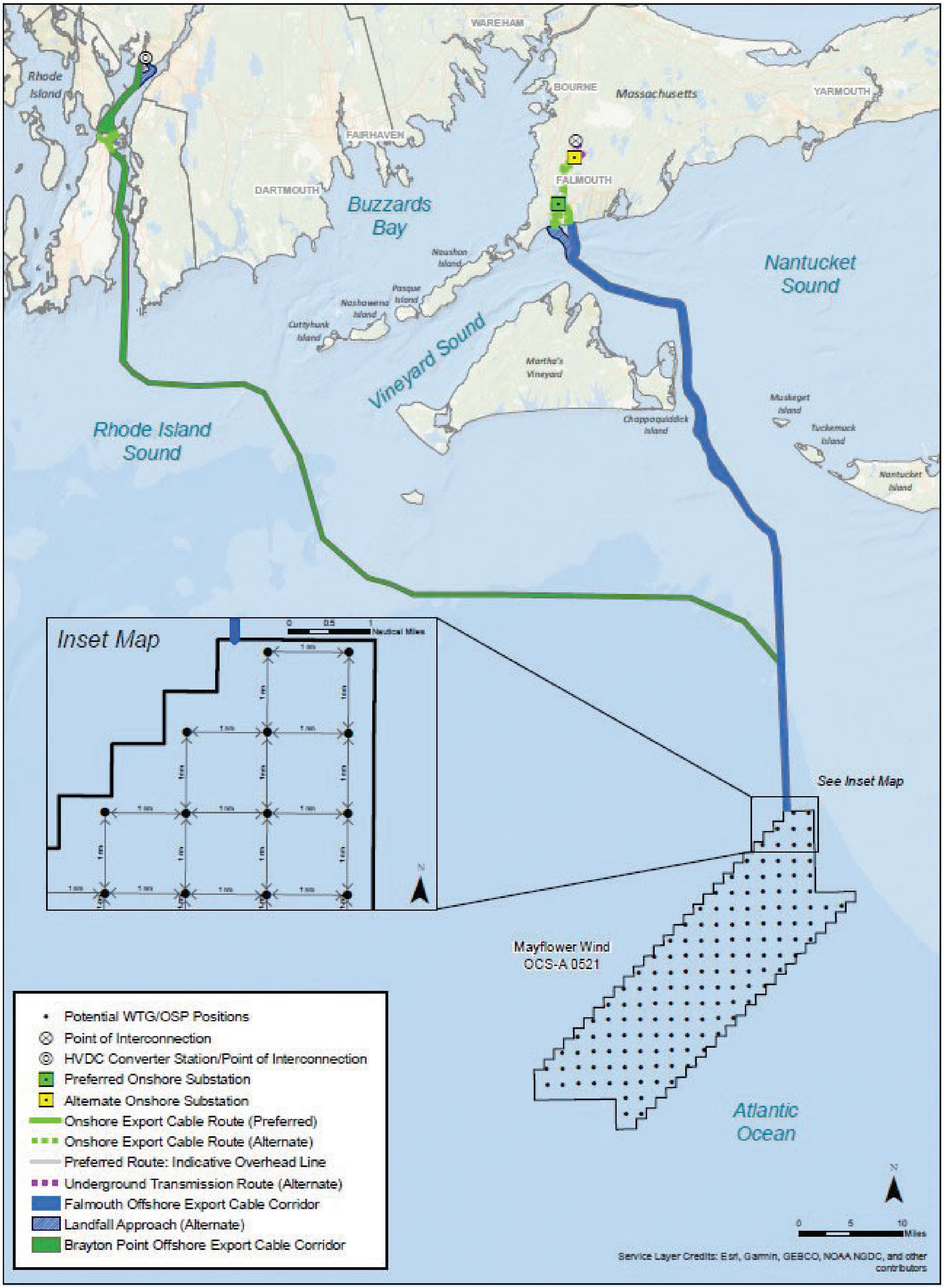

Figure 1. Proposed Project locations including Lease Area, Cable Corridors, Onshore Transmission, and Onshore Substation for the Mayflower Wind Project.

1.2. Modeling Scope and Assumptions

The primary expected source of sound during construction of the Project is from impact pile driving of monopiles and jacket foundation piles during installation in the construction phase of the Project. The objectives of this modeling study were to predict the acoustic and exposure-based radial distances to regulatory-defined acoustic thresholds associated with injury and behavioral disturbance for various marine fauna including fish, marine mammals, and sea turtles that may occur in, or near, the Lease Area during pile driving. JASCO also used the results of animal movement and exposure modeling to estimate potential exposure numbers for marine mammals and sea turtles.

1.2.1. Monopile Foundation

Monopile foundation types proposed for the Lease Area include the realistic scenario monopile with an 11 m diameter and the maximum scenario monopile with a 16 m diameter. Both monopiles are tapered near the water (example design shown in Figure 2).

The realistic and maximum monopile foundation diameters were modeled at two locations representing the variation in water depth in the Lease Area (L01 and L02; Table 3, Figure 4). The realistic and maximum scenario are modeled as being driven to a penetration depth of 35 m (115 ft). This was based on drivability studies in expected upper stiffness soil range.

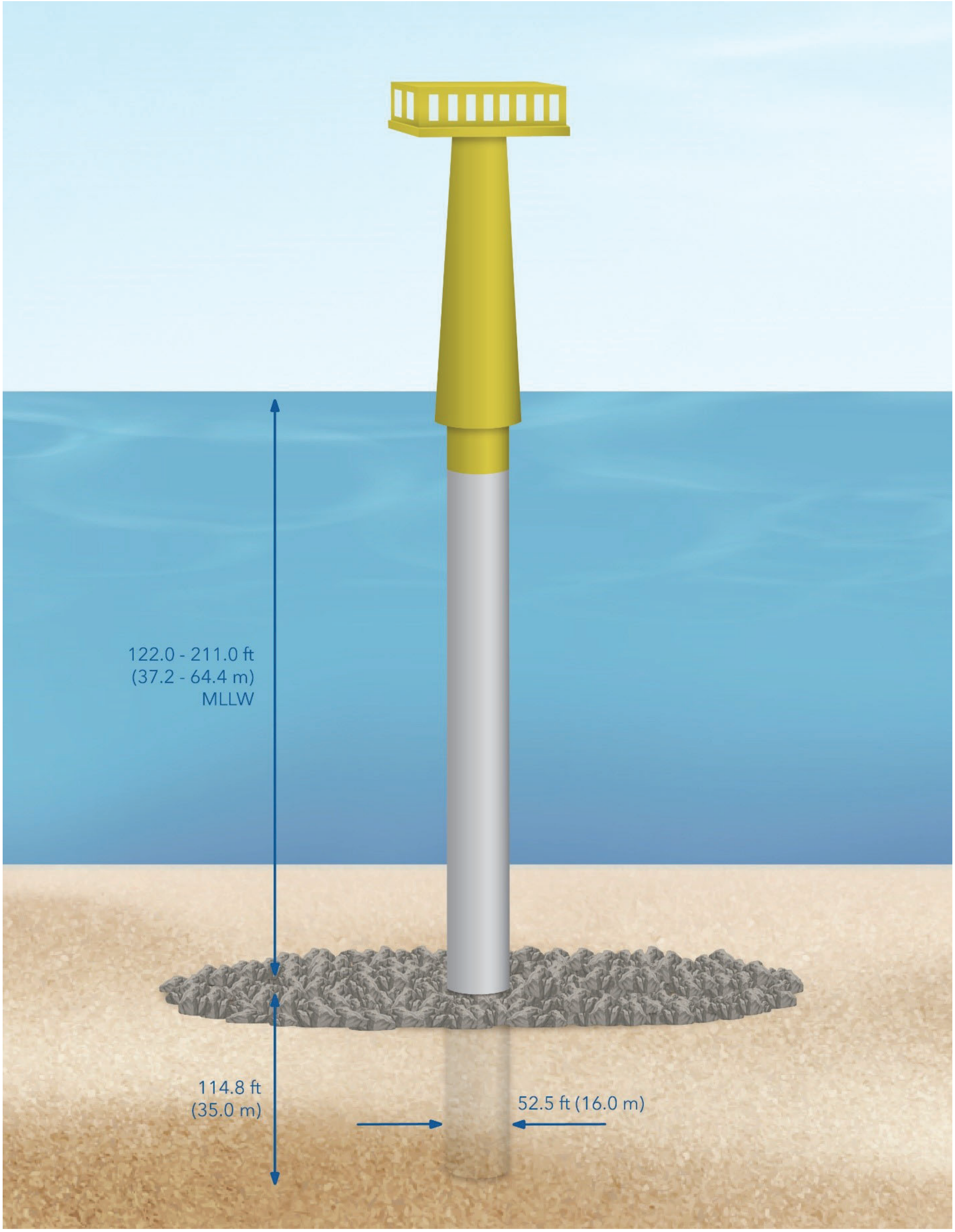

Figure 2. Schematic drawing of maximum scenario (16 m) monopile foundation.

1.2.2. Jacket Foundation

Jacket foundations of various configurations are being considered (example design shown in Figure 3). For the realistic scenario, a 3-legged WTG jacket foundation with 2.9 m diameter pin piles was modeled. For the maximum scenario, the WTG jacket foundation was 4-legged with 4.5 m diameter piles. A variety of jacket foundation configurations may be used for the OSP foundation. The modeled OSP option with the most piles was a 6-legged, twelve pile (two piles per leg) foundation. Regardless of the full number of piles used in the OSP, the maximum number of piles that were modeled for installation in one day was four. For the WTG jacket foundations, the piles will likely be driven through a template on the seafloor and the jacket structure attached to the installed piles (often referred to as pre-piling). OSP jacket foundations will most likely be post-piled, where the jacket foundation is first placed on the seafloor and the piles are driven through “sleeves” or guides mounted to the base of each leg of the jacket structure. Although OSP foundations may utilize a pre-piled installation format, the impact assessment relied on the most likely, and conservative, post-piled installation. Jacket foundations were modeled at the same representative locations in the Lease Area (L01 and L02; Figure 4). The modeled jacket foundation piles are driven to a penetration depth of 51 m (167 ft) for realistic, and 60 m (197 ft) for max case. The estimated number of strikes required to drive piles to completion were provided by Mayflower Wind (Table 1). A full list of model input parameters related to pile driving can be found in Appendix B.

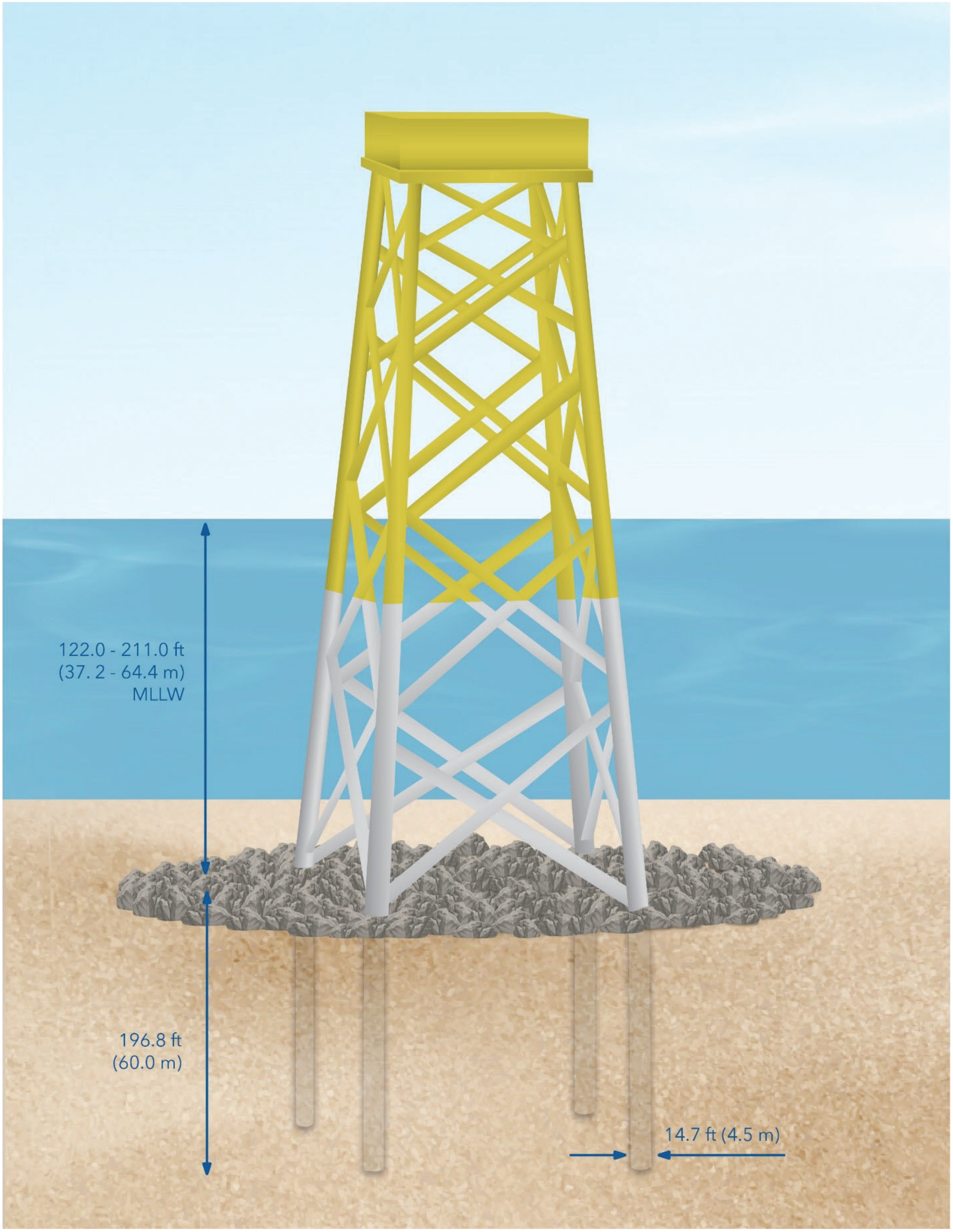

Figure 3. Schematic drawing of an example jacket foundation.

1.2.3. Modeling Inputs for Impact Pile Installation

The amount of sound generated during impact pile installation varies with the energy required to drive the piles to the desired depth, which depends on the sediment resistance encountered. Sediment types with greater resistance require hammers that deliver higher energy strikes and/or an increased number of hammer strikes relative to installations in softer sediment. Maximum sound levels from foundation installation usually occur during the last stage of impact pile driving (Betke 2008). The representative make and model of impact hammers, and the hammer energy schedule used in the acoustic modeling effort to assess various realistic and maximum scenarios were provided by Mayflower Wind and included in Tables 1 and 2, respectively. From these foundation and hammer types and energies, the Project selected two realistic and two maximum scenarios for use in exposure estimation. Acoustic modeling for all foundation types are provided in Appendix F.

Modeling details for the realistic and maximum monopile and jacket foundations scenarios are provided in Appendix B of this report. Monopile and jacket foundation piles are modeled with a vertical installation using a finite-difference structural model of pile vibration based on thin-shell theory. In some cases, hammer energies are sub-divided into discrete penetration depth ranges to account for changes in source characteristics as a function of pile penetration. For example, the 1900 kJ energy level used to drive the 2.9 m pin piles is split, with “1900a” corresponding to the 5–20 m penetration depth range and “1900b” corresponding to a 20–51 m depth range.

For both the realistic and maximum case, drivability studies were conducted in the upper bounds of anticipated stiffness across the Lease Area to conservatively present an average upper bound that was modeled across the Lease Area, however it is worth noting that individual locations may experience additional hammering to achieve final penetration.

For the realistic case, a typical ramp up of energy was applied, and each location will have a refined ramp up executed on a per-location basis, depending on the individual soil profile. For the maximum scenario, no ramp up has been modeled which is intended to demonstrate potential greater effects. As the final design is refined in preparation for the construction IHA, site specific penetrations and blow profiles will be developed that account for additional ramp up energy blows while ensuring the overall effect is within the bounds of what is presented below.

Table 1. Hammer energy schedule and number of strikes for the realistic scenario monopile and jacket foundations.

Modeled realistic scenario	Hammer model	Energy level (kJ)	Strike count	Pile penetration range (m)	Strike rate (strikes/min)
Monopile foundation	Menck MHU 4400S	1100	400	6	30
		2200	800	5	
		4400	4600	24	
		Total	**5800**	**35**	
WTG Jacket foundation	Menck MHU 1900S	475	100	2	30
		950	180	3	
		1900 a[a]	6520 (2126)	15	
		1900 b[a]	6520 (4394)	31	
		Total	**6800**	**51**	
OSP Jacket foundation	IHC S2000	2000 a[a]	2333	20	30
		2000 b[a]	2333	20	
		2000 c[a]	2334	20	
		Total	**7000**	**60**	

[a] Acoustic source characteristics were modeled at different pile penetrations using the full hammer energy to represent the maximum scenario.

Table 2. Hammer energy schedule and number of strikes for the maximum scenario monopile and jacket foundations.

Modeled maximum scenario	Hammer model	Energy level (kJ)	Strike count		Pile penetration range (m)	Strike rate (strikes/min)
Monopile foundation	Theoretical[a] 6600	6600 a[b]	2000	1790	10	30
		6600 b[b]	2000	1790	10	
		6600 c[b]	3000	2685	15	
		Total	**7000**	**6265**	**35**	
WTG/OSP Jacket foundation	Menck MHU 3500S	3500 a[b]	1333		20	30
		3500 b[b]	1333		20	
		3500 c[b]	1334		20	
		Total	**4000**		**60**	

[a] Refers to a proposed hammer.
[b] Acoustic source characteristics were modeled at three pile penetrations using the full hammer energy to represent the maximum scenario.

1.2.4. Modeling Locations

Acoustic propagation modeling was conducted for all foundation types and pile sizes at two locations (L01 and L02 in Figure 4, Table 3) in 53 and 37.6 m water depths. These two locations were chosen to represent the acoustic propagation environment within the Lease Area and may not be actual foundation locations. Water depths at the site locations were extracted from the bathymetry file provided by Shuttle Radar Topography Mission (SRTM), referred to as SRTM-TOPO15+ (Becker et al. 2009). The distribution of animal movement and exposure modeling locations was designed to provide representative spatial coverage within the Lease Area, where each modeled site is located at the position of a planned foundation.

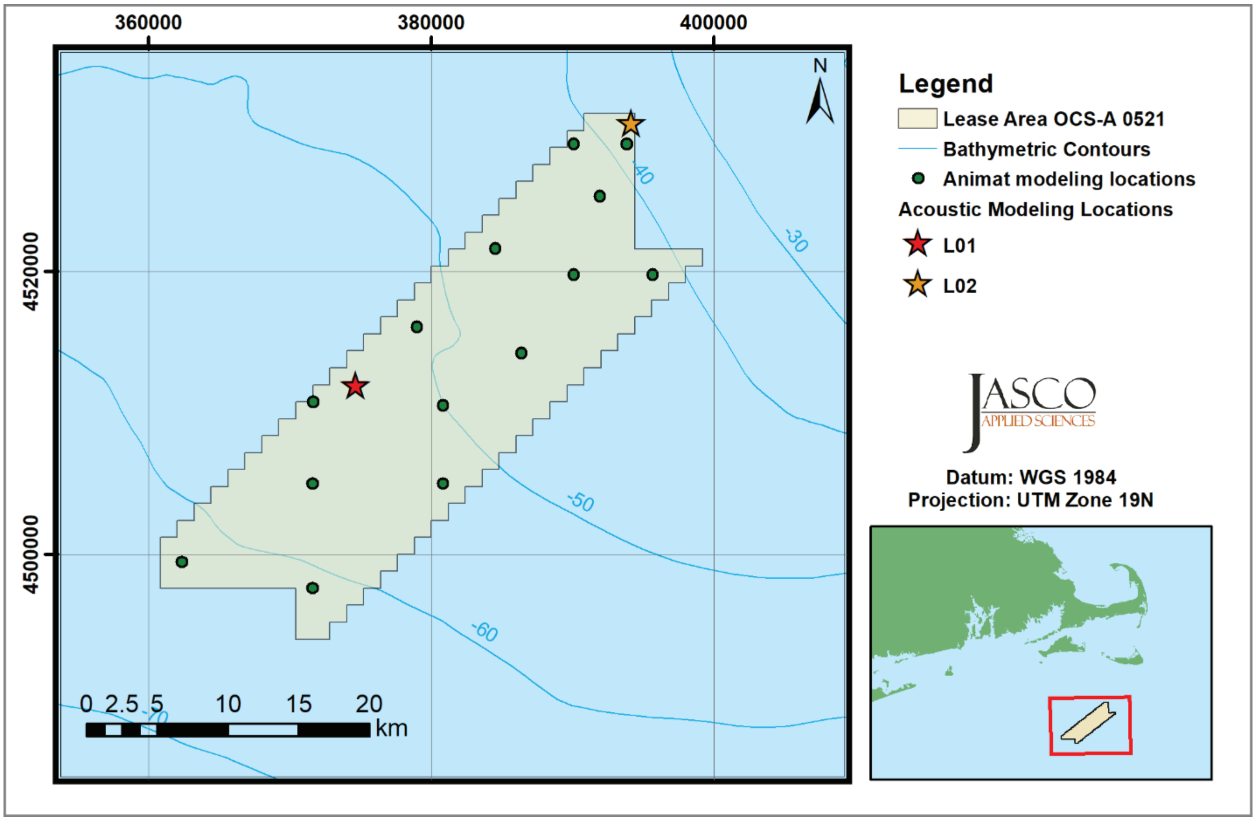

Figure 4. Lease Area with acoustic propagation modeling and animal movement modeling locations.

Table 3. Locations for acoustic modeling of monopile and jacket foundations.

Location name	UTM Zone 19N		Water depth (m)*
	Easting	Northing	
L01	374669.03	4511967.1	53.0
L02	394171.13	4530547.2	37.6

Vertical datum for water depth is Earth Gravitational Model 1996 (EGM96).

1.2.5. Modeling Scenario and Pile Installation Schedule for Modeling

The realistic scenario construction schedule presented in Table 4 assumes the installation of either 146, 11 m monopiles or 146, 3-legged jacket foundations with 2.9 m pin piles to support the WTGs over a two-year period. Three, 4-legged OSP jacket foundations with 4.5 m diameter piles are also included in this schedule, for a total of 12 pin piles. The realistic scenario construction schedules separated by year are included in Appendix G.2.2.

The maximum scenario construction schedule presented in Table 5 assumes the installation of either 146, 16 m monopiles or 146, 4-legged jacket foundations with 4.5 m pin piles to support the WTGs over a one-year period. Three, OSP jacket foundations were modeled with 12, 8, and 8 piles. for a total of 28 pin piles, all with 4.5 m diameter pin piles, in this one-year construction schedule.

For realistic and maximum scenarios, the exposure estimates assume that only one monopile or 4 pin piles per jacket foundation are installed per day, with no concurrent piling. The acoustic ranges for the installation of two monopiles per day were also calculated and are presented in Appendix F.

The estimated pile installation schedules, used for animal movement modeling, were provided by the Mayflower Wind team. The number of suitable weather days per month was obtained from historical weather data (Open Ocean 2020 and Vortex 2020). Pile installation schedules were used for the purpose of estimating marine mammal and sea turtle acoustic exposures during impact assessment and may change as the Project plans evolve.

Table 4. Realistic construction schedules (days of piling per month) used to estimate the total number of marine mammal and sea turtle acoustic exposures for Mayflower Wind. This table combines the schedules for both years of construction. Realistic scenario construction schedules separated by year are included in Appendix G.2.2.

Construction month	Realistic Jacket Scenario		Realistic Monopile Scenario	
	WTG Jacket 2.9 m diameter MHU1900S (3 pin piles/day)	**OSP Jacket** 4.5 m diameter IHCS2000 (4 pin piles/day)	**WTG Monopile** 11 m diameter MHU4400S (1 pile/day)	**OSP Jacket** 4.5 m diameter IHCS2000 (4 pin piles/day)
Jan	0	0	0	0
Feb	0	0	0	0
Mar	0	0	0	0
Apr	0	0	0	0
May	0	0	16	0
Jun	26	3	46	3
Jul	34	0	46	0
Aug	33	0	24	0
Sep	28	0	14	0
Oct	15	0	0	0
Nov	10	0	0	0
Dec	0	0	0	0
Total # of days	**146**	**3**	**146**	**3**

Table 5. Maximum construction schedules (days of piling per month) used to estimate the total number of marine mammal and sea turtle acoustic exposures for Mayflower Wind.

Construction month	Maximum Jacket Scenario		Maximum Monopile Scenario	
	WTG Jacket 4.5 m diameter MHU3500S (4 pin piles/day)	**OSP Jacket** 4.5 m diameter MHU3500S (4 pin piles/day)	**WTG Monopile** 16 m diameter 7000 strikes (1 pile/day)	**OSP Jacket** 4.5 m diameter MHU3500S (4 pin piles/day)
Jan	2	0	2	0
Feb	0	0	0	0
Mar	0	0	0	0
Apr	0	0	0	0
May	11	0	11	0
Jun	23	7	23	7
Jul	23	0	23	0
Aug	24	0	24	0
Sep	23	0	23	0
Oct	15	0	15	0
Nov	15	0	15	0
Dec	10	0	10	0
Total # of days	**146**	**7**	**146**	**7**

1.3. Secondary Sound Sources

There are several other potential anthropogenic sound sources associated with the Project during offshore construction, operation and maintenance, and decommissioning. These sources were not quantitatively modeled because the potential acoustic impact effects of these sound sources are expected to be much less than the impact pile driving sound source associated with hammer-installed foundations. A qualitative consideration of secondary sound sources is discussed in this section.

Anthropogenic sounds from vessels within the Project Area are likely to be similar in acoustic frequency characteristics and sound levels to existing commercial traffic in the region. Vessel sound would be associated with cable installation vessels and operations, piling installation vessels, and general transit to and from the foundation locations during construction, and operations and maintenance. If gravity-based structures are used in the Project, the key sound associated with their installation is related to vessel transport and DP station-keeping during installation. Potential sound effects from cable installation are expected to derive primarily from the cable laying vessel(s).

For example, during a similar type of underwater construction activity, Robinson et al. (2011) measured sound levels radiated from marine aggregate dredgers, mainly trailing suction hopper dredges during normal operation. Robinson et al. (2011) concluded that because of the operation of the propulsion system, noise radiated at less than 500 Hz, which is similar to that of a merchant vessel “traveling at modest speed (i.e., between 8 and 16 knots)” for self-propelled dredges. During dredging operations, additional sound energy generated by the impact and abrasion of the sediment passing through the draghead, suction pipe, and pump, is radiated in the 1 to 2 kHz frequency band. These acoustic components would not be present during cable laying operations, so these higher frequency sounds are not anticipated. Additionally, field studies conducted offshore New Jersey, Virginia, and Alaska show that noise generated by using vibracores and drilling boreholes diminishes below the National Marine

Fisheries Service (NMFS) behavioral response thresholds (120 dB for continuous sound sources) relatively quickly and is unlikely to cause harassment to marine mammals (NMFS 2009, Reiser et al. 2010, 2011, TetraTech 2014).

During construction, it is estimated that multiple vessels may operate concurrently at or as part of the Project. Some of these vessels may maintain their position using DP thrusters during pile driving or other construction activities. The dominant underwater sound source on DP vessels arises from cavitation on the propeller blades of the thrusters (Leggat et al. 1981). The noise power from the propellers is proportional to the number of blades, propeller diameter, and propeller tip speed. Sound levels generated by vessels under DP are dependent on the operational state and weather conditions. Zykov et al. (2013) and McPherson et al. (2019) report a maximum broadband SPL for numerous vessels with varying propulsion power under DP of up to 192 decibel (dB) re 1 micropascal (μPa) (for a pipe-laying vessel in deep water). All vessels emit sound from propulsion systems while in transit. Non-project vessel traffic in the vicinity of the Project includes recreational vessels, fishing vessels, cargo vessels, tankers, passenger vessels, and others. As such, marine mammals, fish, and sea turtles in the general region are regularly subjected to vessel activity and would potentially be habituated to the associated underwater noise as a result of this exposure (BOEM 2014b). Because sound introduced into the environment from vessel traffic associated with construction activities is likely to be similar to background vessel traffic noise, the potential risk of impacts from vessel noise to marine mammals is expected to be low relative to the risk of impact from pile-driving sound.

2. Methods

The basic modeling approach used in this acoustic assessment was to characterize the sound produced by the source, determine how the sounds propagate within the surrounding water column, and then estimate species-specific exposure probability by combining the computed sound fields with animal movement in simulated representative scenarios.

For impact pile driving sounds, time-domain representations of the acoustic pressure waves generated in the water were required for calculating the SPL, SEL, and PK. The source signatures associated with installation of each of the monopile and jacket foundation types were predicted using a finite-difference model that determined the physical vibration of the pile caused by pile driving equipment. The sound field radiating from the pile was simulated as a vertical array of point sources. For this study, synthetic pressure waveforms were computed using FWRAM, which is JASCO's acoustic propagation model capable of producing time-domain waveforms. The sound propagation modeling incorporated site-specific environmental data including bathymetry, sound speed in the water column, and seabed geoacoustics in the proposed construction area. Animal movement modeling integrated the estimated sound fields with species-typical behavioral parameters (e.g., dive patterns) in JASMINE to estimate received sound levels for the modeled animals (animats) that may occur in the construction area. Animats that exceeded pre-defined acoustic thresholds/criteria (e.g., NMFS 2018) were identified and the ranges for the exceedances were determined.

2.1. Acoustic Environment

The Mayflower Wind Lease Area is located in the continental shelf environment characterized by predominantly sandy seabed sediments. Water depths in the Lease Area vary between 37 to 64 m (121 to 210 ft). During the summer months (June-August), the average temperature of the upper 10 to 15 m (32.8 to 49.2 ft) of the water column is higher, resulting in an increased surface layer sound speed. This creates a downward refracting environment in which propagating sound interacts with the seafloor more than in a well-mixed environment. Increased wind mixing combined with a decrease in solar energy in the fall and winter months (September-February) results in a sound speed profile that is more uniform with depth. The shoulder months between summer and winter vary between the two. The average summer sound speed profile for the area was chosen because it is the most realistic sound propagation environment for the proposed activities. See Appendix E.2 for more details on the environmental parameters used in acoustic propagation and exposure modeling.

2.2. Source Modeling: Impact Pile Driving

Piles deform when driven with impulsive impact hammers, creating a bulge that travels down the pile and radiates sound into the surrounding air, water, and seabed. This sound may be received as a direct transmission from the sound source to biological receivers (such as marine mammals, sea turtles, and fish) through the water or as the result of reflected paths from the surface or re-radiated into the water from the seabed (Figure 5). Sound transmission depends on many environmental parameters, such as the sound speeds in water and substrates, sound production parameters of the pile and how it is driven, including the pile material, size (length, diameter, and thickness), and the make and energy of the hammer. A 2 dB increase in received levels for post-pile jacket foundation installation (expected installation method for the OSPs) was included in the propagation calculations based on a recommendation from Bellman et al. (2020).

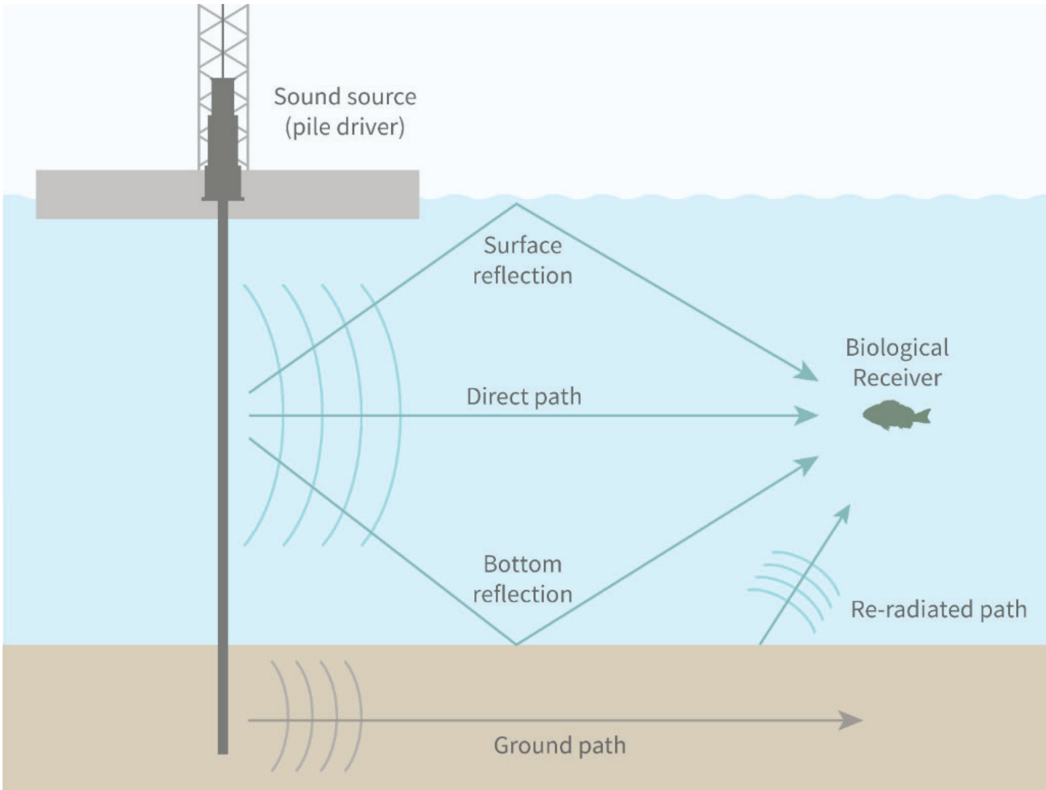

Figure 5. Sound propagation paths associated with pile driving (adapted from Buehler et al. 2015).

JASCO's physical model of pile vibration and near-field sound radiation (MacGillivray 2014) was used in conjunction with the GRLWEAP 2010 wave equation model (GRLWEAP, Pile Dynamics 2010) to predict source levels associated with impact pile driving activities. The sound radiating from the pile itself was simulated using a vertical array of discrete point sources. These models account for several parameters that describe the operation (pile taper, material, size, and length), the pile driving equipment, number of hammer strikes to install the pile, and approximate pile penetration depth. See Appendix E for a more detailed description of source modeling.

Forcing functions were computed for the realistic and maximum monopile and jacket foundations using GRLWEAP 2010 (GRLWEAP, Pile Dynamics 2010). The model assumed direct contact between the representative hammers, helmets, and piles (i.e., no cushion material). The forcing functions serve as the inputs to JASCO's Pile Driving Source Model (PDSM) used to estimate equivalent acoustic source characteristics detailed in Appendix E.1. Decidecade spectral source levels for each pile diameter, hammer energy and modeled location, using an average summer sound speed profile (Appendix E) are provided in Section 3.1.1.

2.3. Sound Attenuation Methods

One way to mitigate potential impacts from pile driving sound on marine fauna is to minimize, as much as possible, the sound levels from the pile driving source. Doing so reduces the zone of potential effect, thus reducing the number of animals exposed and the sound levels to which they would be exposed. These reductions may be achieved with various technologies.

Noise abatement systems (NAS) are often used to decrease the sound levels in the water near a source by inserting a local impedance change that acts as a barrier to sound transmission. Attenuation by impedance change can be achieved through a variety of technologies, including bubble curtains, evacuated sleeve systems (e.g., IHC-Noise Mitigation System (NMS)), encapsulated bubble systems (e.g., HydroSound Dampers (HSD)), or Helmholtz resonators (AdBm NMS). The effectiveness of each system is frequency dependent and may be influenced by local environmental conditions such as current and depth. For example, the size of the bubbles determines the effective frequency band of an air bubble curtain, with larger bubbles needed for lower frequencies.

Small bubble curtains have been measured to reduce sound levels by ~10 dB to more than 20 dB, but are highly dependent on water depth and current and how the curtain is configured and operated (Koschinski and Lüdemann 2013, Bellmann 2014, Austin and Li 2016). Larger bubble curtains tend to perform better and more reliably, particularly when deployed with two rings (Koschinski and Lüdemann 2013, Bellmann 2014, Nehls et al. 2016). A California Department of Transportation (CalTrans) study tested several small, single, bubble-curtain systems and found that the best attenuation systems resulted in 10 to 15 dB of attenuation. Buehler et al. (2015) concluded that attenuation greater than 10 dB could not be reliably predicted from small, single, bubble curtains because sound transmitted through the seabed and re-radiated into the water column is not attenuated by bubble curtains deployed immediately around (within 32 ft [10 m] of) the pile (Buehler et al. 2015).

A recent analysis by Bellmann et al. (2020) of NAS performance measured during impact driving for wind farm foundation installation provides expected performance for common NAS configurations. Measurements with a single bubble curtain and an air supply of 0.3 m^3/min resulted in 7 to 11 dB of broadband attenuation for optimized systems in up to 131.25 ft (40 m) water depth. Increased air flow (0.5 m^3/min) may improve the attenuation levels up to 11 to 13 dB (M. Bellmann, personal communication, 2019). Double bubble curtains add another local impedance change and, for optimized systems, can achieve 15 to 16 dB of broadband attenuation (measured in up to 131.25 ft [40 m] water depth). The IHC-NMS can provide 15 to 17 dB of attenuation but is currently limited to piles <8 m diameter. Other NAS such as the AdBm NMS achieved 6 to 8 dB (M. Bellmann, personal communication, 2019), but HSDs were measured at 10 to 12 dB attenuation and are independent of depth (Bellman et al. 2020). Systems may be deployed in series to achieve higher levels of attenuation.

NAS must be chosen, tailored, and optimized for site-specific conditions. NAS performance of 10 dB broadband attenuation was chosen for this study as an achievable reduction of sound levels produced during pile driving when one NAS is in use, noting that a 10 dB decrease means the sound energy level is reduced by 90 percent. For exposure-based radial distance estimation, no attenuation, 6 dB attenuation, and 15 dB attenuation were included for comparison purposes.

2.4. Acoustic Thresholds Used to Evaluate Potential Impacts Effects to Marine Mammals

The MMPA prohibits the take of marine mammals. The term “take” is defined as: to harass, hunt, capture, or kill, or attempt to harass, hunt, capture, or kill any marine mammal. MMPA regulations define harassment in two categories relevant to the Project operations. These are:

- **Level A**: any act of pursuit, torment, or annoyance that has the potential to injure a marine mammal or marine mammal stock in the wild, and
- **Level B**: any act of pursuit, torment or annoyance which has the potential to disturb a marine mammal or marine mammal stock in the wild by causing a disruption of behavioral patterns, including, but not limited to, migration, breathing, nursing, breeding, feeding, or sheltering but which does not have the potential to injure a marine mammal or marine mammal stock in the wild (16 U.S.C. 1362).

To assess the potential effects of the Mayflower Wind Project-associated sound sources, it is necessary to first establish the acoustic exposure criteria used by United States (US) regulators to estimate marine mammal takes. In 2016, the National Oceanographic and Atmospheric Administration (NOAA) National Marine Fisheries Service (NMFS) issued a Technical Guidance document that provides acoustic thresholds for onset of permanent threshold shift (PTS) in marine mammal hearing for most sound sources, which was updated in 2018 (NMFS 2016, 2018). The Technical Guidance document also recognizes two main types of sound sources: impulsive and non-impulsive. Non-impulsive sources are further broken down into continuous or intermittent categories.

NMFS also provided guidance on the use of weighting functions when applying Level A harassment criteria. The Guidance recommends the use of a dual criterion for assessing Level A exposures, including a peak (unweighted/flat) sound level metric (PK) and a cumulative SEL metric with frequency weighting. Both acoustic criteria and weighting function application are divided into functional hearing groups (low-, mid-, and high-frequency) that species are assigned to, based on their respective hearing ranges. The acoustic analysis applies the most recent sound exposure criteria utilized by NMFS to estimate acoustic harassment (NMFS 2018).

Sound levels thought to elicit disruptive behavioral response are described using the SPL metric (NMFS and NOAA 2005). NMFS currently uses behavioral response thresholds of 160 dB re 1 µPa for impulsive sounds and 120 dB re 1 µPa for non-impulsive sounds for all marine mammal species (NMFS 2018), based on observations of mysticetes (Malme et al. 1983, 1984, Richardson et al. 1986, 1990). Alternative thresholds used in acoustic assessments include a graded probability of response approach and take into account the frequency-dependence of animal hearing sensitivity (Wood et al. 2012). The 160 dB threshold is used in this assessment (DoC and NOAA 2005).

The publication of ISO 18405 Underwater Acoustics–Terminology (ISO 2017) provided a dictionary of underwater bioacoustics (the previous standard was ANSI S1.1-2013 R2013). In the remainder of this report, we follow the definitions and conventions of ISO (2017) except where stated otherwise (Table 6).

Table 6. Summary of relevant acoustic terminology used by US regulators and in the modeling report.

Metric	NMFS (2018)	ISO (2017)	
		Main text	Equations/Tables
Sound pressure level	Not applicable	SPL	L_p
Peak pressure level	PK	PK	L_{pk}
Cumulative sound exposure level[a]	SEL_{cum}	SEL	L_E

[a] The SEL_{cum} metric used by the NMFS describes the sound energy received by a receptor over a period of 24 h. Accordingly, following the ISO standard, this will be denoted as SEL in this report, except for in tables and equations where L_E will be used.

2.4.1. Marine Mammal Hearing Groups

To better reflect the auditory similarities between phylogenetically closely related species, but also significant differences between species groups among the marine mammals, Southall et al. (2007) assigned the extant marine mammal species to functional hearing groups based on their hearing capabilities and sound production. This division into broad categories was intended to provide a realistic number of categories for which individual noise exposure criteria were developed. These groups were revised by NMFS (2018), but the categorization as such has proven to be a scientifically justified and a useful approach in developing auditory weighting functions and deriving noise exposure criteria for marine mammals. The division proposed by Southall et al. (2007) was updated in 2018 by the NMFS using more recent best available science

Southall et al. (2019) published an updated set of Level A sound exposure criteria (i.e., for onset of temporary threshold shift (TTS) and permanent threshold shift (PTS) in marine mammals). While the authors propose a new nomenclature and classification for the marine mammal functional hearing groups, the proposed thresholds and weighting functions do not differ in effect from those proposed by NMFS (2018). The new hearing groups proposed by Southall et al. (2019) have not yet been adopted by NMFS. The NMFS (2018) hearing groups presented in Table 7 are used in this analysis.

Table 7. Marine mammal hearing groups and their hearing range (NMFS 2018).

Faunal group	Generalized hearing range[a]
Low-frequency (LF) cetaceans (mysticetes or baleen whales)	7 Hz to 35 kHz
Mid-frequency (MF) cetaceans (odontocetes: delphinids, beaked whales)	150 Hz to 160 kHz
High-frequency (HF) cetaceans (other odontocetes)	275 Hz to 160 kHz
Phocid pinnipeds in water (PPW)	50 Hz to 86 kHz
Phocid pinnipeds in air (PPA)[b]	50 Hz to 36 kHz

[a] The generalized hearing range is for all species within a group. Individual hearing will vary.
[b] Sound from piling will not reach NMFS thresholds for behavioral disturbance of seals in air (90 dB [rms] re 20 µPa for harbor seals and 100 dB [rms] re 20 µPa for all other seal species) at the closest land-based sites where seals may spend time out of the water. Thus in-air hearing is not considered further.

2.4.2. Marine Mammal Auditory Weighting Functions

The potential for anthropogenic sound to effect marine mammals is largely dependent on whether the sound occurs at frequencies that an animal can hear well, unless the sound pressure level is so high that it can cause physical tissue damage regardless of frequency. Auditory (frequency) weighting functions reflect an animal's ability to hear a sound (Nedwell and Turnpenny 1998, Nedwell et al. 2007). Auditory weighting functions have been proposed for marine mammals, specifically associated with PTS thresholds expressed in metrics that consider what is known about marine mammal hearing (e.g., SEL) (Southall et al. 2007, Erbe et al. 2016, Finneran 2016). Marine mammal auditory weighting functions for all hearing groups (Table 7) published by Finneran (2016) are included in the NMFS (2018) Technical Guidance for use in conjunction with corresponding PTS (Level A) onset acoustic criteria (Table 8).

The application of marine mammal auditory weighting functions emphasizes the importance of taking measurements and characterizing sound sources in terms of their overlap with biologically important frequencies (e.g., frequencies used for environmental awareness, communication, and the detection of predators or prey), and not only the frequencies that are relevant to achieving the objectives of the sound producing activity (i.e., context of sound source; NMFS 2018).

2.4.3. Marine Mammal Auditory Injury Exposure Criteria

Injury to the hearing apparatus of a marine mammal may result from a fatiguing stimulus measured in terms of SEL, which considers the sound level and duration of the exposure signal. Intense sounds may also damage hearing independent of duration, so an additional metric of peak pressure (PK) is also used to assess the risk of injury from acoustic exposure. A PTS in hearing may be considered injurious, but there are no published data on the sound levels that cause PTS in marine mammals. There are data that indicate the received sound levels at which TTS occurs, and PTS onset may be extrapolated from TTS onset level and an assumed growth function (Southall et al. 2007). The NMFS (2018) criteria incorporate the best available science to estimate PTS onset in marine mammals from sound energy accumulated over 24 h (SEL), or very loud, instantaneous PK levels. These dual threshold criteria of SEL and PK are used to calculate marine mammal exposures (Table 8). If a non-impulsive sound has the potential to exceed the PK thresholds associated with impulsive sounds, these thresholds should also be considered.

Table 8. Summary of relevant permanent threshold shift (PTS) onset acoustic thresholds for marine mammal hearing groups (NMFS 2018).

Faunal group	Impulsive signals[a]		Non-impulsive signals
	Unweighted L_{pk} (dB re 1 µPa)	Frequency weighted $L_{E,\,24hr}$ (dB re 1 µPa²s)	Frequency weighted $L_{E,\,24hr}$ (dB re 1 µPa²s)
Low-frequency (LF) cetaceans	219	183	199
Mid-frequency (MF) cetaceans	230	185	198
High-frequency (HF) cetaceans	202	155	173
Phocid seals in water (PW)	218	185	201

[a] Dual metric acoustic thresholds for impulsive sounds: The largest isopleth result of the two criteria are used for calculating PTS onset. If a non-impulsive sound has the potential to exceed the peak sound pressure level thresholds associated with impulsive sounds, these thresholds have also been considered.

2.4.4. Marine Mammal Behavioral Response Exposure Criteria

Numerous studies on marine mammal behavioral responses to sound exposure have not resulted in consensus in the scientific community regarding the appropriate metric for assessing behavioral reactions. It is recognized that the context in which the sound is received affects the nature and extent of responses to a stimulus (Southall et al. 2007, Ellison et al. 2012). Due to the complexity and variability of marine mammal behavioral responses to acoustic exposure, the NMFS has not yet released technical guidance on behavioral thresholds for calculating animal exposures (NMFS 2018). The NMFS currently uses a step function to assess behavioral effects (NOAA 2005). A 50 percent probability of inducing behavioral responses at an SPL of 160 dB re 1 µPa was derived from the HESS (1999) report, which was based on the responses of migrating mysticete whales to airgun sounds (Malme et al. 1983, 1984). The HESS team recognized that behavioral responses to sound may occur at lower levels, but substantial responses were only likely to occur above an SPL of 140 dB re 1 µPa.

An extensive review of behavioral responses to sound was undertaken by Southall et al. (2007, their Appendix B). Southall et al. (2007) found varying responses for most marine mammals between an SPL of 140 and 180 dB re 1 µPa, consistent with the HESS (1999) report, but lack of convergence in the data prevented them from suggesting explicit step functions. In 2012, Wood et al. proposed a graded probability of response for impulsive sounds using a frequency weighted SPL metric. Wood et al. (2012) also designated behavioral response categories for sensitive species (harbor porpoises and beaked whales) and for migrating mysticetes. Both the unweighted NOAA (2005) and the frequency-weighted Wood et al. (2012) criteria are used to estimate Level B exposures to impulsive piling sounds (Table 9).

Table 9. Acoustic thresholds used in this assessment to evaluate potential behavioral impacts effects to marine mammals. Units are sound pressure level (L_p). Probabilities are not additive.

Marine mammal group	Frequency weighted probabilistic response[a] (L_p; dB re 1 µPa)				Unweighted threshold[b] (L_p; dB re 1 µPa)
	120	140	160	180	160
Beaked whales and harbor porpoises	50%	90%	—	—	100%
Migrating mysticete whales	10%	50%	90%	—	100%
All other species	—	10%	50%	90%	100%

[a] Wood et al. (2012).
[b] NMFS recommended threshold.

2.5. Acoustic Thresholds Used to Evaluate Potential Impacts Effects to Sea Turtles and Fish

In a cooperative effort between Federal and State transportation and resource agencies, interim criteria were developed to assess the potential for injury to fish exposed to pile driving sounds (Stadler and Woodbury 2009) and described by the Fisheries Hydroacoustic Working Group (FHWG 2008). Injury and behavioral response levels for fish were based on past literature that was compiled and listed in the NOAA Fisheries Greater Atlantic Regional Fisheries Office (GARFO) acoustics tool for assessing the potential effects to Endangered Species Act (ESA) listed exposed to elevated levels of underwater sound from pile driving. Dual acoustic thresholds for physiological injury to fish included in the tool are 206 dB re 1 µPa PK and either 187 dB re 1 $\mu Pa^2 \cdot s$ SEL (>2 grams [g] fish weight) or 183 dB SEL (<2 g fish weight) (FHWG 2008, Stadler and Woodbury 2009) (Table 10). The behavioral threshold for fish is ≥150 dB SPL (Andersson et al. 2007, Wysocki et al. 2007, Mueller-Blenkle et al. 2010, Purser and Radford 2011).

Injury and behavioral thresholds for sea turtles were developed for use by the US Navy (Finneran et al. 2017) based on exposure studies (e.g., McCauley et al. 2000). For sea turtles, dual acoustic thresholds (PK and SEL) have been suggested for PTS and TTS (Appendix D). The behavioral threshold provided in the GARFO acoustic tool (2019) is an SPL of 175 dB re 1 µPa (McCauley et al. 2000, Finneran et al. 2017) (Table 10).

Table 10. Interim sea turtle and fish injury and behavioral acoustic thresholds currently used by NMFS GARFO and Bureau of Ocean Energy Management (BOEM) for impulsive pile driving.

Faunal group	Injury		TTS		Behavior
	L_{PK}	L_E	L_{PK}	L_E	L_p
Fish ≥2 g[a,b]	206	187	–	–	150
Fish <2 g[a,b]		183	–	–	
Sea turtles[c,d]	232	204	226	189	175

L_{PK} – peak sound pressure (dB re 1 µPa).
L_E – sound exposure level (dB re 1 $\mu Pa^2 \cdot s$).
L_p – root mean square sound pressure (dB re 1 µPa).
TTS – temporary, recoverable hearing effects.
[a] NMFS recommended criteria adopted from the Fisheries Hydroacoustic Working Group (FHWG 2008).
[b] Andersson et al. (2007), Mueller-Blenkle et al. (2010), Purser and Radford (2011), Wysocki et al. (2007).
[c] Finneran (2017).
[d] McCauley et al. (2000).

2.6. Animal Movement Modeling and Exposure Estimation

The JASMINE model was used to estimate the probability of exposure of animals to sound arising from pile driving operations during construction of the Project. Sound exposure models such as JASMINE use simulated animals (animats) to sample the predicted 3-D sound fields with movement rules derived from animal observations (Appendix F.3). The parameters used for forecasting realistic behaviors (e.g., diving, foraging, aversion, and surface times) were determined and interpreted from marine species studies (e.g., tagging studies) where available, or reasonably extrapolated from related species. The predicted sound fields were sampled by the model receiver in a way that real animals are expected to by programming animats to behave like marine species that may be present in, or near, the Project Area. The output of the simulation is the exposure history for each animat within the simulation. An individual animat's sound exposure levels (SELs) are summed over a specified duration, i.e., 24 h (Appendix G.1.1), to determine its total received acoustic energy and maximum received PK and SPL. These received levels are then compared to the threshold criteria described in Section 2.4 within each analysis period. The number of animats predicted to receive sound levels exceeding the thresholds indicates the probability of such exposures, which is then scaled by the real-world density estimates for each species (Section 2.8.2) to obtain the mean number of real-world animals estimated to potentially receive above-threshold sound levels. Due to shifts in animal density and seasonal sound propagation effects, the number of animals predicted to be impacted affected by the pile driving operations is sensitive to the number of foundations installed during each month.

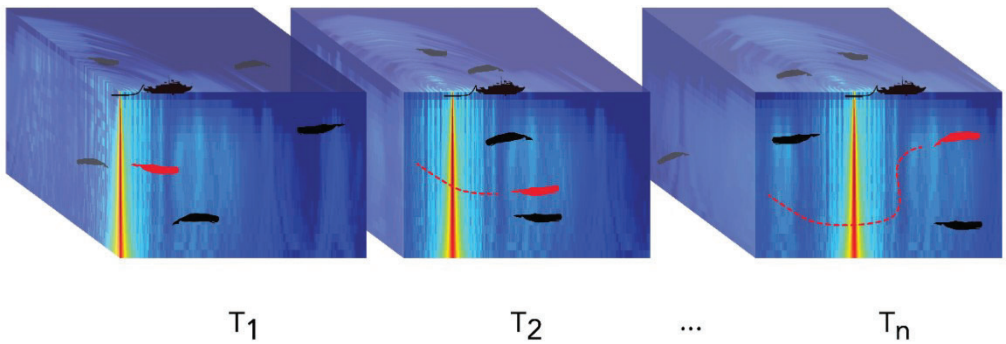

Figure 6. Depiction of animats in an environment with a moving sound field. Example animat (red) shown moving with each time step. The acoustic exposure of each animat is determined by where it is in the sound field, and its exposure history is accumulated as the simulation steps through time.

2.6.1. Animal Aversion

Aversion is a common response of animals to sound, particularly at higher sound exposure levels (Ellison et al. 2012). As received sound level generally decreases with distance from a source, this aspect of natural behavior can strongly influence the estimated maximum sound levels an animal is predicted to receive and significantly affects the probability of more pronounced direct or subsequent behavioral effects. Additionally, animals are less likely to respond to sound levels distant from a source, even when those same levels elicit response at closer ranges; both proximity and received levels are important factors in aversive responses (Dunlop et al. 2017). As a supplement to this modeling study for comparison with non-aversion results, aversion was implemented for North Atlantic right whales and harbor porpoise. Parameters determining aversion at specified sound levels were implemented for the North Atlantic right whale in recognition of their highly endangered status, and harbor porpoise, a species that has demonstrated a strong aversive response to pile driving sounds in multiple studies.

Aversion is implemented in JASMINE by defining a new behavioral state that an animat may transition to when a received level is exceeded. There are very few data on which modeling of aversive behavior can be based. Because of the lack of information and to be consistent within this report, aversion thresholds and probability are based on the Wood et al. (2012) step function that was used to estimate potential behavioral disruption. Animats are assumed to avert by changing their headings by a fixed amount away from the source, with higher received levels associated with a greater deflection (Tables 11 and 12). Animats remain in the aversive state for a specified amount of time, depending on the level of exposure that triggered aversion (Tables 11 and 12). During this time, travel parameters are recalculated periodically as with normal behaviors. At the end of the aversion interval, the animat once again applies the parameters in Tables 11 and 12 and, depending on the current level of exposure, either begins another aversion interval or transitions to a non-aversive behavior; while aversion begins immediately, transition to a regular behavior occurs at the end of the next surface interval, consistent with regular behavior transitions.

Table 11. North Atlantic right whales: Aversion parameters for the animal movement simulation based on Wood et al. (2012) behavioral response criteria.

Probability of aversion	Received sound level (L_p, dB re 1 µPa)	Change in course (°)	Duration of aversion (s)
10%	140	10	30
50%	160	20	60
90%	180	30	300

Table 12. Harbor porpoises: Aversion parameters for the animal movement simulation based on Wood et al. (2012) behavioral response criteria. Harbor porpoises are considered a sensitive species using the Wood et al. (2012) criteria, and their aversive responses are only described at the 50 percent and 90 percent probability levels.

Probability of aversion	Received sound level (L_p, dB re 1 µPa)	Change in course (°)	Duration of aversion (s)
50%	120	20	60
90%	140	30	300

2.7. Estimating Monitoring Zones for Mitigation

Monitoring zones for mitigation purposes have traditionally been estimated by determining the acoustic range to injury and behavioral thresholds (see Appendix F). The traditional method assumes that all receivers (animals) in the area remain stationary for the duration of the sound event. Because where an animal is in a sound field and the pathway it takes through the sound field as it evolves over time determines the received level for each animal, treating animals as stationary may not produce realistic estimates for the monitoring zones.

Animal movement and exposure modeling can be used to account for the movement of receivers when estimating ranges for monitoring zones. The range to the closest point of approach (CPA) for each of the species-specific animats (simulated animals) during a simulation is recorded and then the CPA range that accounts for 95 percent of the animats that exceed an acoustic impact threshold is determined (Figure 7). The ER_{max} (maximum Exposure Range) is the farthest CPA of an animat that exceeded threshold and $ER_{95\%}$ (95 percent Exposure Range) is the horizontal distance that includes 95 percent of the CPAs of animats exceeding the threshold. $ER_{95\%}$ is reported for marine mammals and sea turtles. If used as an exclusion zone, keeping animals farther away from the source than the $ER_{95\%}$ will reduce exposure estimates by 95 percent.

Unlike marine mammals and sea turtles for which animal movement modeling was performed, fish were considered static (not moving) receivers, so exposure ranges were not calculated. Instead, the acoustic ranges to fish impact criteria thresholds were calculated by determining the isopleth at which thresholds could be exceeded (Section 3.7).

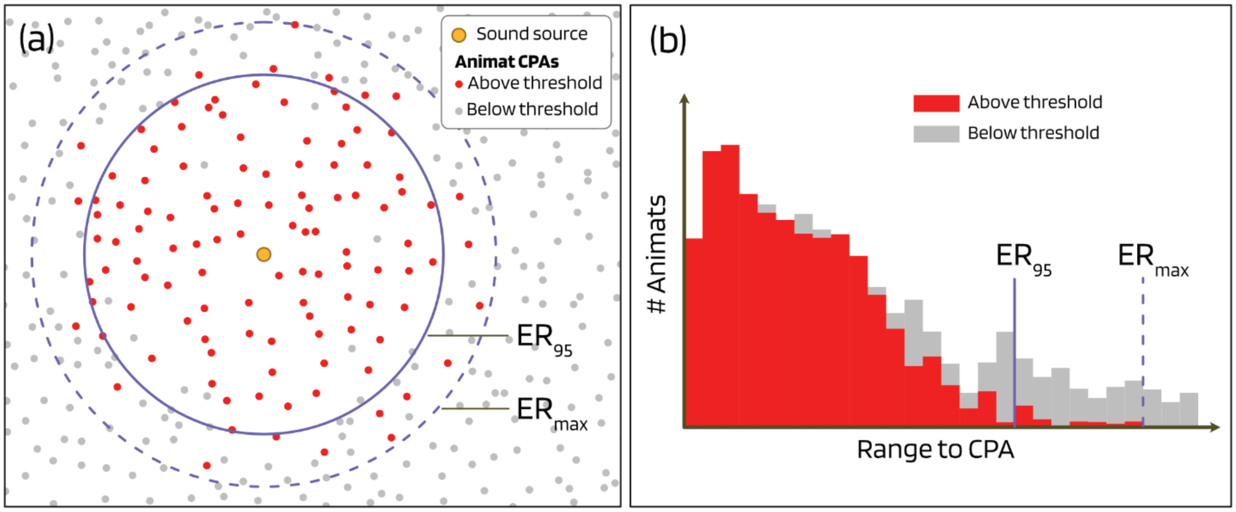

Figure 7. Example distribution of animat closest points of approach (CPAs). Panel (a) shows the horizontal distribution of animats near a sound source. Panel (b) shows the distribution of ranges to animat CPAs. The 95 percent and maximum Exposure Ranges ($ER_{95\%}$ and ER_{max}) are indicated in both panels.

2.8. Marine Fauna Included in the Acoustic Assessment

Marine fauna included in the acoustic assessment are marine mammals (cetaceans and pinnipeds), sea turtles, fish, and invertebrates.

All marine mammal species are protected under the MMPA. Some marine mammal stocks may be designated as Strategic under the MMPA (2015), which requires the jurisdictional agency (NMFS for the Atlantic offshore species considered in this application) to impose additional protection measures. A stock is considered Strategic if:

- Direct human-caused mortality exceeds its Potential Biological Removal (PBR) level (defined as the maximum number of animals, not including natural mortality, that can be removed from the stock while allowing the stock to reach or maintain its optimum sustainable population level);
- It is listed under the ESA;
- It is declining and likely to be listed under the ESA; or
- It is designated as depleted under the MMPA.

A depleted species or population stock is defined by the MMPA as any case in which:

- The Secretary, after consultation with the Marine Mammal Commission and the Committee of Scientific Advisors on Marine Mammals established under MMPA Title II, determines that a species or population stock is below its optimum sustainable population;
- A State, to which authority for the conservation and management of a species or population stock is transferred under Section 109 of the MMPA, determines that such species or stock is below its optimum sustainable population; or
- A species or population stock is listed as an endangered or threatened species under the ESA. Some species are further protected under the ESA (2002).

Under the ESA, a species is considered endangered if it is “in danger of extinction throughout all or a significant portion of its range.” A species is considered threatened if it “is likely to become an endangered species within the foreseeable future throughout all or a significant portion of its range” (ESA 2002).

2.8.1. Marine Mammals that May Occur in the Project Area

Thirty-eight marine mammal species (whales, dolphins, porpoise, seals, and manatees) comprising 38 stocks have been documented as present (some year–round, some seasonally, and some as occasional visitors) in the Northwest Atlantic Outer Continental Shelf (OCS) region. All 38 marine mammal species identified in Table 13 are protected by the MMPA and some are also listed under the ESA. The five ESA-listed marine mammal species known to be present year-round, seasonally, or occasionally in the Project Area (located within the southern New England waters) are the sperm whale (*Physeter macrocephalus*), North Atlantic right whale (NARW) (*Eubalaena glacialis*), fin whale (*Balaenoptera physalus physalus*), blue whale (*Balaenoptera musculus*), and sei whale (*Balaenoptera borealis borealis*). The humpback whale (*Megaptera novaeangliae*), which may occur year-round, has been delisted as an endangered species since September 2016.

Southern New England waters (including the Project Area (Figure 1)) are primarily used as opportunistic feeding areas or habitat during seasonal migration movements that occur between the more northern feeding areas and the more southern breeding areas typically used by some of the large whale species.

Along with cetaceans, seals are protected under the MMPA. The four species of phocids (true seals) that have ranges overlapping the Project Area, are harbor seals (*Phoca vitulina*), gray seals (*Halichoerus grypus*), harp seals (*Pagophilus groenlandicus*), and hooded seals (*Cystophora cristata*) (Hayes et al. 2019).

One species of sirenian, the Florida manatee (*Trichechus manatus latirostris*) is an occasional visitor to the region during summer months (USFWS 2019). The manatee is listed as threatened under the ESA and is protected under the MMPA along with the other marine mammals.

The expected occurrence of each marine mammal species in the Project Area is listed in Table 13. Many of the listed marine mammal species do not commonly occur in this region of the Atlantic Ocean. Species occurrence categories include:

- Common – Occurring consistently in moderate to large numbers;
- Regular – Occurring in low to moderate numbers on a regular basis or seasonally;
- Uncommon – Occurring in low numbers or on an irregular basis; and
- Rare – There are limited species records for some years; range includes the proposed Project Area but due to habitat preferences and distribution information, species are not expected to occur. Recorded observations may exist for adjacent waters.

Species that are identified as rare are not included in the animal movement and exposure modeling. Two of the species, Risso's dolphin and sperm whale, are listed as uncommon in Table 13, but are excluded from the animal movement modeling and exposure analysis since their expected depth range is outside the area potentially affected by noise from the Project piling operations (Hartman 2018, Whitehead 2018). The likelihood of incidental exposure for each species based on its presence, density, and overlap of proposed activities is described in Section 2.8.2.

Table 13. Marine mammals that may occur in the Northwest Atlantic OCS.

Species	Scientific name	Stock[a]	Regulatory status[b]	Abundance	Project Area occurrence
Baleen whales (Mysticeti)					
Blue whale	*Balaenoptera musculus*	Western North Atlantic	ESA-Endangered	402	Rare
Fin whale	*Balaenoptera physalus*	Western North Atlantic	ESA-Endangered	7,418	Common
Humpback whale	*Megaptera novaeangliae*	Gulf of Maine	MMPA	1,396	Common
Minke whale	*Balaenoptera acutorostrata*	Canadian East Coast	MMPA	24,202	Common
North Atlantic right whale	*Eubalaena glacialis*	Western North Atlantic	ESA-Endangered	428[c]	Common
Sei whale	*Balaenoptera borealis*	Nova Scotia	ESA-Endangered	6,292	Common
Toothed whales (Odontoceti)					
Atlantic spotted dolphin	*Stenella frontalis*	Western North Atlantic	MMPA	39,921	Rare
Atlantic white-sided dolphin	*Lagenorhynchus acutus*	Western North Atlantic	MMPA	93,233	Common
Common bottlenose dolphin	*Tursiops truncatus*	Western North Atlantic, Offshore	MMPA	62,851[d]	Common
		Western North Atlantic, Coastal	MMPA	6,639	Common
Clymene dolphin	*Stenella clymene*	Western North Atlantic	MMPA	4,237	Rare
False killer whale	*Pseudorca crassidens*	Western North Atlantic	MMPA-Strategic	1,791	Rare
Fraser's dolphin	*Lagenodelphis hosei*	Western North Atlantic	MMPA	Unknown	Rare
Killer whale	*Orcinus orca*	Western North Atlantic	MMPA	Unknown	Rare
Long-finned pilot whale	*Globicephala melas*	Western North Atlantic	MMPA	39,215	Uncommon
Melon-headed whale	*Peponocephala electra*	Western North Atlantic	MMPA	Unknown	Rare
Pan-tropical spotted dolphin	*Stenella attenuata*	Western North Atlantic	MMPA	6,593	Rare
Pygmy killer whale	*Feresa attenuata*	Western North Atlantic	MMPA	Unknown	Rare
Risso's dolphin	*Grampus griseus*	Western North Atlantic	MMPA	35,493	Uncommon
Rough-toothed dolphin	*Steno bredanensis*	Western North Atlantic	MMPA	136	Rare
Short-beaked common dolphin	*Delphinus delphis*	Western North Atlantic	MMPA	172,825	Common
Short-finned pilot whale	*Globicephala macrorhynchus*	Western North Atlantic	MMPA	28,924	Rare
Sperm whale	*Physeter macrocephalus*	North Atlantic	ESA-Endangered	4,349	Uncommon
Spinner dolphin	*Stenella longirostris*	Western North Atlantic	MMPA	4,102	Rare
Striped dolphin	*Stenella coeruleoalba*	Western North Atlantic	MMPA	67,036	Rare
Beaked whales					
Cuvier's beaked whale	*Ziphius cavirostris*	Western North Atlantic	MMPA	5,744	Rare
Blainville's beaked whale	*Mesoplodon densirostris*	Western North Atlantic	MMPA	10,107[e]	Rare
Gervais' beaked whale	*Mesoplodon europaeus*	Western North Atlantic	MMPA		
Sowerby's beaked whale	*Mesoplodon bidens*	Western North Atlantic	MMPA		
True's beaked whale	*Mesoplodon mirus*	Western North Atlantic	MMPA		
Northern bottlenose whale	*Hyperoodon ampullatus*	Western North Atlantic	MMPA	Unknown	Rare
Dwarf and pygmy sperm whales (Kogiidae)					
Dwarf sperm whale	*Kogia sima*	Western North Atlantic	MMPA	7,750[f]	Rare

Species	Scientific name	Stock[a]	Regulatory status[b]	Abundance	Project Area occurrence
Pygmy sperm whale	*Kogia breviceps*	Western North Atlantic	MMPA	7,750[f]	Rare
Porpoises	*Phocoenidae*				
Harbor porpoise	*Phocoena phocoena*	Gulf of Maine/Bay of Fundy	MMPA	95,543	Common
Earless seals (Phocidae)					
Gray seal	*Halichoerus grypus*	Western North Atlantic	MMPA	27,131[g]	Common
Harbor seal	*Phoca vitulina*	Western North Atlantic	MMPA	75,834	Regular
Harp seal	*Pagophilus groenlandicus*	Western North Atlantic	MMPA	Unknown[h]	Rare
Hooded seal	*Cystophora cristata*	Western North Atlantic	MMPA	Unknown	Rare
Sirenia					
Florida manatee	*Trichechus manatus latirostris*	Florida	ESA-Threatened	4,834	Rare

[a] Best available population estimate is from NOAA Fisheries Stock Assessment Reports (Waring et al. 2016, Hayes et al. 2017, 2018, 2019, 2020).

[b] Denotes the highest federal regulatory classification. A strategic stock is defined as any marine mammal stock: 1) for which the level of direct human-caused mortality exceeds the potential biological removal level; 2) that is declining and likely to be listed as threatened under the ESA; or 3) that is listed as threatened or endangered under the ESA or as depleted under the MMPA (NOAA Fisheries 2019).

[c] Best available population estimate is from NOAA Fisheries Stock Assessment Reports (Waring et al. 2016, Hayes et al. 2017, 2018, 2019, 2020). The NARW consortium has released the preliminary 2020 report card results predicting a NARW population of 356 (Pettis and et al. 2021 in draft). However, the consortium alters the methods of (Pace et al. 2017) to subtract additional mortality. This method is used in order to estimate all mortality, not just the observed mortality, therefore the (Hayes et al. 2020) SAR will be used to report an unaltered output of the (Pace et al. 2017) model (DoC and NOAA 2020).

[d] Common bottlenose dolphins occurring in the Project Area likely belong to the Western North Atlantic Offshore stock.

[e] This estimate includes all undifferentiated *Mesoplodon spp*. beaked whales in the Atlantic. Sources: Kenney and Vigness-Raposa (2009), Rhode Island Ocean SAMP (2011), Waring et al. (2011, 2013, 2015), Hayes et al. (2017, 2018, 2019, 2020).

[f] This estimate includes both the dwarf and pygmy sperm whales. Source: Hayes et al. (2020)

[g] Estimate of gray seal population in US waters. Data are derived from pup production estimates; Hayes et al. (2019, 2020) notes that uncertainty about the relationship between whelping areas along with a lack of reproductive and mortality data make it difficult to reliably assess the population trend.

[h] Hayes et al. (2018, 2019, 2020) report insufficient data to estimate the population size of harp seals in US waters; the best estimate for the whole population is 7.4 million.

2.8.2. Mean Monthly Marine Mammal Density Estimates

Mean monthly marine mammal density estimates (animals per 100 square kilometers [animals/100 km^2]) for all species are provided in Table 14. These were obtained using the Duke University Marine Geospatial Ecological Laboratory model results (Roberts et al. 2016, Roberts et al. 2017) and a model that provides updated densities for the fin whale, humpback whale, minke whale, NARW, sei whale, sperm whale, pilot whales, and harbor porpoise (Roberts et al. 2017). This model incorporates more sighting data than Roberts et al. (2016), including sightings from AMAPPS 2010 to 2014 surveys, which included some aerial surveys over the MA WEA and RI/MA WEA (NEFSC and SEFSC 2011b, 2012, 2014b, 2014a, 2015, 2016). Roberts et al. (2020) further updated model results for NARW by implementing three major changes: increasing spatial resolution to 5 × 5 km grid cells, generating monthly, mean absolute densities for NARW based on three eras of siting data, and dividing the study area into five discrete regions. These changes are designed to produce estimates that better reflect the most current, regionally specific data, and provide better coastal resolution. Density estimates for pinnipeds were calculated using Roberts et al. (2018) density data.

Densities were calculated within a 50 km buffered polygon around the OCS-A 0521 Lease Area perimeter. The 50 km limit is derived from studies of mysticetes that demonstrate received levels, distance from the source, and behavioral context are known to influence the probability of behavioral response (Dunlop et al. 2017).

The mean density for each month was determined by calculating the unweighted mean of all 10 × 10 km grid cells partially or fully within the analysis polygon (Figure 8). Densities were computed for the entire year to coincide with possible planned activities. In cases where monthly densities were unavailable, annual mean densities were used instead.

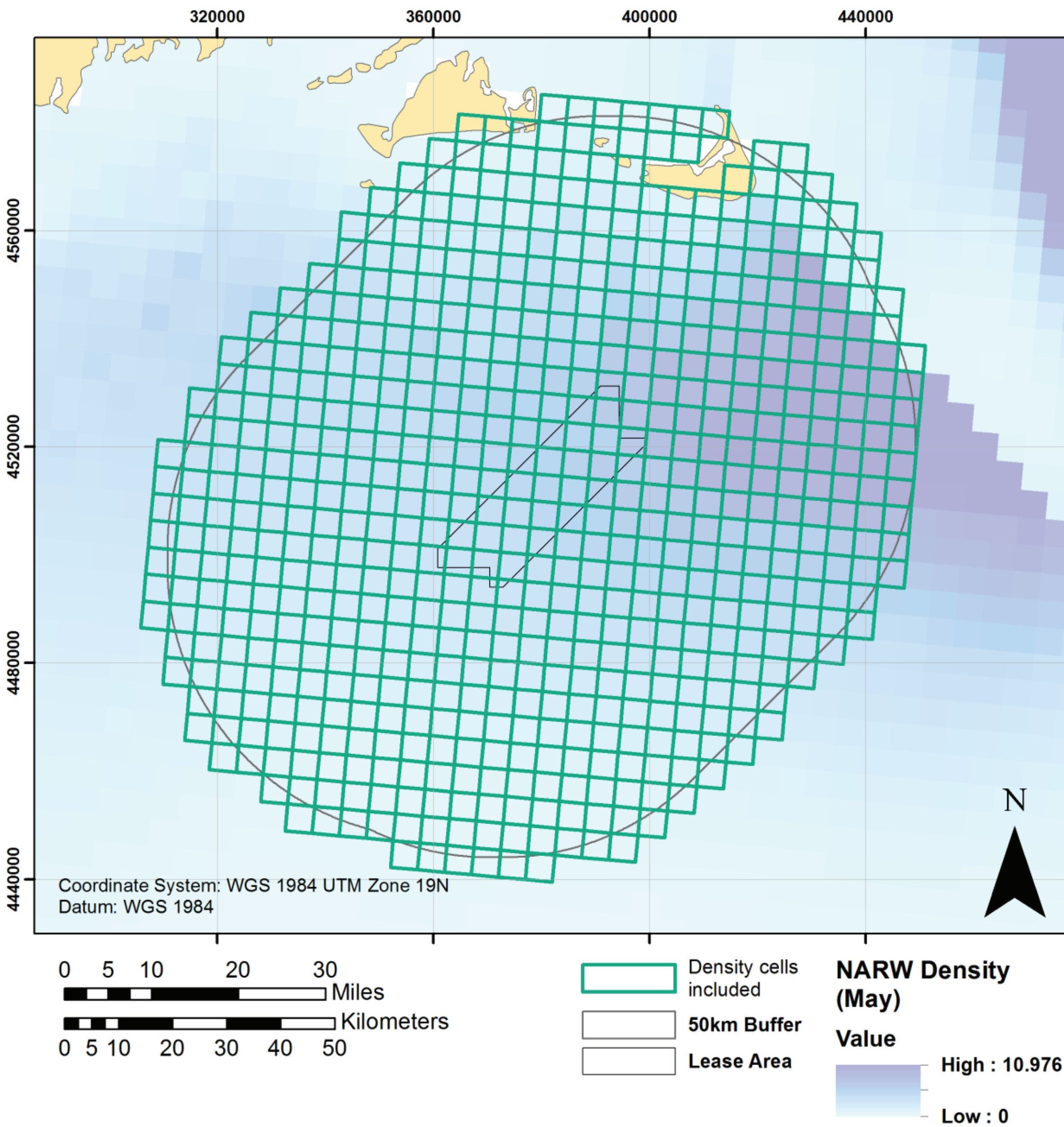

Figure 8. Marine mammal (e.g., NARW) density map showing highlighted grid cells used to calculate mean monthly species estimates within a 50 km buffer around the Lease Area (Roberts et al. 2015, 2016, 2017, 2018, 2020).

Table 14. Mean monthly marine mammal density estimates for all modeled species in the Mayflower Wind Lease Area with a 50 km buffer.

Species of interest	Monthly densities (animals/100 km²)[a]												Annual mean	May to January mean
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec		
Fin whale[b]	0.243	0.241	0.275	0.434	0.473	0.486	0.472	0.405	0.371	0.260	0.219	0.216	0.341	0.349
Humpback whale	0.036	0.026	0.059	0.197	0.256	0.267	0.149	0.071	0.184	0.189	0.132	0.047	0.134	0.148
Minke whale	0.063	0.076	0.078	0.196	0.338	0.307	0.143	0.094	0.089	0.102	0.033	0.046	0.130	0.135
North Atlantic right whale[b]	0.442	0.582	0.618	0.546	0.208	0.022	0.002	0.001	0.002	0.007	0.062	0.243	0.228	0.110
Sei whale[b]	0.004	0.004	0.002	0.067	0.062	0.045	0.017	0.010	0.011	0.003	0.004	0.004	0.019	0.018
Atlantic white sided dolphin	3.442	2.052	2.055	4.040	7.712	7.085	4.673	2.403	2.535	3.594	4.332	4.896	4.068	4.519
Bottlenose dolphin	0.966	0.450	0.233	1.713	1.711	3.283	5.785	4.898	6.119	6.280	3.204	1.594	3.020	3.760
Risso's dolphin	0.159	0.098	0.062	0.070	0.165	0.238	0.470	0.726	0.412	0.166	0.191	0.304	0.255	0.315
Pilot whale[c]	0.983	0.983	0.983	0.983	0.983	0.983	0.983	0.983	0.983	0.983	0.983	0.983	0.983	0.983
Sperm whale	0.010	0.013	0.012	0.019	0.026	0.024	0.041	0.041	0.020	0.018	0.014	0.009	0.022	0.023
Short-beaked common dolphin	22.982	7.866	4.980	8.008	11.590	16.240	12.334	15.766	18.492	23.579	19.557	27.073	15.706	18.624
Harbor porpoise	3.852	5.098	8.703	7.705	4.952	1.698	1.256	1.559	1.102	0.687	1.605	1.924	3.345	2.071
Gray seal	5.545	6.478	7.714	16.522	16.302	4.649	1.404	0.749	0.631	1.084	1.848	4.438	5.614	4.072
Harbor seal	5.545	6.478	7.714	16.522	16.302	4.649	1.404	0.749	0.631	1.084	1.848	4.438	5.614	4.072

[a] Density estimates are from habitat-based density modeling of the entire Atlantic Exclusive Economic Zone (EEZ) from Roberts et al. (2015, 2016, 2017, 2018, 2020).
[b] Listed as Endangered under the ESA.
[c] Long- and short-finned pilot whales are combined.

2.8.3. Sea Turtles and Fish Species of Concern that May Occur in the Project Area

Four species of sea turtles may occur in the Project Area that are listed as threatened or endangered: Loggerhead sea turtle (*Caretta caretta*), Kemp's ridley sea turtle (*Lepidochelys kempii*), green sea turtle (*Chelonia mydas*), and leatherback sea turtle (*Dermochelys coriacea*). Many species of sea turtle prefer coastal waters; however, both the leatherback and loggerhead sea turtles are known to occupy deep-water habitats and are considered common during summer and fall in the Project Area. Kemp's ridley sea turtles are thought to be regular visitors during those seasons. The green sea turtle has a distribution throughout tropical, subtropical and, to a lesser extent, temperate waters. Green sea turtles are expected to occur occasionally in the Project Area.

There are four federally listed threatened or endangered fish species that may occur off the northeast Atlantic coast, including the shortnose sturgeon (*Acipenser brevirostrum*), Atlantic sturgeon (*Acipenser oxyrinchus oxyrinchus*), Atlantic salmon (*Salmo salar)*, and giant manta ray (*Manta birostris*).

Atlantic sturgeon distribution varies by season, but they are primarily found in shallow coastal waters (bottom depth less than 20 m) during the summer months (May to September) and move to deeper waters (20 to 50 m) in winter and early spring (December to March) (Dunton et al. 2010). Shortnose sturgeon occur primarily in fresh and estuarine waters and occasionally enter the coastal ocean. Adults ascend rivers to spawn from February to April, and eggs are deposited over hard bottom, in shallow, fast-moving water (Dadswell et al. 1984). Because of their preference for mainland rivers and fresh and estuarine waters, shortnose sturgeon are unlikely to be found within 50 km of the Lease Area. Atlantic salmon is an anadromous species that historically ranged from northern Quebec southeast to Newfoundland and southwest to Long Island Sound. The Gulf of Maine distinct population segment (DPS) of the Atlantic salmon that spawns within eight coastal watersheds within Maine is federally listed as endangered. In 2009, the DPS was expanded to include all areas of the Gulf of Maine between the Androscoggin River and the Dennys River (NOAA Fisheries 2020a). Only certain Gulf of Maine populations are listed as endangered, and Gulf of Maine salmon are unlikely to be encountered south of Cape Cod (BOEM 2014a). The giant manta ray is found worldwide in tropical, subtropical, and temperate bodies of water and is commonly found offshore, in oceanic waters, and near productive coastlines. As such, giant manta rays can be found in cool water, as low as 19 to 22°C (66.2 to 71.6°F) whereas those off the Yucatan peninsula and Indonesia are commonly found in waters between 25 to 30°C (77 to 86°F) Individuals have been observed as far north as New Jersey in the Western Atlantic basin indicating that the Project Area is located at the northern boundary of the species' range (NOAA Fisheries 2020b).

2.8.4. Sea Turtle Density Estimates

There are limited density estimates for sea turtles in the Lease Area. For this analysis, sea turtle densities were obtained from the US Navy Operating Area Density Estimate (NODE) database on the Strategic Environmental Research and Development Program Spatial Decision Support System (SERDP-SDSS) portal (DoN 2007, 2012) and the Northeast Large Pelagic Survey Collaborative Aerial and Acoustic Surveys for Large Whales and Sea Turtles (Kraus et al. 2016). These numbers were adjusted by the Sea Mammal Research Unit (SMRU, 2013), available in the Ocean Biogeographic Information System Spatial Ecological Analysis of Megavertebrate Populations (OBIS-SEAMAP) (Halpin et al. 2009). These data are summarized seasonally (winter, spring, summer, and fall) and provided as a range of potential densities per square kilometer within each grid square. Leatherback and loggerhead sea turtles were the most commonly observed turtle species during aerial surveys by Kraus et al. (2016) in the MA/RI and MA WEAs, with an additional six identified Kemp's ridley sea turtle sightings over five years. Averaged seasonal leatherback sea turtle densities from Kraus et al. (2016) for summer and fall are used, as they provide more recent, non-zero estimates of leatherback density. Loggerhead densities were calculated for summer and fall by scaling the averaged leatherback densities from Kraus et al. (2016) by the ratio of the seasonal sighting rates of the two species during the surveys.

In OBIS-SEAMAP, because density is provided as a range, the maximum density will always exceed zero, even though turtles are unlikely to be present in winter. Maximum densities were assumed for all seasons. Thus, the winter densities of sea turtles in the Lease Area were very likely overestimated. The Project Area is on the northernmost border of the Mid-Atlantic North region defined in NEFSC and SEFSC (2011a) for sea turtle distribution. Sea turtles are expected to be present in the Lease Area during summer and fall months due to seasonal habitat use, with sea turtles moving to warmer water habitats in the winter months (Hawkes et al. 2007, Dodge et al. 2014, DoN, 2017). Sea turtles were most commonly observed in summer and fall, absent in winter, and nearly absent in spring during the Kraus et al. (2016) surveys of the MA WEA and RI/MA/RI WEAs. Sea turtle densities used in animal movement modeling are listed in Table 15.

Table 15. Sea turtle density estimates for all modeled species in the Mayflower Lease Area with a 50 km buffer.

Common name	Density (animals/100 km^2)[a]			
	Spring	Summer	Fall	Winter
Kemp's ridley sea turtle	0.006	0.006	0.006	0.006
Leatherback sea turtle	0.034	0.630[b]	0.873[b]	0.034
Loggerhead sea turtle	0.084	0.206[c]	0.755[c]	0.084
Green sea turtle[d]	0.006	0.006	0.006	0.006

[a] Density estimates are derived from the Strategic Environmental Research and Development Program - Spatial Decision Support System (Kot et al. 2018) unless otherwise noted.
[b] Densities calculated as averaged seasonal densities from 2011 to 2015 (Kraus et al. 2016).
[c] Densities calculated as the averaged seasonal leatherback sea turtle densities scaled by the relative, seasonal sighting rates of loggerhead and leatherback sea turtles (Kraus et al. 2016).
[d] Kraus et al. (2016) did not observe any green sea turtles in the RI/MA WEA. Densities of Kemp's ridley sea turtles are used as a conservative estimate.

3. Results

Acoustic fields produced by impact pile driving for jacket and monopile foundations were modeled at two sites to ensure representative coverage of water depths in the Lease Area (Table 3; Figure 4). Source modeling results are summarized in Section 3.1 with propagation modeling results (maximum-over depth single-strike sound field contour plots and range tables) detailed in Appendix F. Species-specific exposure ranges ($ER_{95\%}$) predictions are summarized in Sections 3.2 for marine mammals and 3.5 for sea turtles, and the number of marine mammals and sea turtles predicted to be exposed above regulatory thresholds are shown in Sections 3.3 and 3.6, respectively. Distances to regulatory thresholds for fish are provided in Section 3.7.

3.1. Modeled Source Levels

3.1.1. Impact Pile Driving

Forcing functions were computed for each pile diameter (2.9, 4.5, 11, and 16 m) at the two modeling locations, L01 and L02, using GRLWEAP 2010 (GRLWEAP, Pile Dynamics 2010). Resulting forcing functions versus time are shown in Figures 9 to 12 (modeling parameters and assumptions are listed in Appendix B.1). Calculation of the forcing function relies on many parameters, including hammer energy, ground resistance, and pile material and dimensions. To account for the amount of pile in the water and penetration depth when modeling, the letters “a”, “b”, and “c” following some hammer energies are used to represent initial, middle, and final pile driving stages, respectively, at that hammer energy level (Tables 1 and 2).

The forcing functions serve as the inputs to JASCO’s pile driving source models used to estimate equivalent acoustic source characteristics (Appendix E.1). Decidecade band equivalent spectral source levels are shown in Figures 13 to 22. Because sound production characteristics also change with the amount of pile in the water column and in the seabed, the same “a”, “b”, and “c” following some hammer energies were used to designate pile driving stages for source modeling as well.

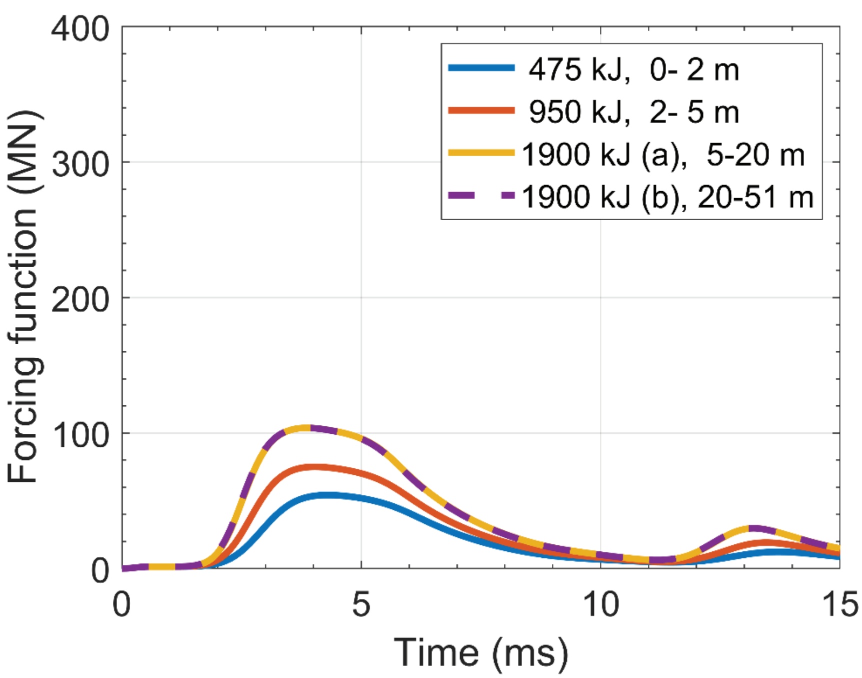

Figure 9. Modeled forcing functions versus time for a 2.9 m jacket foundation pile at different hammer energy levels and pile penetrations.

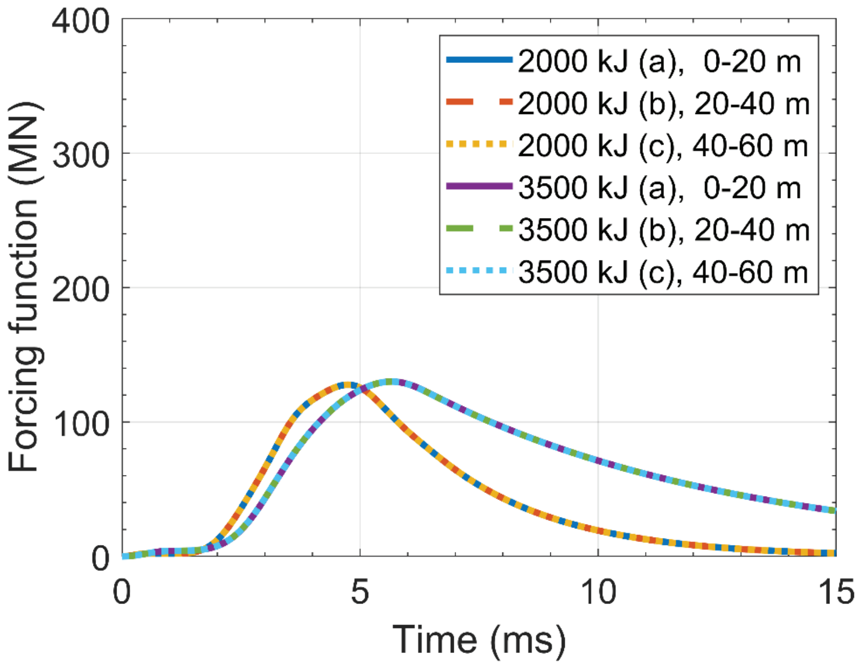

Figure 10. Modeled forcing functions versus time for a 4.5 m jacket foundation pile at different hammer energy levels and pile penetrations.

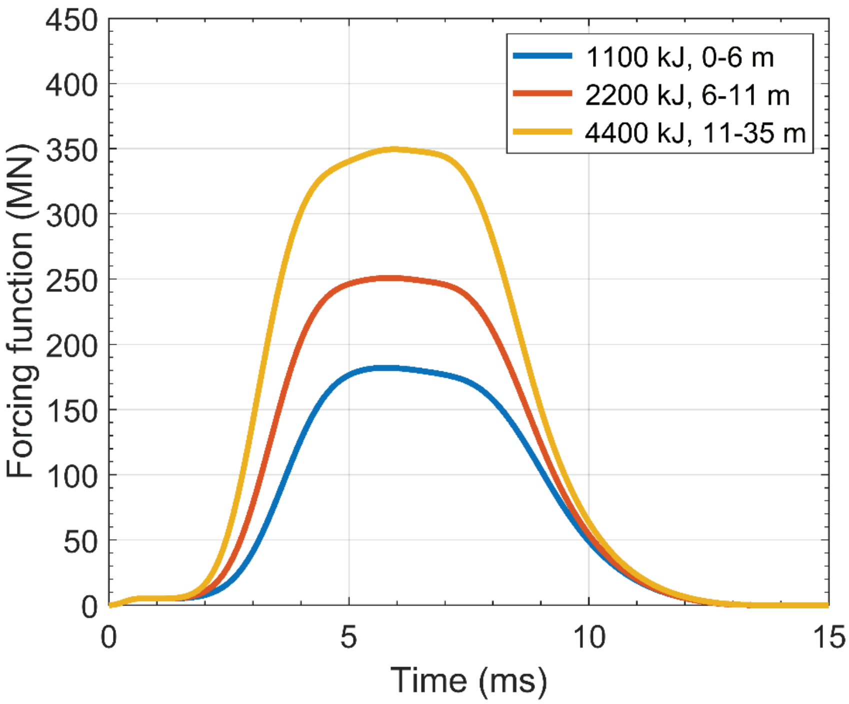

Figure 11. Modeled forcing functions versus time for an 11 m monopile at different hammer energies.

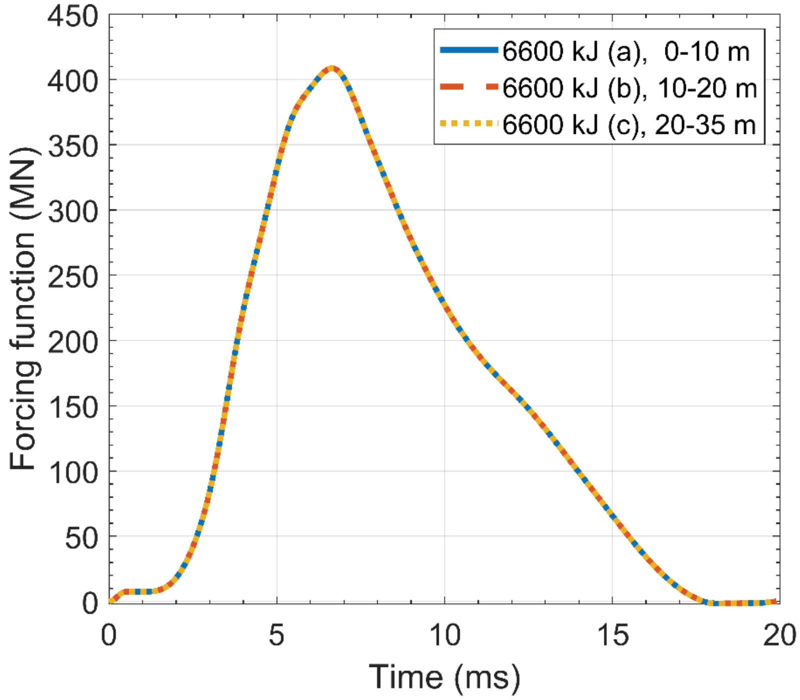

Figure 12. Modeled forcing functions versus time for a 16 m monopile at different pile penetrations.

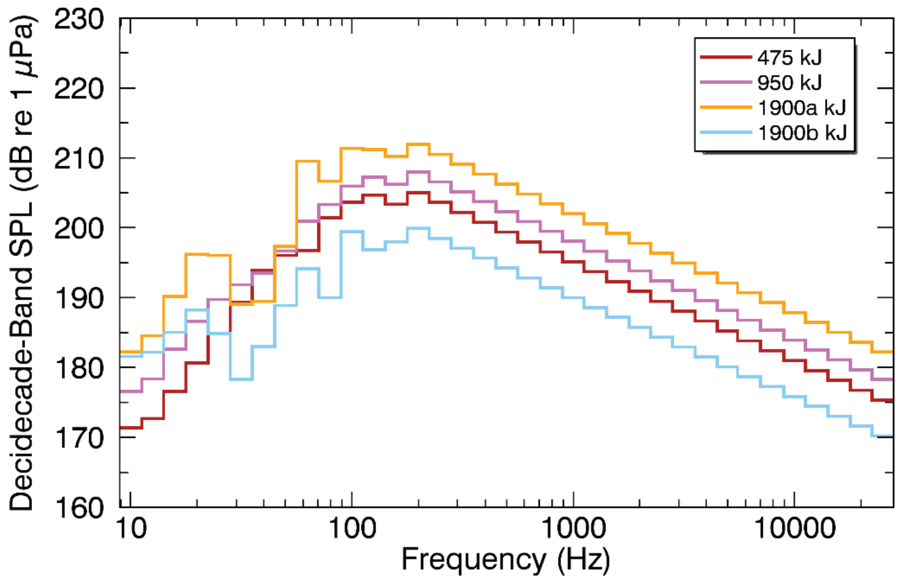

Figure 13. Decidecade band spectral source levels for 2.9 m jacket foundation pile installation using a 1900 kJ hammer energy at Location L01 (Figure 4).

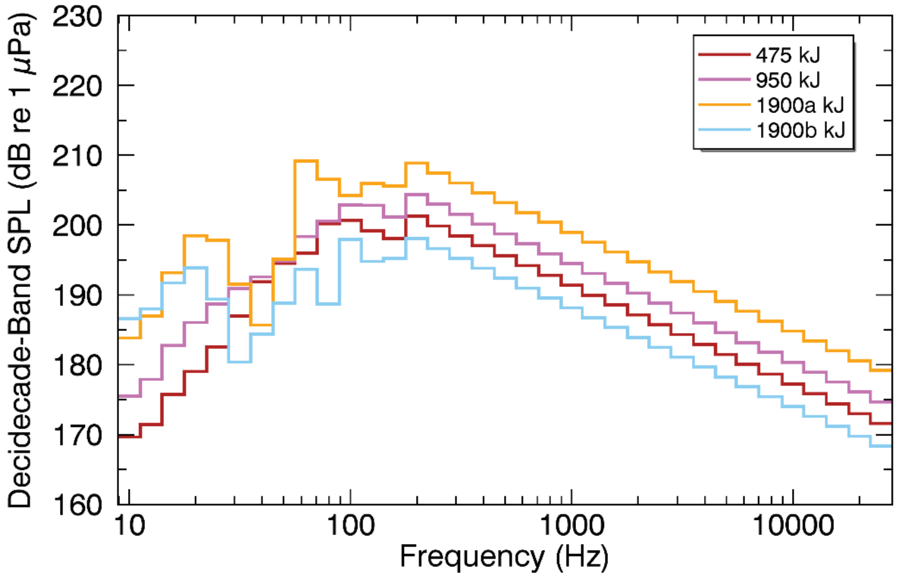

Figure 14. Decidecade band spectral source levels for 2.9 m jacket foundation pile installation using a 1900 kJ hammer energy at Location L02 (Figure 4).

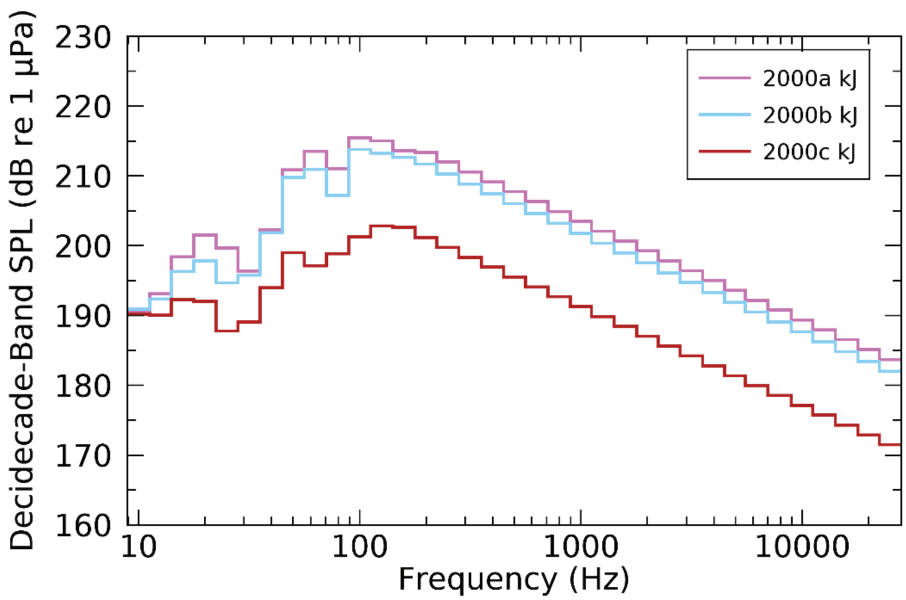

Figure 15. Decidecade band spectral source levels for 4.5 m jacket foundation pile installation using a 2000 kJ hammer energy at Location L01 (Figure 4).

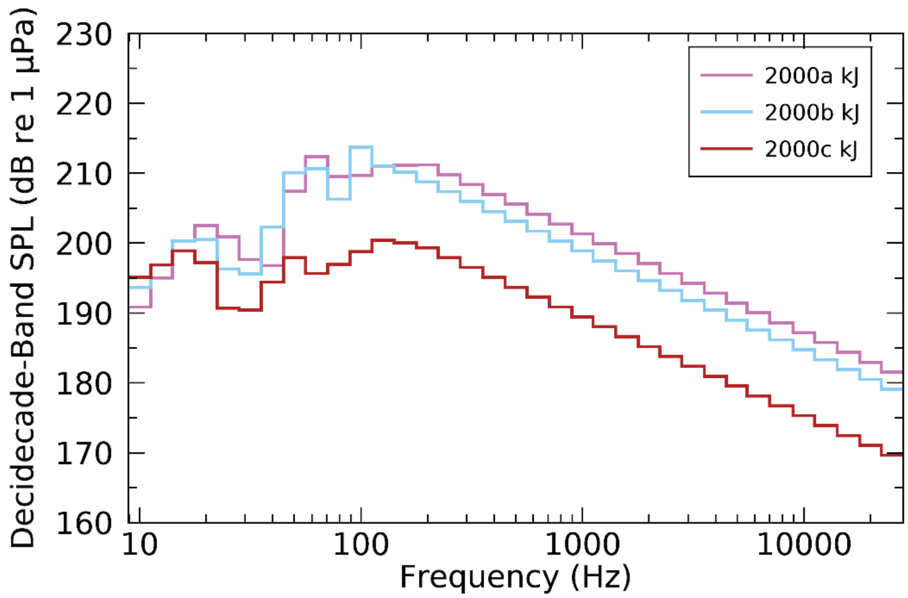

Figure 16. Decidecade band spectral source levels for 4.5 m jacket foundation pile installation using a 2000 kJ hammer energy at Location L02 (Figure 4).

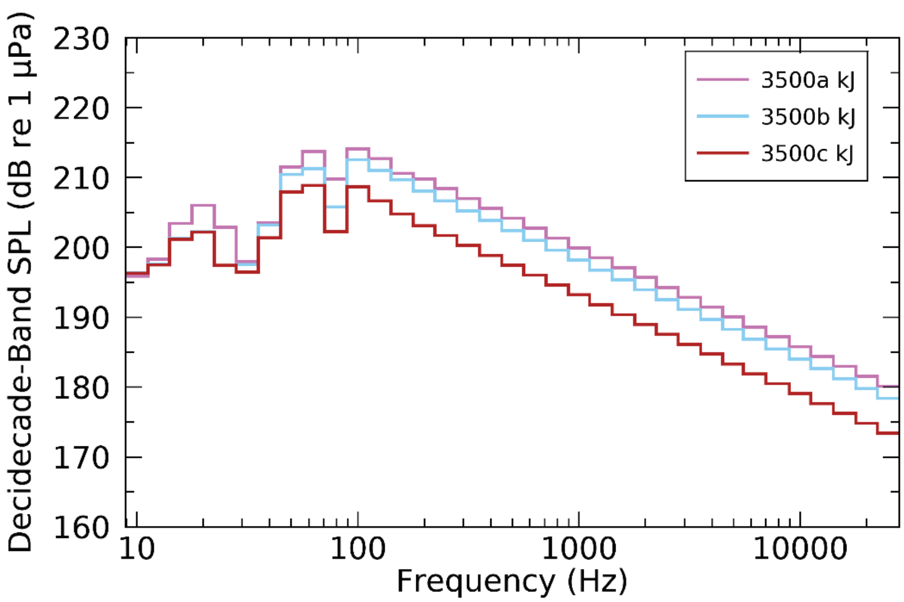

Figure 17. Decidecade band spectral source levels for 4.5 m jacket foundation pile installation using a 3500 kJ hammer energy at Location L01 (Figure 4).

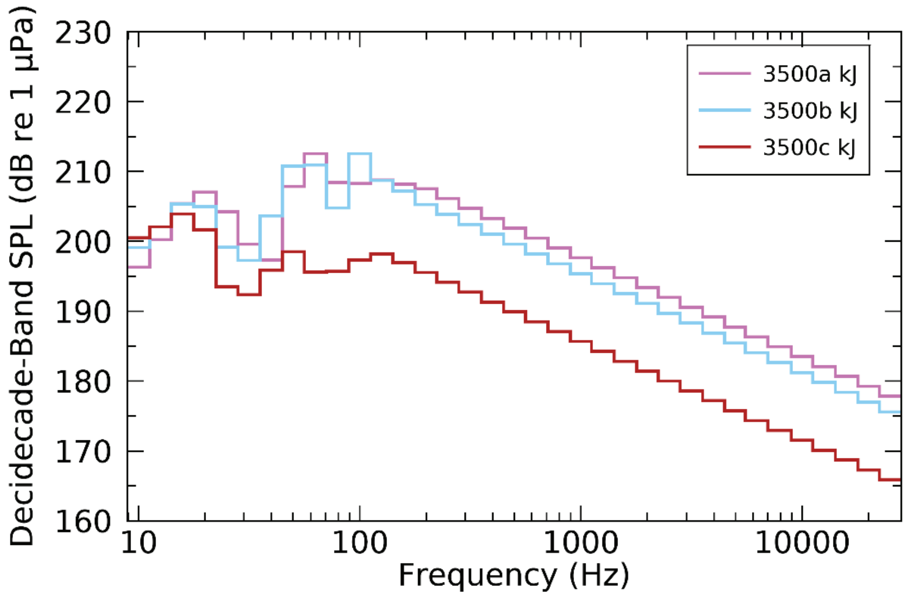

Figure 18. Decidecade band spectral source levels for 4.5 m jacket foundation pile installation using a 3500 kJ hammer energy at Location L02 (Figure 4).

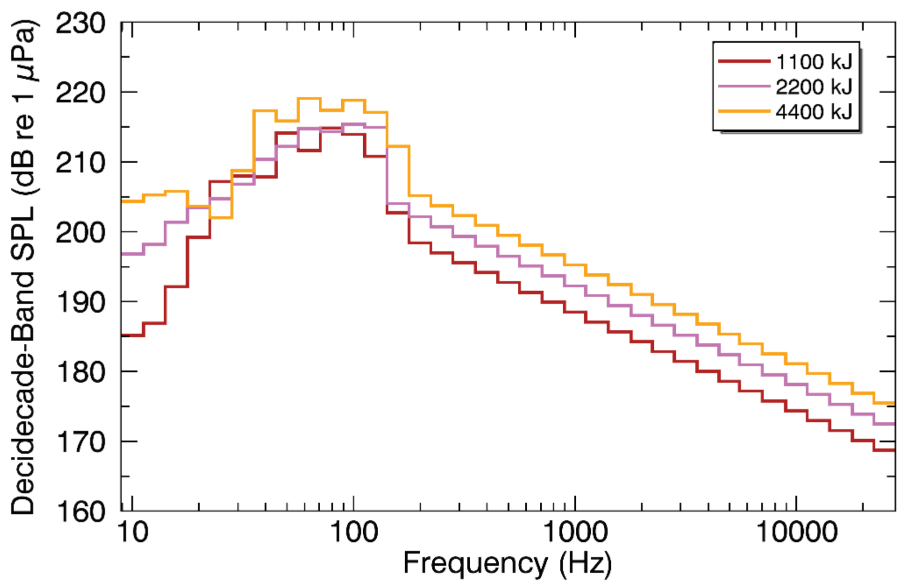

Figure 19. Decidecade band spectral source levels for 11 m monopile installation using 4400 kJ hammer energy at Location L01 (Figure 4).

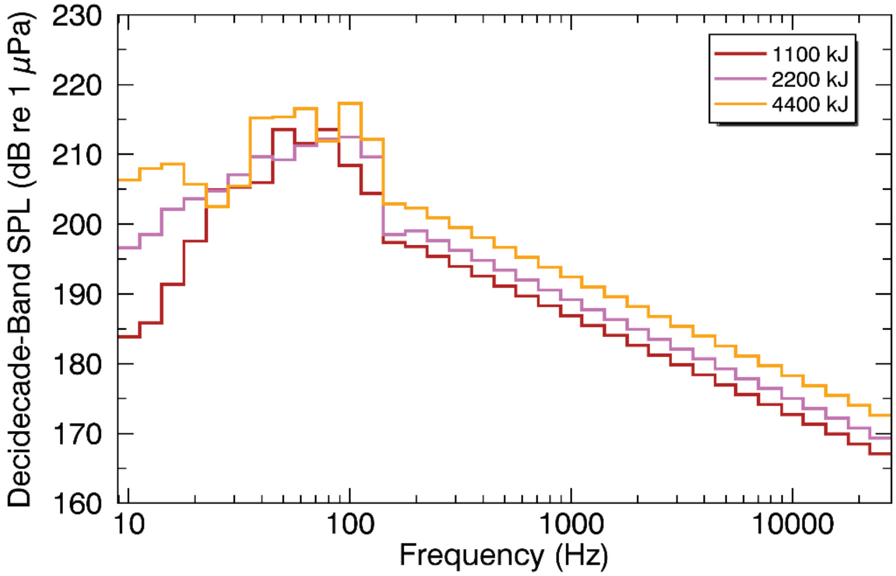

Figure 20. Decidecade band spectral source levels for 11 m monopile installation using 4400 kJ hammer energy at Location L02 (Figure 4).

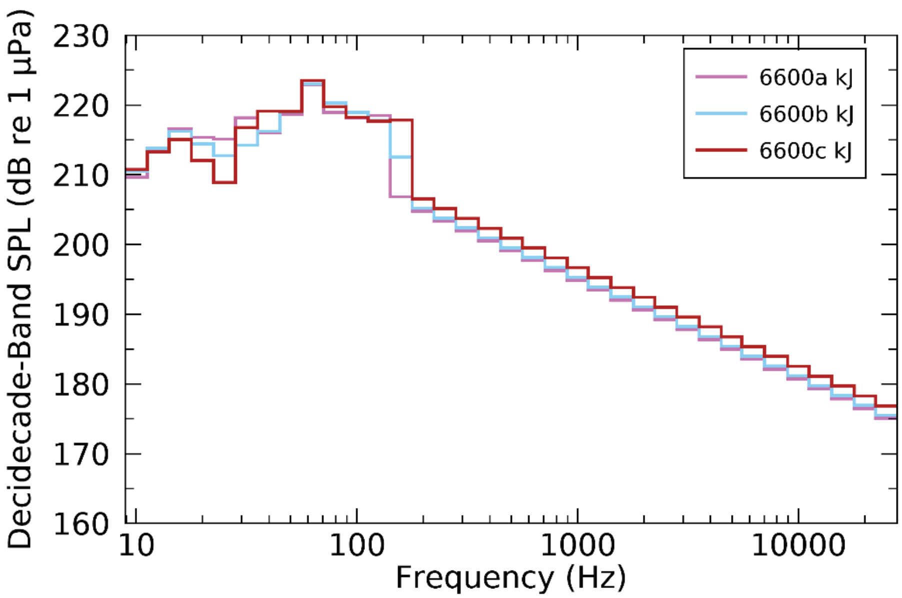

Figure 21. Decidecade band spectral source levels for 16 m monopile installation using 6600 kJ hammer energy at Location L01 (Figure 4).

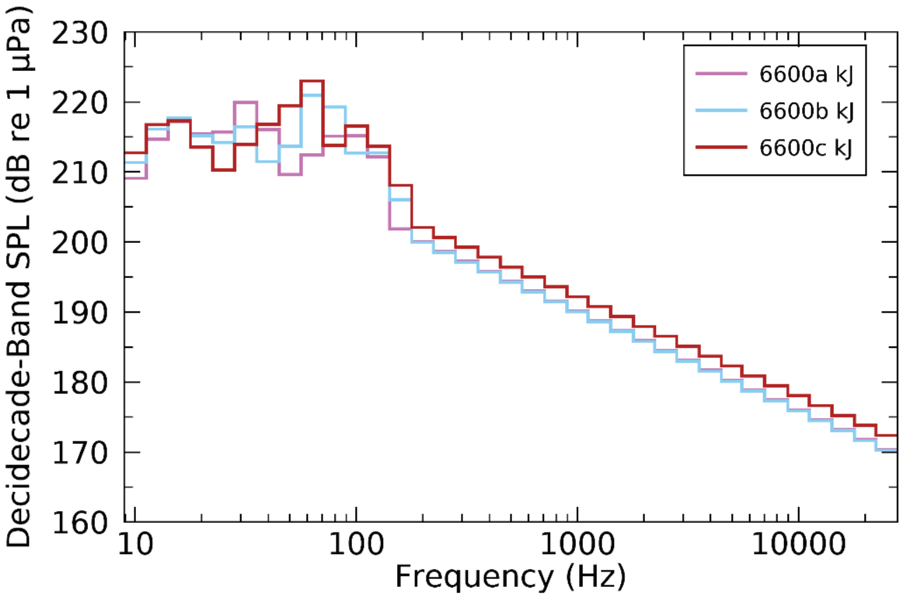

Figure 22. Decidecade band spectral source levels for 16 m monopile installation using 6600 kJ hammer energy at Location L02 (Figure 4).

3.2. Marine Mammal Exposure Range Estimates

Three-dimensional (3-D) sound fields for the realistic and maximum scenario monopile and jacket foundation piles were calculated using the source characteristics (Section 3.1.1 and Appendix E) at the two representative locations (L01 and L02). Environmental parameters (bathymetry, geoacoustic information, and sound speed profiles) chosen for the propagation modeling and the modeling procedures are described in Appendix E.2. Resultant acoustic radial distances to various isopleths for single hammer strikes at the different hammer energy levels are included in Appendix F.

Animal movement modeling (Section 2.6) is used to sample the 3-D sound fields in a way that incorporates the expected movements of real animals. Each species is governed by rules specific to that species, and the resulting exposure histories of the simulated animals (animats) can be used to predict the probability of threshold exceedance and features that contribute to it, such as distances from the source at which the exceedance may occur. Tables 16 to 21 show species-specific exposure ranges ($ER_{95\%}$, see Section 2.7); the closest points of approach accounting for 95 percent of exposures above Level A (NMFS 2018) and Level B (NOAA 2005, Wood et al. 2012) acoustic thresholds. Results are shown for the pile types included in the realistic and maximum scenarios in Tables 4 and 5 for jacket and monopile foundations with broadband attenuation of 0, 6, 10, and 15 dB. Exposure ranges for pile types not included in the construction schedules can be found in Appendix G.2.1.

Table 16. Realistic scenario WTG jacket foundation (2.9 m diameter, MHU1900S hammer, three piles per day) exposure ranges ($ER_{95\%}$) in km to marine mammal Level A and Level B thresholds with sound attenuation.

Low-frequency cetaceans																
Fin whale[a] (sei whale[a,b])	5.94	2.98	1.65	0.74	<0.01	0	0	0	8.31	4.46	3.12	2.48	8.35	4.47	3.12	2.48
Minke whale	3.91	1.92	0.86	0.20	0.01	0	0	0	7.74	4.34	3.01	2.37	7.82	4.37	3.02	2.38
Humpback whale	9.04	4.21	2.02	0.86	0	0	0	0	8.87	4.74	3.23	2.56	8.89	4.74	3.18	2.56
North Atlantic right whale[a]	5.69	3.05	1.57	0.69	0.02	0	0	0	8.40	4.38	3.23	2.39	8.47	4.38	3.22	2.39
Mid-frequency cetaceans																
Atlantic white sided dolphin	0.01	0	0	0	0	0	0	0	7.95	4.37	2.99	2.32	5.84	3.16	2.59	1.39
Short-beaked common dolphin	0.02	0.02	0.02	0	0	0	0	0	8.04	4.43	3.08	2.41	5.88	3.17	2.73	1.55
Bottlenose dolphin	0.07	<0.01	<0.01	0	0	0	0	0	9.27	4.99	3.29	2.74	6.77	3.48	2.94	1.64
Risso's dolphin	0.01	0.01	0.01	0	0	0	0	0	8.13	4.40	3.00	2.30	5.92	3.14	2.57	1.46
Pilot whale	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sperm whale[a]	0	0	0	0	0	0	0	0	8.52	4.64	3.05	2.35	5.96	3.15	2.61	1.41
High-frequency cetaceans																
Harbor porpoise	4.76	2.62	1.65	0.61	0.40	0.16	0.09	0.05	8.29	4.55	3.06	2.39	57.31	53.91	49.83	43.14
Pinnipeds in water																
Gray seal	2.10	0.79	0.21	0.04	<0.01	<0.01	<0.01	0	8.89	4.80	3.27	2.34	7.62	4.21	3.06	2.11
Harbor seal	2.03	0.69	0.18	0	0.06	0	0	0	8.73	4.72	3.16	2.66	7.80	4.21	3.04	2.02

[a] Listed as Endangered under the ESA.
[b] Fin whale used as a surrogate for sei whale behavioral definition.

Table 17. Realistic scenario OSP jacket foundation[a] (4.5 m diameter, IHCS2000 hammer, four piles per day) exposure ranges ($ER_{95\%}$) in km to marine mammal Level A and Level B thresholds with sound attenuation.

Species	Level A								Level B							
	L_E (NMFS 2018)				L_{PK} (NMFS 2018)				L_p (NOAA 2005)				L_p (Wood et al. 2012)			
	Attenuation (dB)								Attenuation (dB)							
	0	6	10	15	0	6	10	15	0	6	10	15	0	6	10	15
Low-frequency cetaceans																
Fin whale[b] (sei whale[b,c])	11.39	6.11	3.69	1.76	0.07	0	0	0	10.80	6.53	4.41	3.06	11.04	6.63	4.45	3.06
Minke whale	6.79	3.52	1.98	0.72	0.07	0.01	0	0	10.56	6.36	4.36	3.00	10.79	6.45	4.38	3.00
Humpback whale	18.49	10.29	6.53	2.77	0	0	0	0	11.47	6.78	4.61	3.02	11.59	6.80	4.65	3.02
North Atlantic right whale[a]	10.88	5.77	3.62	1.83	0.07	0	0	0	10.79	6.44	4.40	3.09	10.97	6.50	4.43	3.09
Mid-frequency cetaceans																
Atlantic white sided dolphin	0.04	0	0	0	0	0	0	0	10.77	6.38	4.43	3.00	7.86	4.31	3.04	2.33
Short-beaked common dolphin	0.02	0.02	0.02	0	0	0	0	0	10.78	6.47	4.36	3.04	7.76	4.25	3.08	2.35
Bottlenose dolphin	0.82	0.07	<0.01	<0.01	0	0	0	0	11.45	7.09	4.82	3.22	8.57	4.98	3.29	2.69
Risso's dolphin	0.02	0.01	0.01	0.01	0	0	0	0	10.85	6.31	4.42	3.04	7.87	4.38	3.08	2.25
Pilot whale	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sperm whale[b]	0.27	<0.01	0	0	0	0	0	0	11.09	6.68	4.51	3.02	7.91	4.34	3.02	2.31
High-frequency cetaceans																
Harbor porpoise	7.37	4.46	2.85	1.65	0.65	0.33	0.16	0.10	10.92	6.68	4.54	3.03	59.63	57.84	52.82	47.33
Pinnipeds in water																
Gray seal	5.27	2.19	1.11	0.20	0.04	0	0	0	11.42	6.84	4.64	3.15	9.91	5.78	3.59	2.72
Harbor seal	4.86	2.12	1.03	0.21	0.09	0.03	0	0	11.23	6.83	4.60	3.12	9.74	5.72	3.76	2.89

[a] OSP foundations include a 2 dB shift for post piling.
[b] Listed as Endangered under the ESA.
[c] Fin whale used as a surrogate for sei whale behavioral definition.

Table 18. Realistic scenario WTG monopile foundation (11 m diameter, MHU4400S hammer, one pile per day) exposure ranges in km to marine mammal Level A and Level B thresholds with sound attenuation.

Species	Level A								Level B							
	L_E (NMFS 2018)				L_{PK} (NMFS 2018)				L_p (NOAA 2005)				L_p (Wood et al. 2012)			
	Attenuation (dB)								Attenuation (dB)							
	0	6	10	15	0	6	10	15	0	6	10	15	0	6	10	15
Low-frequency cetaceans																
Fin whale[a] (sei whale[a,b])	7.17	3.63	2.06	0.75	0.05	<0.01	0	0	10.54	6.64	4.57	3.13	10.61	6.64	4.59	3.12
Minke whale	4.48	1.86	0.83	0.12	0.01	0	0	0	10.27	6.41	4.43	3.04	10.42	6.46	4.44	3.04
Humpback whale	9.69	4.62	2.44	1.13	0.04	0	0	0	10.87	6.71	4.62	3.06	10.87	6.67	4.62	3.06
North Atlantic right whale[a]	6.45	3.41	1.77	0.68	0.06	0	0	0	10.55	6.52	4.52	3.16	10.58	6.52	4.51	3.17
Mid-frequency cetaceans																
Atlantic white sided dolphin	0	0	0	0	0	0	0	0	10.55	6.35	4.34	3.03	4.29	2.80	2.44	1.22
Short-beaked common dolphin	0.02	0	0	0	0	0	0	0	10.44	6.50	4.40	3.10	4.42	2.89	2.43	1.26
Bottlenose dolphin	0	0	0	0	0	0	0	0	10.65	6.69	4.66	3.27	4.62	3.03	2.60	1.35
Risso's dolphin	<0.01	<0.01	0	0	0	0	0	0	10.55	6.51	4.41	3.15	4.43	2.92	2.39	1.28
Pilot whale	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sperm whale[a]	0	0	0	0	0	0	0	0	10.64	6.71	4.62	3.05	4.54	2.91	2.41	1.41
High-frequency cetaceans																
Harbor porpoise	3.00	1.31	0.52	<0.01	0.71	0.32	0.25	0.10	10.51	6.59	4.54	3.15	56.31	50.00	40.66	28.78
Pinnipeds in water																
Gray seal	1.38	0.29	0.01	0	0.08	0	0	0	10.78	6.81	4.65	3.14	7.73	4.33	3.19	2.59
Harbor seal	1.37	0.24	0	0	0	0	0	0	10.69	6.73	4.68	3.19	7.73	4.20	3.19	2.72

[a] Listed as Endangered under the ESA.
[b] Fin whale used as a surrogate for sei whale behavioral definition.

Table 19. Maximum scenario WTG jacket foundation (4.5 m diameter, MHU3500S hammer, four piles per day) exposure ranges ($ER_{95\%}$) in km to marine mammal Level A and Level B thresholds with sound attenuation.

Low-frequency cetaceans																
Fin whale[a] (sei whale[a,b])	6.33	2.92	1.64	0.49	0.03	0	0	0	7.28	4.23	3.04	2.45	7.40	4.26	3.05	2.47
Minke whale	3.78	1.60	0.67	0.08	0.01	0	0	0	7.16	4.11	3.03	2.43	7.24	4.12	3.04	2.40
Humpback whale	10.26	4.53	2.48	0.85	0	0	0	0	7.89	4.50	3.07	2.54	7.90	4.52	3.07	2.55
North Atlantic right whale[a]	6.01	2.93	1.61	0.72	<0.01	0	0	0	7.38	4.20	3.15	2.41	7.45	4.19	3.15	2.41
Mid-frequency cetaceans																
Atlantic white sided dolphin	0	0	0	0	0	0	0	0	7.18	4.14	3.10	2.38	4.30	2.79	2.21	1.29
Short-beaked common dolphin	0.02	0.02	0	0	0	0	0	0	7.27	4.22	3.04	2.41	4.41	2.77	2.25	1.29
Bottlenose dolphin	0.11	0	0	0	0	0	0	0	7.92	4.61	3.31	2.69	4.95	3.00	2.40	1.41
Risso's dolphin	<0.01	0	0	0	0	0	0	0	7.28	4.19	3.05	2.36	4.48	2.79	2.20	1.24
Pilot whale	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sperm whale[a]	0	0	0	0	0	0	0	0	7.57	4.31	3.06	2.40	4.45	2.75	2.31	1.22
High-frequency cetaceans																
Harbor porpoise	4.33	2.30	1.25	0.41	0.42	0.13	0.09	0.05	7.40	4.26	3.12	2.46	57.73	50.83	47.38	33.11
Pinnipeds in water																
Gray seal	1.88	0.45	0.16	0.02	0.02	0	0	0	7.75	4.43	3.28	2.51	6.27	3.41	2.80	2.10
Harbor seal	1.95	0.43	0.18	<0.01	<0.01	0	0	0	7.77	4.37	3.19	2.55	6.12	3.26	2.86	1.90

[a] Listed as Endangered under the ESA.
[b] Fin whale used as a surrogate for sei whale behavioral definition.

Table 20. Maximum scenario OSP jacket foundation[a] (4.5 m diameter, MHU3500S hammer, four piles per day) exposure ranges ($ER_{95\%}$) in km to marine mammal Level A and Level B thresholds with sound attenuation.

Low-frequency cetaceans																
Fin whale[b] (sei whale[b,c])	7.81	3.81	2.22	0.81	0.03	0.03	0	0	8.88	5.11	3.50	2.64	9.00	5.14	3.51	2.64
Minke whale	4.73	2.16	1.05	0.22	0.03	0	0	0	8.47	5.03	3.38	2.67	8.63	5.07	3.38	2.67
Humpback whale	12.83	6.29	3.41	1.37	0	0	0	0	9.45	5.39	3.60	2.78	9.46	5.39	3.60	2.78
North Atlantic right whale[b]	7.42	3.68	2.07	0.90	<0.01	0	0	0	8.97	5.13	3.44	2.71	9.06	5.16	3.45	2.71
Mid-frequency cetaceans																
Atlantic white sided dolphin	0	0	0	0	0	0	0	0	8.57	4.99	3.35	2.64	5.41	3.10	2.47	1.52
Short-beaked common dolphin	0.02	0.02	0	0	0	0	0	0	8.63	5.13	3.33	2.65	5.48	3.06	2.57	1.62
Bottlenose dolphin	0.32	0	0	0	0	0	0	0	9.59	5.54	3.70	2.92	6.01	3.37	2.92	1.94
Risso’s dolphin	<0.01	0	0	0	0	0	0	0	8.74	5.01	3.48	2.63	5.57	3.06	2.52	1.54
Pilot whale	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sperm whale[b]	0	0	0	0	0	0	0	0	9.10	5.35	3.46	2.62	5.60	3.03	2.48	1.50
High-frequency cetaceans																
Harbor porpoise	5.21	2.83	1.73	0.69	0.51	0.24	0.09	0.05	8.81	5.16	3.45	2.69	58.44	53.74	49.45	38.45
Pinnipeds in water																
Gray seal	3.27	1.01	0.43	0.04	0.02	<0.01	0	0	9.33	5.37	3.62	2.80	7.41	4.00	3.11	2.21
Harbor seal	2.77	0.93	0.23	<0.01	0.06	0	0	0	9.15	5.12	3.60	2.86	7.42	4.07	3.05	2.32

[a] OSP foundations include a 2 dB shift for post piling.
[b] Listed as Endangered under the ESA.
[c] Fin whale used as a surrogate for sei whale behavioral definition.

Table 21. Maximum scenario WTG monopile foundation (16 m diameter, 6600 kJ hammer, 7000 strikes, one pile per day) exposure ranges ($ER_{95\%}$) in km to marine mammal Level A and Level B thresholds with sound attenuation.

Low-frequency cetaceans																
Fin whale[a] (sei whale[a,b])	10.43	5.96	3.70	1.81	0.11	<0.01	0	0	13.78	9.08	6.63	4.16	13.87	9.17	6.67	4.15
Minke whale	6.73	3.49	1.94	0.73	0.08	<0.01	0	0	13.37	8.99	6.48	4.05	13.53	9.09	6.49	4.04
Humpback whale	14.84	8.36	4.92	2.45	0.07	0	0	0	14.12	9.26	6.80	4.39	14.20	9.30	6.80	4.40
North Atlantic right whale[a]	9.72	5.40	3.59	1.63	0.07	0	0	0	13.68	8.97	6.63	4.22	13.82	9.04	6.64	4.23
Mid-frequency cetaceans																
Atlantic white sided dolphin	0	0	0	0	0	0	0	0	13.54	8.95	6.50	4.05	6.34	3.26	2.72	1.83
Short-beaked common dolphin	0.02	0.02	0	0	0	0	0	0	13.47	8.99	6.57	4.07	6.54	3.34	2.76	2.05
Bottlenose dolphin	0	0	0	0	0	0	0	0	13.80	9.39	6.79	4.37	6.92	3.59	2.95	2.29
Risso’s dolphin	<0.01	<0.01	0	0	0	0	0	0	13.70	9.03	6.58	4.13	6.62	3.33	2.78	2.00
Pilot whale	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sperm whale[a]	0	0	0	0	0	0	0	0	13.91	9.23	6.73	4.28	6.78	3.38	2.85	2.22
High-frequency cetaceans																
Harbor porpoise	4.11	2.18	1.04	0.27	0.81	0.34	0.24	0.10	13.76	9.21	6.53	4.16	57.30	52.92	49.63	37.37
Pinnipeds in water																
Gray seal	2.64	0.82	0.37	0.01	0.07	0	0	0	13.79	9.38	6.78	4.26	10.61	6.43	4.00	2.93
Harbor seal	2.29	0.61	0.19	0.02	0.10	0.02	0	0	13.79	9.24	6.72	4.25	10.57	6.38	4.21	3.01

[a] Listed as Endangered under the ESA.
[b] Fin whale used as a surrogate for sei whale behavioral definition.

3.3. Marine Mammal Exposure Estimates

Exposure forecasts of animats in the animal movement modeling simulations predict the probability of threshold exceedance. The number of real-world animals predicted to exceed thresholds, the exposure estimates, are derived by scaling the number of animats exceeding threshold (Appendix G.2) by the ratio of the real-world density (Section 2.8.2) to the modeling density (Appendix G.1.3). Project-level exposure estimates are found by summing the number of individuals above threshold in each construction month.

The construction schedules described in Tables 4 and 5 were used to determine the total number of real-world individual marine mammals predicted to receive sound levels above the Level A and Level B thresholds (NOAA 2005, Wood et al. 2012, NMFS 2018) in the Lease Area over both years of the Project, for both realistic and maximum scenarios. Tables 22 to 25 show the mean number of individual animals expected to exceed threshold assuming broadband attenuation of 0, 6, 10, and 15 dB during the summer season. The mean number represents a probability of exposure. For example, a mean exposure of 0.10 indicates that there is a 10 percent chance of exposing one animal above threshold. A mean exposure greater than 1 indicates that more than one animal is predicted to exceed threshold. Similar results for the realistic scenario are provided separately for each Project year in Appendix G.2.2. The exposure estimates reported in Tables 22 to 25 do not take into account animals avoiding loud sounds (aversion) or the implementation of mitigation measures other than sound attenuation. For comparative purposes only, a demonstration of the effect of aversion on exposure estimates is provided in Section 3.3.1.

Table 22. Realistic WTG jacket foundation schedule: the mean number of modeled marine mammals estimated to experience sound levels above exposure criteria for different sound attenuation levels (Table 4). The schedule includes the installation of both WTG and OSP foundations (Table 4).

Species	Level A								Level B							
	L_E (NMFS 2018)				L_{pk} (NMFS 2018)				L_p (NOAA 2005)				L_p (Wood et al. 2012)			
	Attenuation (dB)								Attenuation (dB)							
	0	6	10	15	0	6	10	15	0	6	10	15	0	6	10	15
Low-frequency cetaceans																
Fin whale[a]	345.92	136.14	58.83	15.77	0.17	0	0	0	544.05	281.71	181.85	114.25	571.96	320.67	216.41	136.22
Minke whale	110.85	40.02	15.59	3.27	0.11	<0.01	0	0	300.73	160.34	104.63	63.03	269.53	158.40	111.04	71.38
Humpback whale	24.49	9.03	4.28	1.49	0	0	0	0	30.96	12.71	7.50	5.16	36.74	20.36	13.49	7.91
North Atlantic right whale[a]	5.24	2.26	1.05	0.29	<0.01	0	0	0	9.48	4.60	2.92	1.75	10.22	5.64	3.80	2.31
Sei whale[a]	15.87	6.38	2.84	0.81	<0.01	0	0	0	24.54	12.79	8.28	5.24	25.63	14.42	9.75	6.16
Mid-frequency cetaceans																
Atlantic white sided dolphin	1.89	0	0	0	0	0	0	0	5622.89	2917.59	1813.68	1054.39	4390.99	2375.01	1605.40	918.68
Short-beaked common dolphin	8.96	8.88	4.48	0	0	0	0	0	32811.52	18515.42	12225.50	7475.73	23055.88	13295.51	9501.94	5553.42
Bottlenose dolphin	7.05	2.28	2.14	0.03	0	0	0	0	2052.34	738.83	392.54	220.51	2122.43	1053.65	657.16	319.79
Risso's dolphin	0.36	0.18	0.18	<0.01	0	0	0	0	527.55	284.33	190.41	120.75	424.33	234.12	163.46	93.17
Pilot whale[b]	0	0	0	0	0	0	0	0	0	0	0	0	0.31	0	0	0
Sperm whale[a]	<0.01	<0.01	0	0	0	0	0	0	22.78	10.15	6.33	4.16	19.94	10.44	6.96	3.65
High-frequency cetaceans																
Harbor porpoise	860.67	381.58	176.08	62.65	48.82	21.72	7.98	1.34	1743.59	866.62	532.47	332.45	13991.50	11171.35	9098.06	6644.30
Pinnipeds in water																
Gray seal	153.75	34.61	9.10	2.16	0.82	0.70	0.70	0	1152.43	506.14	301.53	183.54	1305.49	678.41	435.97	245.41
Harbor seal	123.77	27.05	9.03	0.54	0.95	0.04	0	0	1114.84	473.72	281.11	165.16	1273.87	649.19	420.96	230.48

[a] Listed as Endangered under the ESA.
[b] Long- and short-finned pilot whales are combined.

Table 23. Realistic WTG monopile foundation schedule: the mean number of modeled marine mammals estimated to experience sound levels above exposure criteria for different sound attenuation levels (Table 4). The schedule includes the installation of both WTG and OSP foundations (Table 4).

Species	Level A								Level B							
	L_E (NMFS 2018)				L_{pk} (NMFS 2018)				L_p (NOAA 2005)				L_p (Wood et al. 2012)			
	Attenuation (dB)								Attenuation (dB)							
	0	6	10	15	0	6	10	15	0	6	10	15	0	6	10	15
Low-frequency cetaceans																
Fin whale [a]	225.70	95.68	46.85	13.16	0.63	0.15	0	0	460.49	253.22	161.68	110.94	474.65	276.35	187.89	120.53
Minke whale	88.33	33.73	13.79	2.30	0.14	<0.01	0	0	282.08	166.09	113.91	79.73	259.81	157.42	111.23	74.99
Humpback whale	20.92	6.61	3.25	1.13	0.04	0	0	0	34.54	14.71	7.94	4.91	37.26	21.24	14.02	8.25
North Atlantic right whale [a]	8.18	3.39	1.44	0.54	0.03	0	0	0	22.04	11.04	7.07	4.42	23.11	12.96	8.86	5.49
Sei whale [a]	15.16	6.49	3.21	0.93	0.04	<0.01	0	0	30.39	16.73	10.70	7.35	31.24	18.21	12.39	7.96
Mid-frequency cetaceans																
Atlantic white sided dolphin	0.24	0	0	0	0	0	0	0	5082.29	2680.04	1750.23	1200.00	2404.79	1345.13	910.26	492.22
Short-beaked common dolphin	4.04	0.09	0.09	0	0	0	0	0	19565.90	11663.17	8059.14	5805.07	9037.12	5457.09	3815.28	2177.34
Bottlenose dolphin	0.73	0.17	0.03	0.03	0	0	0	0	2100.68	893.63	493.85	269.16	1060.41	516.60	311.84	132.43
Risso's dolphin	0.18	0.17	<0.01	<0.01	0	0	0	0	385.97	218.71	139.82	96.92	184.50	103.58	70.86	40.04
Pilot whale[b]	0	0	0	0	0	0	0	0	0	0	0	0	0.31	0	0	0
Sperm whale[a]	<0.01	<0.01	0	0	0	0	0	0	21.78	10.39	6.08	3.83	10.53	5.64	3.53	1.74
High-frequency cetaceans																
Harbor porpoise	310.57	129.56	53.18	8.91	80.55	32.19	14.47	3.28	1740.47	943.24	581.98	396.51	11899.07	8572.68	6217.08	3942.07
Pinnipeds in water																
Gray seal	92.79	26.22	5.80	0.76	4.97	0	0	0	2466.32	1142.37	667.84	371.42	1977.45	1047.68	668.52	396.60
Harbor seal	72.09	14.94	2.90	0.54	0.27	0.04	0	0	2287.19	1066.54	594.06	361.75	1905.88	973.56	638.88	351.76

[a] Listed as Endangered under the ESA.
[b] Long- and short-finned pilot whales are combined.

Table 24. Maximum WTG jacket foundation schedule: the mean number of modeled marine mammals estimated to experience sound levels above exposure criteria for different sound attenuation levels (Table 5). The schedule includes the installation of both WTG and OSP foundations (Table 5).

Species	Level A								Level B							
	L_E (NMFS 2018)				L_{pk} (NMFS 2018)				L_p (NOAA 2005)				L_p (Wood et al. 2012)			
	Attenuation (dB)								Attenuation (dB)							
	0	6	10	15	0	6	10	15	0	6	10	15	0	6	10	15
Low-frequency cetaceans																
Fin whale[a]	359.27	152.59	69.32	17.57	0.53	<0.01	0	0	498.73	284.29	214.07	152.87	497.81	292.80	210.87	141.76
Minke whale	131.55	45.75	16.15	2.65	0.10	0	0	0	329.21	189.58	142.98	99.87	281.91	170.80	127.83	88.85
Humpback whale	26.63	9.67	4.84	1.49	0	0	0	0	26.38	12.06	7.87	5.89	32.35	18.21	12.09	7.35
North Atlantic right whale[a]	25.18	10.65	5.16	1.51	0.02	0	0	0	39.79	21.77	16.04	11.00	41.84	24.12	17.12	11.00
Sei whale[a]	19.07	8.13	3.72	0.96	0.03	<0.01	0	0	26.42	15.06	11.30	8.09	26.37	15.51	11.15	7.51
Mid-frequency cetaceans																
Atlantic white sided dolphin	0	0	0	0	0	0	0	0	6034.31	3398.74	2541.28	1703.19	3820.33	2280.07	1557.87	845.02
Short-beaked common dolphin	9.64	5.03	0	0	0	0	0	0	35608.26	21512.07	16749.46	12219.05	20477.79	13208.39	9509.82	5349.79
Bottlenose dolphin	5.97	0	0	0	0	0	0	0	1414.07	573.72	348.93	205.71	1332.26	665.44	398.79	179.36
Risso's dolphin	0.16	0	0	0	0	0	0	0	440.47	261.22	200.45	147.21	292.02	177.51	123.18	70.26
Pilot whale[b]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sperm whale[a]	0	0	0	0	0	0	0	0	18.06	8.96	6.49	4.85	13.13	7.36	4.96	2.54
High-frequency cetaceans																
Harbor porpoise	1037.50	490.48	234.57	52.75	75.85	22.73	11.09	6.68	2071.84	1161.17	850.09	608.20	16374.66	12401.40	9900.92	6465.16
Pinnipeds in water																
Gray seal	230.64	52.66	9.21	2.85	2.76	0.09	0	0	1745.05	835.05	570.65	403.10	1829.67	964.84	645.22	357.21
Harbor seal	198.41	31.71	8.66	1.34	1.43	0	0	0	1674.07	771.44	537.66	354.69	1777.26	924.97	622.61	335.82

[a] Listed as Endangered under the ESA.
[b] Long- and short-finned pilot whales are combined.

Table 25. Maximum WTG monopile foundation schedule: the mean number of modeled marine mammals estimated to experience sound levels above exposure criteria for different sound attenuation levels (Table 5). The schedule includes the installation of both WTG and OSP foundations (Table 5).

Species	Level A								Level B							
	L_E (NMFS 2018)				L_{pk} (NMFS 2018)				L_p (NOAA 2005)				L_p (Wood et al. 2012)			
	Attenuation (dB)								Attenuation (dB)							
	0	6	10	15	0	6	10	15	0	6	10	15	0	6	10	15
Low-frequency cetaceans																
Fin whale[a]	344.82	160.24	88.14	35.67	1.50	0.13	0	0	585.91	341.35	233.61	141.21	558.91	345.65	243.56	152.99
Minke whale	117.55	53.65	24.67	6.12	0.45	0.04	0	0	309.38	195.02	139.12	90.22	270.27	176.48	127.83	84.05
Humpback whale	37.07	14.12	6.22	2.55	0.11	0	0	0	47.06	22.78	13.41	6.98	44.26	26.85	18.42	11.04
North Atlantic right whale[a]	25.41	10.90	5.99	2.11	0.06	0	0	0	53.24	29.42	19.24	11.31	51.39	31.17	21.37	13.27
Sei whale[a]	18.35	8.52	4.67	1.87	0.08	<0.01	0	0	30.78	17.92	12.28	7.51	29.43	18.15	12.79	8.07
Mid-frequency cetaceans																
Atlantic white sided dolphin	0	0	0	0	0	0	0	0	6617.60	3797.83	2582.81	1585.81	3086.25	1694.07	1177.74	701.09
Short-beaked common dolphin	5.03	5.03	0	0	0	0	0	0	35322.02	22075.32	15803.01	10321.53	15684.59	9286.38	6857.45	4337.32
Bottlenose dolphin	0.46	0	0	0	0	0	0	0	3162.34	1524.99	863.13	415.06	1555.02	766.44	466.37	236.10
Risso's dolphin	0.16	0.15	0	0	0	0	0	0	533.58	311.74	217.39	136.53	249.46	138.85	96.44	59.50
Pilot whale[b]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sperm whale[a]	0	0	0	0	0	0	0	0	28.20	14.74	9.22	4.98	12.98	6.77	4.52	2.47
High-frequency cetaceans																
Harbor porpoise	466.71	198.07	90.11	15.58	98.29	42.36	20.21	5.28	2444.19	1410.80	947.56	572.44	12783.62	9673.28	7775.23	5075.06
Pinnipeds in water																
Gray seal	154.71	43.65	13.07	1.57	6.62	0.09	0	0	2954.85	1521.03	927.16	498.34	2304.97	1234.34	788.60	465.32
Harbor seal	123.49	21.72	6.17	1.34	2.68	1.25	0	0	2822.87	1422.01	866.07	443.34	2219.05	1162.22	744.85	429.59

[a] Listed as Endangered under the ESA.
[b] Long- and short-finned pilot whales are combined.

3.3.1. Effect of Aversion

The mean exposure estimates reported in Tables 22 to 25 do not take into account animals avoiding loud sounds (aversion) or implementation of mitigation measures other than sound attenuation. Some marine mammals are well known for their aversive responses to anthropogenic sound (e.g., harbor porpoise), although it is assumed that most species will avert from noise. The Wood et al. (2012) step function includes a probability of response that is based primarily on observed aversive behavior in field studies. Additional exposure estimates with aversion based on the Wood et al. (2012) response probabilities were calculated for harbor porpoise and the North Atlantic right whale in this study. For comparative purposes only, the results are shown with and without aversion (Tables 26 and 27).

Table 26. Maximum WTG jacket foundation schedule: mean exposure estimates with and without aversion for North Atlantic right whales and harbor porpoises. The schedule includes the installation of both WTG and OSP foundations (Table 5).

Species	10 dB attenuation – no aversion				10 dB attenuation – with aversion			
	Level A		Level B		Level A		Level B	
	L_E	L_{pk}	L_p	L_p	L_E	L_{pk}	L_p	L_p
North Atlantic right whale	5.16	0	16.04	17.12	0.95	0	10.28	15.17
Harbor porpoise	234.57	11.09	850.09	9900.92	3.14	0	74.67	7544.20

Table 27. Maximum WTG monopile foundation schedule: mean exposure estimates with and without aversion for North Atlantic right whales and harbor porpoises (Table 5). The schedule includes the installation of both WTG and OSP foundations (Table 5).

Species	10 dB attenuation – no aversion				10 dB attenuation – with aversion			
	Level A		Level B		Level A		Level B	
	L_E	L_{pk}	L_p	L_p	L_E	L_{pk}	L_p	L_p
North Atlantic right whale	5.99	0	19.24	21.37	1.33	0	13.83	18.72
Harbor porpoise	90.11	20.21	947.56	7775.23	0.34	0	202.99	6197.64

3.4. Potential Impacts Relative to Species' Abundance

As described above, animal movement modeling was used to predict the number of individual animals that could receive sound levels above injury exposure thresholds. Those individual exposure numbers must then be assessed in the context of the species' populations or stocks.

Defining biologically significant impacts to a population of animals that result from injury or behavioral responses estimated from exposure models and acoustic thresholds remains somewhat subjective. The percentage of the stock or population exposed has been commonly used as an indication of the extent of potential impact (e.g., NSF 2011). In this way, the potential number of exposed animals can be interpreted in an abundance context, which allows for consistency across different populations or stock sizes. The exposure results shown in Section 3.3, estimated using the schedules combining years 1 and 2 and described in Tables 4 and 5, are presented as a percentage of species abundance in Tables 28 to 31. Abundance numbers for the Northwest Atlantic OCS used in these calculations are provided in Table 13.

Table 28. Realistic WTG jacket foundation schedule: estimated auditory Level A and Level B response threshold exposures as a percentage of species' abundance with varying levels of sound attenuation. The schedule includes the installation of both WTG and OSP foundations (Table 4).

Low-frequency cetaceans																
Fin whale[a]	4.66	1.84	0.79	0.21	<0.01	0	0	0	7.33	3.80	2.45	1.54	7.71	4.32	2.92	1.84
Minke whale	0.46	0.17	0.06	0.01	<0.01	<0.01	0	0	1.24	0.66	0.43	0.26	1.11	0.65	0.46	0.29
Humpback whale	1.75	0.65	0.31	0.11	0	0	0	0	2.22	0.91	0.54	0.37	2.63	1.46	0.97	0.57
North Atlantic right whale[a]	1.22	0.53	0.25	0.07	<0.01	0	0	0	2.21	1.08	0.68	0.41	2.39	1.32	0.89	0.54
Sei whale[a]	0.25	0.10	0.05	0.01	<0.01	0	0	0	0.39	0.20	0.13	0.08	0.41	0.23	0.15	0.10
Mid-frequency cetaceans																
Atlantic white sided dolphin	<0.01	0	0	0	0	0	0	0	6.03	3.13	1.95	1.13	4.71	2.55	1.72	0.99
Short-beaked common dolphin	<0.01	<0.01	<0.01	0	0	0	0	0	18.99	10.71	7.07	4.33	13.34	7.69	5.50	3.21
Bottlenose dolphin	0.01	<0.01	<0.01	<0.01	0	0	0	0	3.27	1.18	0.62	0.35	3.38	1.68	1.05	0.51
Risso's dolphin	<0.01	<0.01	<0.01	<0.01	0	0	0	0	1.49	0.80	0.54	0.34	1.20	0.66	0.46	0.26
Pilot whale	0	0	0	0	0	0	0	0	0	0	0	0	<0.01	0	0	0
Sperm whale	<0.01	<0.01	0	0	0	0	0	0	0.52	0.23	0.15	0.10	0.46	0.24	0.16	0.08
High-frequency cetaceans																
Harbor porpoise	0.90	0.40	0.18	0.07	0.05	0.02	<0.01	<0.01	1.82	0.91	0.56	0.35	14.64	11.69	9.52	6.95
Pinnipeds in water																
Gray seal	0.57	0.13	0.03	<0.01	<0.01	<0.01	<0.01	0	4.25	1.87	1.11	0.68	4.81	2.50	1.61	0.90
Harbor seal	0.16	0.04	0.01	<0.01	<0.01	<0.01	0	0	1.47	0.62	0.37	0.22	1.68	0.86	0.56	0.30

[a] Listed as endangered under the ESA

Table 29. Realistic WTG monopile foundation schedule: Estimated auditory Level A and Level B response threshold exposures as a percentage of species' abundance with varying levels of sound attenuation. The schedule includes the installation of both WTG and OSP foundations (Table 4).

Low-frequency cetaceans																
Fin whale[a]	3.04	1.29	0.63	0.18	<0.01	<0.01	0	0	6.21	3.41	2.18	1.50	6.40	3.73	2.53	1.62
Minke whale	0.36	0.14	0.06	<0.01	<0.01	<0.01	0	0	1.17	0.69	0.47	0.33	1.07	0.65	0.46	0.31
Humpback whale	1.50	0.47	0.23	0.08	<0.01	0	0	0	2.47	1.05	0.57	0.35	2.67	1.52	1.00	0.59
North Atlantic right whale[a]	1.91	0.79	0.34	0.13	<0.01	0	0	0	5.15	2.58	1.65	1.03	5.40	3.03	2.07	1.28
Sei whale[a]	0.24	0.10	0.05	0.01	<0.01	<0.01	0	0	0.48	0.27	0.17	0.12	0.50	0.29	0.20	0.13
Mid-frequency cetaceans																
Atlantic white sided dolphin	<0.01	0	0	0	0	0	0	0	5.45	2.87	1.88	1.29	2.58	1.44	0.98	0.53
Short-beaked common dolphin	<0.01	<0.01	<0.01	0	0	0	0	0	11.32	6.75	4.66	3.36	5.23	3.16	2.21	1.26
Bottlenose dolphin	<0.01	<0.01	<0.01	<0.01	0	0	0	0	3.34	1.42	0.79	0.43	1.69	0.82	0.50	0.21
Risso's dolphin	<0.01	<0.01	<0.01	<0.01	0	0	0	0	1.09	0.62	0.39	0.27	0.52	0.29	0.20	0.11
Pilot whale	0	0	0	0	0	0	0	0	0	0	0	0	<0.01	0	0	0
Sperm whale	<0.01	<0.01	0	0	0	0	0	0	0.50	0.24	0.14	0.09	0.24	0.13	0.08	0.04
High-frequency cetaceans																
Harbor porpoise	0.33	0.14	0.06	<0.01	0.08	0.03	0.02	<0.01	1.82	0.99	0.61	0.42	12.45	8.97	6.51	4.13
Pinnipeds in water																
Gray seal	0.34	0.10	0.02	<0.01	0.02	0	0	0	9.09	4.21	2.46	1.37	7.29	3.86	2.46	1.46
Harbor seal	0.10	0.02	<0.01	<0.01	<0.01	<0.01	0	0	3.02	1.41	0.78	0.48	2.51	1.28	0.84	0.46

[a] Listed as endangered under the ESA.

Table 30. Maximum WTG jacket foundation schedule: estimated auditory Level A and Level B response threshold exposures as a percentage of species' abundance with varying levels of sound attenuation. The schedule includes the installation of both WTG and OSP foundations (Table 5).

Low-frequency cetaceans																
Fin whale[a]	4.84	2.06	0.93	0.24	<0.01	<0.01	0	0	6.72	3.83	2.89	2.06	6.71	3.95	2.84	1.91
Minke whale	0.54	0.19	0.07	0.01	<0.01	0	0	0	1.36	0.78	0.59	0.41	1.16	0.71	0.53	0.37
Humpback whale	1.91	0.69	0.35	0.11	0	0	0	0	1.89	0.86	0.56	0.42	2.32	1.30	0.87	0.53
North Atlantic right whale[a]	5.88	2.49	1.21	0.35	<0.01	0	0	0	9.30	5.09	3.75	2.57	9.77	5.63	4.00	2.57
Sei whale[a]	0.30	0.13	0.06	0.02	<0.01	<0.01	0	0	0.42	0.24	0.18	0.13	0.42	0.25	0.18	0.12
Mid-frequency cetaceans																
Atlantic white sided dolphin	0	0	0	0	0	0	0	0	6.47	3.65	2.73	1.83	4.10	2.45	1.67	0.91
Short-beaked common dolphin	<0.01	<0.01	0	0	0	0	0	0	20.60	12.45	9.69	7.07	11.85	7.64	5.50	3.10
Bottlenose dolphin	<0.01	0	0	0	0	0	0	0	2.25	0.91	0.56	0.33	2.12	1.06	0.63	0.29
Risso's dolphin	<0.01	0	0	0	0	0	0	0	1.24	0.74	0.56	0.41	0.82	0.50	0.35	0.20
Pilot whale	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sperm whale	0	0	0	0	0	0	0	0	0.42	0.21	0.15	0.11	0.30	0.17	0.11	0.06
High-frequency cetaceans																
Harbor porpoise	1.09	0.51	0.25	0.06	0.08	0.02	0.01	<0.01	2.17	1.22	0.89	0.64	17.14	12.98	10.36	6.77
Pinnipeds in water																
Gray seal	0.85	0.19	0.03	0.01	0.01	<0.01	0	0	6.43	3.08	2.10	1.49	6.74	3.56	2.38	1.32
Harbor seal	0.26	0.04	0.01	<0.01	<0.01	0	0	0	2.21	1.02	0.71	0.47	2.34	1.22	0.82	0.44

[a] Listed as endangered under the ESA

Table 31. Maximum WTG monopile foundation schedule: estimated auditory Level A and Level B response threshold exposures as a percentage of species' abundance with varying levels of sound attenuation. The schedule includes the installation of both WTG and OSP foundations (Table 5).

Low-frequency cetaceans																
Fin whale[a]	4.65	2.16	1.19	0.48	0.02	<0.01	0	0	7.90	4.60	3.15	1.90	7.53	4.66	3.28	2.06
Minke whale	0.49	0.22	0.10	0.03	<0.01	<0.01	0	0	1.28	0.81	0.57	0.37	1.12	0.73	0.53	0.35
Humpback whale	2.66	1.01	0.45	0.18	<0.01	0	0	0	3.37	1.63	0.96	0.50	3.17	1.92	1.32	0.79
North Atlantic right whale[a]	5.94	2.55	1.40	0.49	0.01	0	0	0	12.44	6.87	4.50	2.64	12.01	7.28	4.99	3.10
Sei whale[a]	0.29	0.14	0.07	0.03	<0.01	<0.01	0	0	0.49	0.28	0.20	0.12	0.47	0.29	0.20	0.13
Mid-frequency cetaceans																
Atlantic white sided dolphin	0	0	0	0	0	0	0	0	7.10	4.07	2.77	1.70	3.31	1.82	1.26	0.75
Short-beaked common dolphin	<0.01	<0.01	0	0	0	0	0	0	20.44	12.77	9.14	5.97	9.08	5.37	3.97	2.51
Bottlenose dolphin	<0.01	0	0	0	0	0	0	0	5.03	2.43	1.37	0.66	2.47	1.22	0.74	0.38
Risso's dolphin	<0.01	<0.01	0	0	0	0	0	0	1.50	0.88	0.61	0.38	0.70	0.39	0.27	0.17
Pilot whale	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sperm whale	0	0	0	0	0	0	0	0	0.65	0.34	0.21	0.11	0.30	0.16	0.10	0.06
High-frequency cetaceans																
Harbor porpoise	0.49	0.21	0.09	0.02	0.10	0.04	0.02	<0.01	2.56	1.48	0.99	0.60	13.38	10.12	8.14	5.31
Pinnipeds in water																
Gray seal	0.57	0.16	0.05	<0.01	0.02	<0.01	0	0	10.89	5.61	3.42	1.84	8.50	4.55	2.91	1.72
Harbor seal	0.16	0.03	<0.01	<0.01	<0.01	<0.01	0	0	3.72	1.88	1.14	0.58	2.93	1.53	0.98	0.57

[a] Listed as endangered under the ESA

3.5. Sea Turtle Exposure Range Estimates

Similar to the results presented for marine mammals (Section 3.2), the exposure ranges ($ER_{95\%}$) for sea turtles to potential injury and behavioral disruption thresholds (McCauley et al. 2000, Finneran et al. 2017) were calculated for monopile and jacket foundations assuming broadband attenuation of 0, 6, 10, and 15 dB. Tables 32 to 37 show exposure ranges for pile types included in the realistic (Tables 32 to 34) and maximum scenarios (Tables 35 to 37) described in Tables 4 and 5 for jacket and monopile foundations. Exposure ranges for pile types not included in the construction schedules can be found in Appendix G.2.3.

Table 32. Realistic scenario WTG jacket foundation (2.9 m diameter, MHU1900S hammer, three piles per day) exposure ranges ($ER_{95\%}$) in km to sea turtle injury and behavioral thresholds with sound attenuation.

Species	**Injury**								**Behavior**			
	L_E				L_{pk}				L_p			
	Attenuation (dB)								Attenuation (dB)			
	0	6	10	15	0	6	10	15	0	6	10	15
Kemp's ridley turtle[a]	0.33	0	0	0	0	0	0	0	2.35	0.90	0.48	0.25
Leatherback turtle[a]	0.36	0.02	0	0	0	0	0	0	1.82	0.75	0.44	0.10
Loggerhead turtle	0.14	0	0	0	0	0	0	0	1.80	0.77	0.37	0.20
Green turtle	0.51	0.06	<0.01	0	0	0	0	0	2.65	1.05	0.49	0.20

[a] Listed as Endangered under the ESA.

Table 33. Realistic scenario OSP jacket foundation[a] (4.5 m diameter, IHCS2000 hammer, four piles per day) exposure ranges ($ER_{95\%}$) in km to sea turtle injury and behavioral thresholds with sound attenuation.

Species	**Injury**								**Behavior**			
	L_E				L_{pk}				L_p			
	Attenuation (dB)								Attenuation (dB)			
	0	6	10	15	0	6	10	15	0	6	10	15
Kemp's ridley turtle[b]	1.51	0.36	0.15	0	0	0	0	0	3.03	1.88	1.14	0.54
Leatherback turtle[b]	1.73	0.53	0.08	0.02	0	0	0	0	2.80	1.47	0.93	0.39
Loggerhead turtle	0.83	0.19	0.04	0	0	0	0	0	2.59	1.46	0.88	0.37
Green turtle	2.49	0.65	0.40	0.03	0	0	0	0	3.03	2.19	1.29	0.55

[a] OSP foundations include a 2 dB shift for post piling.
[b] Listed as Endangered under the ESA.

Table 34. Realistic scenario WTG monopile foundation (11 m diameter, MHU4400S hammer, one pile per day) exposure ranges ($ER_{95\%}$) in km to sea turtle injury and behavioral thresholds with sound attenuation.

Species	Injury								Behavior			
	L_E				L_{pk}				L_p			
	Attenuation (dB)								Attenuation (dB)			
	0	6	10	15	0	6	10	15	0	6	10	15
Kemp's ridley turtle[a]	1.11	0.15	0	0	0	0	0	0	3.11	2.27	1.19	0.50
Leatherback turtle[a]	1.70	0.52	0	0	0	0	0	0	2.93	1.80	1.03	0.42
Loggerhead turtle	0.87	0	0	0	0	0	0	0	2.70	1.90	0.95	0.57
Green turtle	1.62	0.54	0.12	0	0	0	0	0	3.06	2.41	1.42	0.61

[a] Listed as Endangered under the ESA.

Table 35. Maximum scenario WTG jacket foundation (4.5 m diameter, MHU3500S hammer, four piles per day) exposure ranges ($ER_{95\%}$) in km to sea turtle injury and behavioral thresholds with sound attenuation.

Species	Injury								Behavior			
	L_E				L_{pk}				L_p			
	Attenuation (dB)								Attenuation (dB)			
	0	6	10	15	0	6	10	15	0	6	10	15
Kemp's ridley turtle[a]	0.54	0	0	0	0	0	0	0	2.34	1.09	0.63	0.22
Leatherback turtle[a]	1.19	0.02	0	0	0	0	0	0	1.96	1.15	0.46	0.14
Loggerhead turtle	0.11	0	0	0	0	0	0	0	1.78	0.97	0.61	0.23
Green turtle	1.11	0.20	<0.01	0	0	0	0	0	2.49	1.27	0.60	0.28

[a] Listed as Endangered under the ESA.

Table 36. Maximum scenario OSP jacket foundation[a] (4.5 m diameter, MHU3500S hammer, four piles per day) exposure ranges ($ER_{95\%}$) in km to sea turtle injury and behavioral thresholds with sound attenuation.

Species	Injury								Behavior			
	L_E				L_{pk}				L_p			
	Attenuation (dB)								Attenuation (dB)			
	0	6	10	15	0	6	10	15	0	6	10	15
Kemp's ridley turtle[b]	0.79	0.19	0	0	0	0	0	0	2.68	1.40	0.74	0.34
Leatherback turtle[b]	0.61	0.03	0.02	0	0	0	0	0	2.59	1.22	0.67	0.18
Loggerhead turtle	0.60	0.01	0	0	0	0	0	0	2.25	1.19	0.77	0.23
Green turtle	1.40	0.43	0.06	<0.01	0	0	0	0	2.72	1.74	0.74	0.30

[a] OSP foundations include a 2 dB shift for post piling.
[b] Listed as Endangered under the ESA.

Table 37. Maximum scenario WTG monopile foundation (16 m diameter, 6600 kJ hammer, 7000 strikes, one pile per day) exposure ranges in km to sea turtle injury and behavior thresholds with sound attenuation.

Species	Injury								Behavior			
	L_E				L_{pk}				L_p			
	Attenuation (dB)								Attenuation (dB)			
	0	6	10	15	0	6	10	15	0	6	10	15
Kemp's ridley turtle[a]	2.11	0.87	0.44	0	0	0	0	0	3.81	2.79	2.23	1.17
Leatherback turtle[a]	3.20	0.95	0.51	0	0	0	0	0	3.75	2.57	1.94	1.24
Loggerhead turtle	0.96	0.33	0.10	0	0	0	0	0	3.20	2.58	1.91	0.98
Green turtle	3.77	1.43	0.62	0.11	0	0	0	0	4.16	2.86	2.41	1.37

[a] Listed as Endangered under the ESA.

3.6. Sea Turtle Exposure Estimates

As was done for marine mammals (Section 3.3), the number of individual sea turtles predicted to receive above threshold sound levels were determine from animal movement modeling. The construction schedules described in Tables 4 and 5 were used to calculate the total mean number of real-world individual turtles predicted to receive sound levels above injury and behavior thresholds (Finneran et al. 2017) in the Lease Area over both years of the Project. Tables 38 to 41 show exposure ranges for the maximum scenario assuming broadband attenuation of 0, 6, 10, and 15 dB during the summer season, calculated in the same way as the marine mammal exposures (Section 3.3). Realistic scenario results are provided separately for each Project year in Appendix G.2.4.

Table 38. Realistic WTG jacket foundation schedule: The mean number of modeled sea turtles estimated to experience sound levels above exposure criteria for different sound attenuation levels. The schedule includes the installation of both WTG and OSP foundations (Table 4).

Species	Injury								Behavior			
	L_E				L_{pk}				L_p			
	Attenuation (dB)								Attenuation (dB)			
	0	6	10	15	0	6	10	15	0	6	10	15
Kemp's ridley turtle[a]	0.04	<0.01	<0.01	0	0	0	0	0	0.50	0.15	0.06	0.02
Leatherback turtle[a]	2.85	0.64	0.03	<0.01	0	0	0	0	40.89	14.58	7.30	2.29
Loggerhead turtle	0.42	0.01	<0.01	0	0	0	0	0	44.49	14.83	4.67	0.82
Green turtle	0.10	0.01	<0.01	<0.01	0	0	0	0	0.53	0.18	0.09	0.04

[a] Listed as Endangered under the ESA.

Table 39. Realistic WTG monopile foundation schedule: The mean number of modeled sea turtles estimated to experience sound levels above exposure criteria for different sound attenuation levels. The schedule includes the installation of both WTG and OSP foundations (Table 4).

Species	**Injury**								**Behavior**			
	L_E				L_{pk}				L_p			
	Attenuation (dB)								Attenuation (dB)			
	0	6	10	15	0	6	10	15	0	6	10	15
Kemp's ridley turtle[a]	0.08	<0.01	<0.01	0	0	0	0	0	0.47	0.23	0.11	0.04
Leatherback turtle[a]	5.18	0.76	0.03	<0.01	0	0	0	0	35.60	16.59	8.20	3.61
Loggerhead turtle	0.80	0.01	<0.01	0	0	0	0	0	26.47	13.07	7.40	2.60
Green turtle	0.16	0.05	0.01	<0.01	0	0	0	0	0.53	0.32	0.16	0.07

[a] Listed as Endangered under the ESA.

Table 40. Maximum WTG jacket foundation schedule: the mean number of modeled sea turtles estimated to experience sound levels above exposure criteria for different sound attenuation levels. The schedule includes the installation of both WTG and OSP foundations (Table 5).

Species	**Injury**								**Behavior**			
	L_E				L_{pk}				L_p			
	Attenuation (dB)								Attenuation (dB)			
	0	6	10	15	0	6	10	15	0	6	10	15
Kemp's ridley turtle[a]	0.09	<0.01	0	0	0	0	0	0	0.63	0.26	0.12	0.04
Leatherback turtle[a]	4.70	0.49	0.02	0	0	0	0	0	48.39	19.67	9.36	2.68
Loggerhead turtle	0.50	<0.01	0	0	0	0	0	0	59.40	21.55	7.39	1.52
Green turtle	0.18	0.02	<0.01	<0.01	0	0	0	0	0.63	0.27	0.13	0.05

[a] Listed as Endangered under the ESA.

Table 41. Maximum WTG monopile foundation schedule: The mean number of modeled sea turtles estimated to experience sound levels above exposure criteria for different sound attenuation levels. The schedule includes the installation of both WTG and OSP foundations (Table 5).

Species	**Injury**								**Behavior**			
	L_E				L_{pk}				L_p			
	Attenuation (dB)								Attenuation (dB)			
	0	6	10	15	0	6	10	15	0	6	10	15
Kemp's ridley turtle[a]	0.22	0.05	0.01	0	0	0	0	0	0.74	0.45	0.29	0.13
Leatherback turtle[a]	14.14	2.74	0.92	0	0	0	0	0	59.86	35.19	21.05	10.33
Loggerhead turtle	4.20	0.81	0.16	0	0	0	0	0	65.84	40.39	24.14	11.34
Green turtle	0.53	0.14	0.06	<0.01	0	0	0	0	0.83	0.50	0.36	0.16

[a] Listed as Endangered under the ESA.

3.7. Acoustic Impacts to Fish

Unlike marine mammals and sea turtles, fish were assumed to remain stationary during pile driving so ranges to regulatory thresholds (Andersson et al. 2007, Wysocki et al. 2007, FHWG 2008, Stadler and Woodbury 2009, Mueller-Blenkle et al. 2010, Purser and Radford 2011) were calculated directly from the sound fields (see Section 2.5). Like the criteria for marine mammals and sea turtles, dual acoustic criteria are used to assess the potential for physiological injury to fish. For the sound exposure level, SEL, acoustic energy was accumulated for all pile driving strikes in a 24 h period. Distances to potential injury and behavioral disruption thresholds for fish exposed to pile driving sound for the different piles (jacket: 2.9 and 4.5 m, and monopile: 11 and 16 m) are shown in Tables 42 to 46.

Table 42. Realistic jacket foundation (2.9 m diameter) hammering schedule with acoustic ranges in km to thresholds for fish (GARFO 2019) using a 1900 kJ hammer with 10 dB attenuation.

Faunal group	Metric	Threshold	Hammer energy (kJ)							
			L01				L02			
			475	950	1900a	1900b	475	950	1900a	1900b
Small fish	L_E	183	6.476				4.017			
	L_{pk}	206	0.008	0.017	0.085	0.019	0.011	0.069	0.082	0.021
Large fish	L_E	186	4.728				2.882			
	L_{pk}	206	0.008	0.017	0.085	0.019	0.011	0.069	0.082	0.021
All fish	L_p	150	5.22	7.012	9.203	2.863	4.091	5.371	7.951	2.786

L_{pk}= unweighted peak sound pressure (dB re 1 µPa); L_E = unweighted sound exposure level (dB re 1 µPa^2·s); L_p= unweighted sound pressure (dB re 1 µPa). Small fish are defined as having a total mass of less than 2 g; large fish are defined as having a total mass of greater than or equal to 2 g.

Table 43. Maximum jacket foundation (4.5 m diameter) hammering schedule with acoustic ranges in km to thresholds for fish (GARFO 2019) using a 2000 kJ hammer with 10 dB attenuation.

Faunal group	Metric	Threshold	Hammer energy (kJ)					
			L01			L02		
			2000a	2000b	2000c	2000a	2000b	2000c
Small fish	L_E	183	10.123			6.786		
	L_{pk}	206	0.111	0.073	0.027	0.1	0.072	0.028
Large fish	L_E	186	7.783			5.294		
	L_{pk}	206	0.111	0.073	0.027	0.1	0.072	0.028
All fish	L_p	150	10.301	8.692	2.917	9.825	8.715	3.103

L_{pk}= unweighted peak sound pressure (dB re 1 µPa); L_E = unweighted sound exposure level (dB re 1 µPa^2·s); L_p= unweighted sound pressure (dB re 1 µPa). Small fish are defined as having a total mass of less than 2 g; large fish are defined as having a total mass of greater than or equal to 2 g.

Table 44. Maximum jacket foundation (4.5 m diameter) hammering schedule with acoustic ranges in km to thresholds for fish (GARFO 2019) using a 3500 kJ hammer with 10 dB attenuation.

Faunal group	Metric	Threshold	Hammer energy (kJ)					
			L01			L02		
			3500a	3500b	3500c	3500a	3500b	3500c
Small fish	L_E	183	7.1			4.582		
	L_{pk}	206	0.085	0.05	0.027	0.083	0.05	0.019
Large fish	L_E	186	5.181			3.481		
	L_{pk}	206	0.085	0.05	0.027	0.083	0.05	0.019
All fish	L_p	150	8.26	7.078	4.83	7.37	6.657	2.783

L_{pk}= unweighted peak sound pressure (dB re 1 µPa); L_E = unweighted sound exposure level (dB re 1 µPa^2·s); L_p= unweighted sound pressure (dB re 1 µPa). Small fish are defined as having a total mass of less than 2 g; large fish are defined as having a total mass of greater than or equal to 2 g.

Table 45. Realistic scenario (11 m diameter) monopile acoustic ranges in km to thresholds for fish (GARFO 2019) using a 4400 kJ hammer with 10 dB attenuation.

Faunal group	Metric	Threshold	Hammer energy (kJ)					
			L01			L02		
			1100	2200	4400	1100	2200	4400
Small fish	L_E	183	12.013			7.368		
	L_{pk}	206	0.059	0.089	0.139	0.2	0.32	0.48
Large fish	L_E	186	9.652			5.983		
	L_{pk}	206	0.059	0.089	0.139	0.2	0.32	0.48
All fish	L_p	150	8.324	8.963	11.154	6.983	7.115	8.76

L_{pk}= unweighted peak sound pressure (dB re 1 µPa); L_E = unweighted sound exposure level (dB re 1 µPa^2·s); L_p= unweighted sound pressure (dB re 1 µPa). Small fish are defined as having a total mass of less than 2 g; large fish are defined as having a total mass of greater than or equal to 2 g.

Table 46. Maximum scenario (16 m diameter) monopile acoustic ranges in km to thresholds for fish (GARFO 2019) using a 5500 kJ hammer with 10 dB attenuation.

Faunal group	Metric	Threshold	Hammer energy (kJ)					
			L01			L02		
			6600a	6600b	6600c	6600a	6600b	6600c
Small fish	L_E	183	16.653			9.762		
	L_{pk}	206	0.142	0.147	0.153	0.094	0.106	0.11
Large fish	L_E	186	13.799			8.188		
	L_{pk}	206	0.142	0.147	0.153	0.094	0.106	0.11
All fish	L_p	150	13.719	14.1	14.626	8.711	9.843	10.304

L_{pk}= unweighted peak sound pressure (dB re 1 µPa); L_E = unweighted sound exposure level (dB re 1 µPa^2·s); L_p= unweighted sound pressure (dB re 1 µPa). Small fish are defined as having a total mass of less than 2 g; large fish are defined as having a total mass of greater than or equal to 2 g.

4. Discussion

Impact pile driving generates broadband sounds with maximum sound energy at frequencies <500 Hz. Larger piles with larger hammers generally produce sounds at lower frequencies than smaller piles and smaller hammers. In this study, the greatest sound energy produced by 2.9 m pin piles for jacket foundations was at ~200 Hz using a 1900 kJ hammer (Figures 13 and 14) while impact pile driving of 4.5 m pin piles resulted in greatest sound energy production at ~125 Hz and ~100 Hz using a 2000 kJ (Figures 15 and 16), and 3500 kJ (Figures 17 and 18) hammers, respectively. The greatest sound energy for 11 m monopiles was at frequencies <100 Hz (Figures 19 to 22). The frequency content of the sounds produced is important because of the hearing range of the animals receiving the sounds. Most fish and sea turtles hear at low frequencies, <1000 Hz, so the sounds produced by impact pile driving are within the best hearing range of these animals. The best hearing frequency ranges for most marine mammals is above the frequency band produced by impact pile driving and the sound field is adjusted for assessing injury (SEL) and behavioral disruption (Wood et al. 2012) by discounting sound levels in frequency bands according to hearing group auditory weighting functions (Appendix D). The most sensitive hearing range of mid-frequency cetaceans is >8,800 Hz, for high-frequency cetaceans it is >12,000 Hz, and for pinnipeds it is >1,900 Hz (Table D-1). The most sensitive hearing frequency range for low-frequency cetaceans, such as NARW, is >200 Hz (Table D-1), so there is little discount to the sound fields for these species.

While smaller piles driven with smaller hammers may produce sounds that are closer to the most sensitive hearing frequency range of many marine mammals, larger piles driven with larger hammers at higher hammer energy levels typically produce higher sound levels than the smaller piles. Because of the higher sound levels, 11 m monopiles could be expected to have greater impacts than pin piles, and they do in some circumstances. Distances to the peak sound levels, PK, are longer for monopiles than pin piles (Appendix F.3) and a greater number of marine mammals are predicted to receive sound at levels exceeding PK thresholds for monopiles compared to pin piles (Tables 22 to 25); though exposures associated with injury criteria are primarily predicted to occur as a result of exceeding the SEL threshold not the PK threshold. Because of the higher sound levels with monopiles, the distances to behavioral disruption are greater for the larger monopiles than the smaller pin piles when the hearing frequency range of the animals are not considered (NMFS 2005) (Appendix F.2).

It is worth noting that it is the combination of pile and hammer dimensions that determine the produced sound characteristics. While smaller piles and hammers produce higher frequency sounds and larger piles and hammers produce louder sounds, comparing the acoustic impacts from driving the 2.9 m and 4.5 m jacket foundation pin-piles shows that using a larger hammer and larger diameter pile may not lead to larger impact distance. To demonstrate, the realistic WTG jacket foundation (Table 16) uses fewer piles, smaller diameter piles, and a smaller hammer, but the resulting exposure ranges are similar to the maximum WTG jacket foundation (Table 19). An additional factor influencing this result is that the MHU 1900S used to drive the 2.9 m piles requires nearly twice as many strikes as the MHU 3500S used to drive the 4.5 m piles. The driven state of the pile is also important. As the pile penetrates farther into the seabed, greater hammer energy is required to overcome the increasing resistance. This results in higher sound levels generated as pile driving continues. For the jacket foundation pin piles, however, the final driving position is usually a few meters above the seabed with the hammer submerged and little of the pile left to radiate sound directly into the water, leading to a steady reduction in propagated sound.

In this study, the total acoustic energy (SEL) predicts a greater potential for injury than the PK level. SEL includes the number of strikes required to install the pile and SEL sound fields are adjusted according to the hearing range of sea turtles and the marine mammal hearing groups (Appendix D). SEL sound fields were not adjusted for fish because the sounds produced by piles are in the best hearing range of these animals. Driving smaller, longer piles may produce as much or more total sound energy as driving a shorter, larger diameter pile. Because of the higher frequencies produced by smaller piles and more strikes required to install them to required depth, the jacket foundation pin piles are predicted to result in a greater number of predicted exposures associated with injury thresholds and can have higher behavioral exposures (realistic case Table 22 vs Table 23 and maximum case Table 24 vs Table 25) despite lower single strike sound levels.

Exposure estimates for maximum and realistic construction scenarios were modeled (Sections 3.3 and 3.6). The maximum and realistic scenarios included options where WTG foundations are all monopiles or all jacketed and all scenarios assumed OSPs would use jacketed foundations. More exposures are predicted for either maximum case compared to the realistic cases. On average, for both the realistic and maximum cases, fewer exposures are predicted for monopile installations compared to jacket foundation installations within taxonomic groups. The modeled installation schedules that included combinations of WTG (monopile and jacket) and OSP (jacket) foundation types resulted in slightly more exposures of the endangered North Atlantic right whales compared to the analogous jacket foundation WTG scenarios. This contrasts with the general case that monopile WTG foundations result in fewer exposures than jacketed WTG foundations. The difference in estimated exposures was due to the distribution of WTG foundation installations in different months in each scenario.

Exposure ranges, $ER_{95\%}$, the distance that accounts for 95 percent of the exposure around the source, were determined on a species-specific basis for marine mammals and sea turtles for the maximum and realistic scenarios. The exposure ranges for the maximum scenario were larger than for the realistic scenario. Maximum monopile foundations resulted in longer distances than the maximum jacket foundations and the realistic monopile foundations resulted in longer distances than the realistic jacketed foundations.

Literature Cited

[BOEM] Bureau of Ocean Energy Management. 2014a. *Atlantic OCS Proposed Geological and Geophysical Activities: Mid-Atlantic and South Atlantic Planning Area Final Programmatic Environmental Impact Statement*. Volume Volume I: Chapters 1-8, Figures, Tables, and Keyword Index. OCS EIS/EA BOEM 2014-001. U.S. Department of the Interior, Bureau of Ocean Energy Management, Gulf of Mexico OCS Region. https://www.boem.gov/sites/default/files/oil-and-gas-energy-program/GOMR/BOEM-2014-001-v1.pdf.

[BOEM] Bureau of Ocean Energy Management. 2014b. *Commercial Wind Lease Issuance and Site Assessment Activities on the Atlantic Outer Continental Shelf Offshore Massachusetts: Revised Environmental Assessment*. Document Number 2014-603. US Department of the Interior, Bureau of Ocean Energy Management, Office of Renewable Energy Programs. https://www.federalregister.gov/documents/2014/06/18/2014-14004/commercial-wind-lease-issuance-and-site-assessment-activities-on-the-atlantic-outer-continental.

[BOEM] Bureau of Ocean Energy Management. 2019. *Commercial Lease of Submerged Lands for Renewable Energy Development on the Outer Continental Shelf*. Repoprt for United States Department of the Interior, Sterling, VA.

[DoC] Department of Commerce (US) and [NOAA] National Oceanic and Atmospheric Administration (US). 2020. 2019 Marine Mammal Stock Assessment Reports. *Federal Register* 85(149): 46589-46598. https://www.federalregister.gov/d/2020-16720.

[ESA] Endangered Species Act of 1973 as Amended through the 108th Congress. 2002. United States Pub. L. No. 93–205, 87 Stat. 884, 16 U.S.C. 1531 (Dec 28, 1973) as amended by Pub. L. No. 107–136 (Jan 24, 2002). http://www.fws.gov/endangered/esa-library/pdf/ESAall.pdf.

[DoN] Department of the Navy (US). 2007. *Navy OPAREA Density Estimate (NODE) for the Gulf of Mexico*. Report prepared by Geo-Marine, Inc. for the Department of the Navy, US Fleet Forces Command. Contract #N62470-02 D-9997, CTO 0030. https://seamap.env.duke.edu/downloads/resources/serdp/Northeast%20NODE%20Final%20Report.pdf.

[DoN] Department of the Navy (US). 2012. *Commander Task Force 20, 4th, and 6th Fleet Navy marine species density database*. Technical report for Naval Facilities Engineering Command Atlantic, Norfolk, VA.

[DoN] Department of the Navy (US). 2017. *U.S. Navy marine species density database phase III for the Atlantic Fleet training and testing study area. NAVFAC Atlantic Final Technical Report*. Naval Facilities Engineering Command Atlantic, Norfolk, VA.

[FHWG] Fisheries Hydroacoustic Working Group. 2008. *Agreement in Principle for Interim Criteria for Injury to Fish from Pile Driving Activities*. 12 Jun 2008 edition. http://www.dot.ca.gov/hq/env/bio/files/fhwgcriteria_agree.pdf.

[GARFO] Greater Atlantic Regional Fisheries Office. 2019. *GARFO Acoustics Tool: Analyzing the effects of pile driving on ESA-listed species in the Greater Atlantic Region.* https://www.fisheries.noaa.gov/new-england-mid-atlantic/consultations/section-7-consultation-technical-guidance-greater-atlantic.

[HESS] High Energy Seismic Survey. 1999. *High Energy Seismic Survey Review Process and Interim Operational Guidelines for Marine Surveys Offshore Southern California*. Prepared for the California State Lands Commission and the United States Minerals Management Service Pacific Outer Continental Shelf Region by the High Energy Seismic Survey Team, Camarillo, CA, USA. 98 p. https://ntrl.ntis.gov/NTRL/dashboard/searchResults/titleDetail/PB2001100103.xhtml.

[ISO] International Organization for Standardization. 2017. *ISO 18405:2017. Underwater acoustics – Terminology*. Geneva. https://www.iso.org/standard/62406.html.

[NAVO] Naval Oceanography Office (US). 2003. *Database description for the Generalized Digital Environmental Model (GDEM-V) (U)*. Document Number MS 39522-5003. Oceanographic Data Bases Division, Stennis Space Center.

[NEFSC] Northeast Fisheries Science Center and [SEFSC] Southeast Fisheries Science Center. 2011a. *Preliminary summer 2010 regional abundance estimate of loggerhead turtles (Caretta caretta) in northwestern Atlantic Ocean continental shelf waters*. *In*: US Department of Commerce, N.F.S.C. (ed.). Document Number 11-03. https://repository.library.noaa.gov/view/noaa/3879/Share.

[NEFSC] Northeast Fisheries Science Center and [SEFSC] Southeast Fisheries Science Center. 2011b. *2011 Annual Report to the Inter-Agency Agreement M10PG00075/0001: A Comprehensive Assessment of Marine Mammal, Marine Turtle, and Seabird Abundance and Spatial Distribution in US Waters of the western North Atlantic Ocean.* https://www.fisheries.noaa.gov/resource/publication-database/atlantic-marine-assessment-program-protected-species.

[NEFSC] Northeast Fisheries Science Center and [SEFSC] Southeast Fisheries Science Center. 2012. *2012 Annual Report of a Comprehensive Assessment of Marine Mammal, Marine Turtle, and Seabird Abundance and Spatial Distribution in US Waters of the Western North Atlantic Ocean*. https://www.fisheries.noaa.gov/resource/publication-database/atlantic-marine-assessment-program-protected-species.

[NEFSC] Northeast Fisheries Science Center and [SEFSC] Southeast Fisheries Science Center. 2014a. *2013 Annual Report of a Comprehensive Assessment of Marine Mammal, Marine Turtle, and Seabird Abundance and Spatial Distribution in US Waters of the Western North Atlantic Ocean*. https://www.fisheries.noaa.gov/resource/publication-database/atlantic-marine-assessment-program-protected-species.

[NEFSC] Northeast Fisheries Science Center and [SEFSC] Southeast Fisheries Science Center. 2014b. *2014 Annual Report of a Comprehensive Assessment of Marine Mammal, Marine Turtle, and Seabird Abundance and Spatial Distribution in US Waters of the Western North Atlantic Ocean*. https://www.fisheries.noaa.gov/resource/publication-database/atlantic-marine-assessment-program-protected-species.

[NEFSC] Northeast Fisheries Science Center and [SEFSC] Southeast Fisheries Science Center. 2015. *2015 Annual Report of a Comprehensive Assessment of Marine Mammal, Marine Turtle, and Seabird Abundance and Spatial Distribution in US Waters of the Western North Atlantic Ocean – AMAPPS II*. https://doi.org/10.25923/kxrc-g028.

[NEFSC] Northeast Fisheries Science Center and [SEFSC] Southeast Fisheries Science Center. 2016. *2016 Annual Report of a Comprehensive Assessment of Marine Mammal, Marine Turtle, and Seabird Abundance and Spatial Distribution in US Waters of the Western North Atlantic Ocean – AMAPPS II*. https://doi.org/10.25923/gbap-g480.

[NMFS] National Marine Fisheries Service (US) and [NOAA] National Oceanic and Atmospheric Administration (US). 2005. Endangered fish and wildlife: Notice of intent to prepare an environmental impact statement. *Federal Register* 70(7): 1871-1875. https://www.federalregister.gov/documents/2005/01/11/05-525/endangered-fish-and-wildlife-notice-of-intent-to-prepare-an-environmental-impact-statement.

[NMFS] National Marine Fisheries Service (US). 2009. *Non-Competitive Leases for Wind Resource Data Collection on the Northeast Outer Continental Shelf, May 14, 2009. Letter to Dr. James Kendall, Chief, Environmental Division, Minerals Management Service, and Mr. Frank Cianfrani, Chief – Philadelphia District, US Army Corps of Engineers*.

[NMFS] National Marine Fisheries Service (US). 2016. *Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing: Underwater Acoustic Thresholds for Onset of Permanent and Temporary Threshold Shifts*. US Department of Commerce, NOAA. NOAA Technical Memorandum NMFS-OPR-55. 178 p.

[NMFS] National Marine Fisheries Service (US). 2018. *2018 Revision to: Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing (Version 2.0): Underwater Thresholds for Onset of Permanent and Temporary Threshold Shifts*. US Department of Commerce, NOAA. NOAA Technical Memorandum NMFS-OPR-59. 167 p. https://www.fisheries.noaa.gov/webdam/download/75962998.

[NOAA] National Oceanic and Atmospheric Administration (US). 2005. Notice of Public Scoping and Intent to Prepare an Environmental Impact Statement. *Federal Register* 70(7): 1871-1875. https://www.govinfo.gov/content/pkg/FR-2005-01-11/pdf/05-525.pdf.

[NOAA] National Oceanic and Atmospheric Administration (US). 2013. *Draft guidance for assessing the effects of anthropogenic sound on marine mammals: Acoustic threshold levels for onset of permanent and temporary threshold shifts*. National Oceanic and Atmospheric Administration, US Department of Commerce, and NMFS Office of Protected Resources, Silver Spring, MD, USA. 76 p.

[NSF] National Science Foundation (US), Geological Survey (US), and [NOAA] National Oceanic and Atmospheric Administration (US). 2011. *Final Programmatic Environmental Impact Statement/Overseas. Environmental Impact Statement for Marine Seismic Research Funded by the National Science Foundation or Conducted by the US Geological Survey*. National Science Foundation, Arlington, VA, USA. https://www.nsf.gov/geo/oce/envcomp/usgs-nsf-marine-seismic-research/nsf-usgs-final-eis-oeis_3june2011.pdf.

[SMRU] Sea Mammal Research Unit. 2013. *Supporting documentation for predicted density data*.

[USFWS] US Fish and Wildlife Service. 2019. West Indian manatee *Trichechus manatus*. https://www.fws.gov/southeast/wildlife/mammals/manatee (Accessed 17 Oct 2019).

Aerts, L.A.M., M. Blees, S.B. Blackwell, C.R. Greene, Jr., K.H. Kim, D.E. Hannay, and M.E. Austin. 2008. *Marine mammal monitoring and mitigation during BP Liberty OBC seismic survey in Foggy Island Bay, Beaufort Sea, July-August 2008: 90-day report*. Document Number P1011-1. Report by LGL Alaska Research Associates Inc., LGL Ltd., Greeneridge Sciences Inc., and JASCO Applied Sciences for BP Exploration Alaska. 199 p. ftp://ftp.library.noaa.gov/noaa_documents.lib/NMFS/Auke%20Bay/AukeBayScans/Removable%20Disk/P1011-1.pdf

Andersson, M.H., E. Dock-Åkerman, R. Ubral-Hedenberg, M.C. Öhman, and P. Sigray. 2007. Swimming behavior of roach (*Rutilus rutilus*) and three-spined stickleback (*Gasterosteus aculeatus*) in response to wind power noise and single-tone frequencies. *AMBIO* 36(8): 636-638. https://tethys.pnnl.gov/sites/default/files/publications/Anderssonetal2007.pdf.

ANSI S12.7-1986. R2006. *American National Standard Methods for Measurements of Impulsive Noise*. American National Standards Institute, NY, USA.

ANSI S1.1-1994. R2004. *American National Standard Acoustical Terminology*. American National Standards Institute, NY, USA.

ANSI S1.1-2013. R2013. *American National Standard Acoustical Terminology*. American National Standards Institute, NY, USA.

ANSI/ASA S1.13-2005. R2010. *American National Standard Measurement of Sound Pressure Levels in Air*. American National Standards Institute and Acoustical Society of America, NY, USA.

Aoki, K., M. Amano, M. Yoshioka, K. Mori, D. Tokuda, and N. Miyazaki. 2007. Diel diving behavior of sperm whales off Japan. *Marine Ecology Progress Series* 349: 277-287. https://doi.org/10.3354/meps07068.

Austin, M.E. and G.A. Warner. 2012. *Sound Source Acoustic Measurements for Apache's 2012 Cook Inlet Seismic Survey*. Version 2.0. Technical report by JASCO Applied Sciences for Fairweather LLC and Apache Corporation.

Austin, M.E. and L. Bailey. 2013. *Sound Source Verification: TGS Chukchi Sea Seismic Survey Program 2013*. Document Number 00706, Version 1.0. Technical report by JASCO Applied Sciences for TGS-NOPEC Geophysical Company.

Austin, M.E., A. McCrodan, C. O'Neill, Z. Li, and A.O. MacGillivray. 2013. *Marine mammal monitoring and mitigation during exploratory drilling by Shell in the Alaskan Chukchi and Beaufort Seas, July–November 2012: 90-Day Report*. *In*: Funk, D.W., C.M. Reiser, and W.R. Koski (eds.). Underwater Sound Measurements. LGL Rep. P1272D–1. Report from LGL Alaska Research Associates Inc. and JASCO Applied Sciences, for Shell Offshore Inc., National Marine Fisheries Service (US), and US Fish and Wildlife Service. 266 pp plus appendices.

Austin, M.E. 2014. Underwater noise emissions from drillships in the Arctic. *In*: Papadakis, J.S. and L. Bjørnø (eds.). *UA2014 - 2nd International Conference and Exhibition on Underwater Acoustics*. 22-27 Jun 2014, Rhodes, Greece. pp. 257-263.

Austin, M.E., H. Yurk, and R. Mills. 2015. *Acoustic Measurements and Animal Exclusion Zone Distance Verification for Furie's 2015 Kitchen Light Pile Driving Operations in Cook Inlet*. Version 2.0. Technical report by JASCO Applied Sciences for Jacobs LLC and Furie Alaska.

Austin, M.E. and Z. Li. 2016. *Marine Mammal Monitoring and Mitigation During Exploratory Drilling by Shell in the Alaskan Chukchi Sea, July–October 2015: Draft 90-day report*. *In*: Ireland, D.S. and L.N. Bisson (eds.). Underwater Sound Measurements. LGL Rep. P1363D. Report from LGL Alaska Research Associates Inc., LGL Ltd., and JASCO Applied Sciences Ltd. For Shell Gulf of Mexico Inc, National Marine Fisheries Service, and US Fish and Wildlife Service. 188 pp + appendices.

Becker, J.J., D.T. Sandwell, W.H.F. Smith, J. Braud, B. Binder, J. Depner, D. Fabre, J. Factor, S. Ingalls, et al. 2009. Global Bathymetry and Elevation Data at 30 Arc Seconds Resolution: SRTM30_PLUS. *Marine Geodesy* 32(4): 355-371. https://doi.org/10.1080/01490410903297766.

Bellman, M.A., A. May, T. Wendt, S. Gerlach, P. Remmers, and J. Brinkmann. 2020. *Underwater noise during percussive pile driving: Influencing factors on pile-driving noise and technical possibilities to comply with noise mitigation values*. Report edited by the itap GmbH for the Federal Maritime and Hydrographic Agency (Bundesamt für Seeschifffahrt und Hydrographie) and supported by the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (Bundesministerium für Umwelt, Naturschutz und nukleare Sicherheit).

Bellmann, M.A. 2014. Overview of existing noise mitigation systems for reducing pile-driving noise. *Inter-noise2014*. Melbourne, Australia. https://www.acoustics.asn.au/conference_proceedings/INTERNOISE2014/papers/p358.pdf.

Betke, K. 2008. *Measurement of Wind Turbine Construction Noise at Horns Rev II*. Report Number 1256-08-a-KB. Technical report by Institut für technische und angewandte Physik GmbH (ITAP) for BioConsultSH, Husun, Germany. 30 p. https://tethys.pnnl.gov/sites/default/files/publications/Betke-2008.pdf.

Buckingham, M.J. 2005. Compressional and shear wave properties of marine sediments: Comparisons between theory and data. *Journal of the Acoustical Society of America* 117: 137-152. https://doi.org/10.1121/1.1810231.

Buehler, D., R. Oestman, J.A. Reyff, K. Pommerenck, and B. Mitchell. 2015. *Technical Guidance for Assessment and Mitigation of the Hydroacoustic Effects of Pile Driving on Fish*. Report Number CTHWANP-RT-15-306.01.01. California Department of Transportation (CALTRANS), Division of Environmental Analysis. 532 p. https://dot.ca.gov/-/media/dot-media/programs/environmental-analysis/documents/env/bio-tech-guidance-hydroacoustic-effects-110215-a11y.pdf.

Collins, M.D. 1993. A split-step Padé solution for the parabolic equation method. *Journal of the Acoustical Society of America* 93(4): 1736-1742. https://doi.org/10.1121/1.406739.

Collins, M.D., R.J. Cederberg, D.B. King, and S. Chin-Bing. 1996. Comparison of algorithms for solving parabolic wave equations. *Journal of the Acoustical Society of America* 100(1): 178-182. https://doi.org/10.1121/1.415921.

Coppens, A.B. 1981. Simple equations for the speed of sound in Neptunian waters. *Journal of the Acoustical Society of America* 69(3): 862-863. https://doi.org/10.1121/1.382038.

Dadswell, M.J., B.D. Taubert, T.S. Squiers, D. Marchette, and J. Buckley. 1984. *Synopsis of biological data on shortnose sturgeon, Acipenser brevirostrum LeSueur 1818*. NOAA/National Marine Fisheries Service. NOAA Technical Report NMFS 14

Dodge, K.L., B. Galuardi, T.J. Miller, and M.E. Lutcavage. 2014. Leatherback Turtle Movements, Dive Behavior, and Habitat Characteristics in Ecoregions of the Northwest Atlantic Ocean. *PLOS ONE* 9(3): e91726. https://doi.org/10.1371/journal.pone.0091726.

Dunlop, R.A., M.J. Noad, R.D. McCauley, L. Scott-Hayward, E. Kniest, R. Slade, D. Paton, and D.H. Cato. 2017. Determining the behavioural dose–response relationship of marine mammals to air gun noise and source proximity. *Journal of Experimental Biology* 220(16): 2878-2886. https://jeb.biologists.org/content/220/16/2878.

Dunton, K.J., A. Jordaan, K.A. McKown, D.O. Conover, and M.G. Frisk. 2010. Abundance and distribution of Atlantic sturgeon (*Acipenser oxyrinchus*) within the Northwest Atlantic Ocean, determined from five fishery-independent surveys. *Fishery Bulletin* 108(4): 450-464.

Ellison, W.T., K.S. Weixel, and C.W. Clark. 1999. An acoustic integration model (AIM) for assessing the impact of underwater noise on marine wildlife. *Journal of the Acoustical Society of America* 106(4): 2250-2250. https://doi.org/10.1121/1.427674.

Ellison, W.T., B.L. Southall, C.W. Clark, and A.S. Frankel. 2012. A New Context-Based Approach to Assess Marine Mammal Behavioral Responses to Anthropogenic Sounds. *Conservation Biology* 26(1): 21-28. https://doi.org/10.1111/j.1523-1739.2011.01803.x.

Ellison, W.T., R.G. Racca, C.W. Clark, B. Streever, A.S. Frankel, E. Fleishman, R.P. Angliss, J. Berger, D.R. Ketten, et al. 2016. Modeling the aggregated exposure and responses of bowhead whales *Balaena mysticetus* to multiple sources of anthropogenic underwater sound. *Endangered Species Research* 30: 95-108. https://doi.org/10.3354/esr00727.

Erbe, C., R.D. McCauley, and A. Gavrilov. 2016. Characterizing marine soundscapes. *In* Popper, A.N. and A.D. Hawkins (eds.). *The Effects of Noise on Aquatic Life II*. Springer, New York. pp. 265-271. https://dx.doi.org/10.1007/978-1-4939-2981-8_31.

Finneran, J.J. 2015. *Auditory weighting functions and TTS/PTS exposure functions for cetaceans and marine carnivores*. Technical report by SSC Pacific, San Diego, CA, USA.

Finneran, J.J. 2016. *Auditory weighting functions and TTS/PTS exposure functions for marine mammals exposed to underwater noise*. Technical Report for Space and Naval Warfare Systems Center Pacific, San Diego, CA, USA. 49 p. https://apps.dtic.mil/dtic/tr/fulltext/u2/1026445.pdf.

Finneran, J.J., E.E. Henderson, D.S. Houser, K. Jenkins, S. Kotecki, and J. Mulsow. 2017. *Criteria and Thresholds for U.S. Navy Acoustic and Explosive Effects Analysis (Phase III)*. Technical report by Space and Naval Warfare Systems Center Pacific (SSC Pacific). 183 p. https://apps.dtic.mil/dtic/tr/fulltext/u2/a561707.pdf.

Frankel, A.S., W.T. Ellison, and J. Buchanan. 2002. Application of the acoustic integration model (AIM) to predict and minimize environmental impacts. *Oceans '02 MTS/IEEE*. 29-31 Oct 2002. IEEE, Biloxi, MI, USA. pp. 1438-1443. https://doi.org/10.1109/OCEANS.2002.1191849.

Funk, D.W., D.E. Hannay, D.S. Ireland, R. Rodrigues, and W.R. Koski. 2008. *Marine mammal monitoring and mitigation during open water seismic exploration by Shell Offshore Inc. in the Chukchi and Beaufort Seas, July–November 2007: 90-day report*. LGL Report P969-1. Prepared by LGL Alaska Research Associates Inc., LGL Ltd., and JASCO Research Ltd. for Shell Offshore Inc., National Marine Fisheries Service (US), and US Fish and Wildlife Service. 218 p.

Halpin, P.N., A.J. Read, E. Fujioka, B.D. Best, B. Donnelly, L.J. Hazen, C. Kot, K. Urian, E. LaBrecque, et al. 2009. OBIS-SEAMAP: The world data center for marine mammal, sea bird, and sea turtle distributions. *Oceanography* 22(2): 104-115. https://doi.org/10.5670/oceanog.2009.42.

Hannay, D.E. and R.G. Racca. 2005. *Acoustic Model Validation*. Document Number 0000-S-90-04-T-7006-00-E, Revision 02. Technical report by JASCO Research Ltd. for Sakhalin Energy Investment Company Ltd. 34 p.

Hartman, K.L. 2018. Risso's Dolphin: *Grampus griseus*. *In* Würsig, B., J.G.M. Thewissen, and K.M. Kovacs (eds.). *Encyclopedia of Marine Mammals*. 3rd edition. Academic Press. pp. 824-827. https://doi.org/10.1016/B978-0-12-804327-1.00219-3.

Hawkes, L.A., A.C. Broderick, M.S. Coyne, M.H. Godfrey, and B.J. Godley. 2007. Only some like it hot—quantifying the environmental niche of the loggerhead sea turtle. *Diversity and Distributions* 13(4): 447-457. https://doi.org/10.1111/j.1472-4642.2007.00354.x.

Hayes, S.A., E. Josephson, K. Maze-Foley, and P.E. Rosel. 2017. *U.S. Atlantic and Gulf of Mexico Marine Mammal Stock Assessments—2016 (second edition)*. NOAA Technical Memorandum NMFS-NE-241, Woods Hole, MA, USA. 274 p.

Hayes, S.A., E. Josephson, K. Maze-Foley, and P.E. Rosel. 2018. *U.S. Atlantic and Gulf of Mexico Marine Mammal Stock Assessments—2017 (second edition)*. NOAA Technical Memorandum NMFS-NE-245, Woods Hole, MA, USA. 371 p. https://repository.library.noaa.gov/view/noaa/22730.

Hayes, S.A., E. Josephson, K. Maze-Foley, and P.E. Rosel. 2019. *U.S. Atlantic and Gulf of Mexico Marine Mammal Stock Assessments—2018*. NOAA Technical Memorandum NMFS-NE-258, Woods Hole, MA, USA. 298 p. https://doi.org/10.25923/9rrd-tx13.

Hayes, S.A., E. Josephson, K. Maze-Foley, and P.E. Rosel. 2020. *U.S. Atlantic and Gulf of Mexico Marine Mammal Stock Assessments—2019*. US Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, and Northeast Fisheries Science Center. NOAA Technical Memorandum NMFS-NE-264, Woods Hole, MA, USA. 479 p. https://www.fisheries.noaa.gov/webdam/download/109188360.

Houser, D.S. and M.J. Cross. 1999. *Marine Mammal Movement and Behavior (3MB): A Component of the Effects of Sound on the Marine Environment (ESME) Distributed Model*. Version 8.08, by BIOMIMETICA.

Houser, D.S. 2006. A method for modeling marine mammal movement and behavior for environmental impact assessment. *IEEE Journal of Oceanic Engineering* 31(1): 76-81. https://doi.org/10.1109/JOE.2006.872204.

Ireland, D.S., R. Rodrigues, D.W. Funk, W.R. Koski, and D.E. Hannay. 2009. *Marine mammal monitoring and mitigation during open water seismic exploration by Shell Offshore Inc. in the Chukchi and Beaufort Seas, July–October 2008: 90-Day Report*. Document Number P1049-1. 277 p.

Kenney, R.D. and K.J. Vigness-Raposa. 2009. *Marine Mammals and Sea Turtles of Narragansett Bay, Block Island Sound, Rhode Island Sound, and Nearby Waters: An Analysis of Existing Data for the Rhode Island Ocean Special Area Management Plan: Draft Technical Report*. University of Rhode Island. 361 p. https://seagrant.gso.uri.edu/oceansamp/pdf/documents/research_marine_mammals.pdf.

Koschinski, S. and K. Lüdemann. 2013. *Development of Noise Mitigation Measures in Offshore Wind Farm Construction*. Commissioned by the Federal Agency for Nature Conservation (Bundesamt für Naturschutz, BfN). Original report (in German) published Jul 2011, updated Feb 2013, Nehmten and Hamburg, Germany. 97 p. https://www.bfn.de/fileadmin/MDB/documents/themen/meeresundkuestenschutz/downloads/Berichte-und-Positionspapiere/Mitigation-Measures-Underwater-Noise_2013-08-27_final.pdf.

Kot, C.Y., E. Fujioka, A. Dimatteo, B. Wallace, B. Hutchinson, J. Cleary, P. Halpin, and R. Mast. 2018. The State of the World's Sea Turtles Online Database: Data provided by the SWOT Team and hosted on OBIS-SEAMAP. Oceanic Society, IUCN Marine Turtle Specialist Group (MTSG), and Marine Geospatial Ecology Lab, Duke University. http://seamap.env.duke.edu/swot (Accessed 12 Jun 2020).

Kraus, S.D., S. Leiter, K. Stone, B. Wikgren, C.A. Mayo, P. Hughes, R.D. Kenney, C.W. Clark, A.N. Rice, et al. 2016. *Northeast Large Pelagic Survey Collaborative Aerial and Acoustic Surveys for Large Whales and Sea Turtles*. US Department of the Interior, Bureau of Ocean Energy Management. OCS Study BOEM 2016-054, Sterling, Virginia. 117 + appendices p. https://www.boem.gov/RI-MA-Whales-Turtles/.

Leggat, L.J., H.M. Merklinger, and J.L. Kennedy. 1981. *LNG Carrier Underwater Noise Study for Baffin Bay*. Defence Research Establishment Atlantic, Dartmouth, NS, Canada. 32 p.

MacGillivray, A.O. and N.R. Chapman. 2012. Modeling underwater sound propagation from an airgun array using the parabolic equation method. *Canadian Acoustics* 40(1): 19-25. https://jcaa.caa-aca.ca/index.php/jcaa/article/view/2502/2251.

MacGillivray, A.O. 2014. A model for underwater sound levels generated by marine impact pile driving. *Proceedings of Meetings on Acoustics* 20(1). https://doi.org/10.1121/2.0000030

MacGillivray, A.O. 2018. Underwater noise from pile driving of conductor casing at a deep-water oil platform. *Journal of the Acoustical Society of America* 143(1): 450-459. https://doi.org/10.1121/1.5021554.

Malme, C.I., P.R. Miles, C.W. Clark, P.L. Tyack, and J.E. Bird. 1983. *Investigations of the Potential Effects of Underwater Noise from Petroleum Industry Activities on Migrating Gray Whale Behavior*. Report Number 5366. Report by Bolt Beranek and Newman Inc. for US Department of the Interior, Minerals Management Service, Alaska OCS Office. http://www.boem.gov/BOEM-Newsroom/Library/Publications/1983/rpt5366.aspx.

Malme, C.I., P.R. Miles, C.W. Clark, P.L. Tyack, and J.E. Bird. 1984. *Investigations of the Potential Effects of Underwater Noise from Petroleum Industry Activities on Migrating Gray Whale Behavior. Phase II: January 1984 migration*. Report Number 5586. Report by Bolt, Beranek and Newman Inc. for the US Department of the Interior, Minerals Management Service, Cambridge, MA, USA. https://www.boem.gov/BOEM-Newsroom/Library/Publications/1983/rpt5586.aspx.

Martin, B., K. Bröker, M.-N.R. Matthews, J.T. MacDonnell, and L. Bailey. 2015. Comparison of measured and modeled air-gun array sound levels in Baffin Bay, West Greenland. *OceanNoise 2015*. 11-15 May 2015, Barcelona, Spain.

Martin, B., J.T. MacDonnell, and K. Bröker. 2017a. Cumulative sound exposure levels—Insights from seismic survey measurements. *Journal of the Acoustical Society of America* 141(5): 3603-3603. https://doi.org/10.1121/1.4987709.

Martin, S.B. and A.N. Popper. 2016. Short- and long-term monitoring of underwater sound levels in the Hudson River (New York, USA). *Journal of the Acoustical Society of America* 139(4): 1886-1897. https://doi.org/10.1121/1.4944876.

Martin, S.B., M.-N.R. Matthews, J.T. MacDonnell, and K. Bröker. 2017b. Characteristics of seismic survey pulses and the ambient soundscape in Baffin Bay and Melville Bay, West Greenland. *Journal of the Acoustical Society of America* 142(6): 3331-3346. https://doi.org/10.1121/1.5014049.

Matthews, M.-N.R. and A.O. MacGillivray. 2013. Comparing modeled and measured sound levels from a seismic survey in the Canadian Beaufort Sea. *Proceedings of Meetings on Acoustics* 19(1): 1-8. https://doi.org/10.1121/1.4800553

McCauley, R.D., J. Fewtrell, A.J. Duncan, C. Jenner, M.-N. Jenner, J.D. Penrose, R.I.T. Prince, A. Adhitya, J. Murdoch, et al. 2000. Marine seismic surveys: A study of environmental implications. *Australian Petroleum Production Exploration Association (APPEA) Journal* 40(1): 692-708. https://doi.org/10.1071/AJ99048.

McCrodan, A., C.R. McPherson, and D.E. Hannay. 2011. *Sound Source Characterization (SSC) Measurements for Apache's 2011 Cook Inlet 2D Technology Test*. Version 3.0. Technical report by JASCO Applied Sciences for Fairweather LLC and Apache Corporation. 51 p.

McPherson, C.R. and G.A. Warner. 2012. *Sound Sources Characterization for the 2012 Simpson Lagoon OBC Seismic Survey 90-Day Report*. Document Number 00443, Version 2.0. Technical report by JASCO Applied Sciences for BP Exploration (Alaska) Inc. Appendix A in: https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.295.4197&rep=rep1&type=pdf.

McPherson, C.R., K. Lucke, B.J. Gaudet, S.B. Martin, and C.J. Whitt. 2018. *Pelican 3-D Seismic Survey Sound Source Characterisation*. Document Number 001583. Version 1.0. Technical report by JASCO Applied Sciences for RPS Energy Services Pty Ltd.

McPherson, C.R. and B. Martin. 2018. *Characterisation of Polarcus 2380 in^3 Airgun Array*. Document Number 001599, Version 1.0. Technical report by JASCO Applied Sciences for Polarcus Asia Pacific Pte Ltd.

McPherson, C.R., Z. Li, and J.E. Quijano. 2019. *Underwater sound propagation modelling to illustrate potential noise exposure to Maui dolphins from seismic surveys and vessel traffic on West Coast North Island, New Zealand*. Report by JASCO Applied Sciences for Fisheries New Zealand. New Zealand Aquatic Environment and Biodiversity Report No. 217. © Crown Copyright. 62 p. https://mpigovtnz.cwp.govt.nz/dmsdocument/35013.

Mueller-Blenkle, C., P.K. McGregor, A.B. Gill, M.H. Andersson, J. Metcalfe, V. Bendall, P. Sigray, D.T. Wood, and F. Thomsen. 2010. *Effects of Pile-driving Noise on the Behaviour of Marine Fish*. COWRIE Ref: Fish 06-08; Cefas Ref: C3371. 62 p. https://dspace.lib.cranfield.ac.uk/handle/1826/8235.

Nedwell, J.R. and A.W. Turnpenny. 1998. The use of a generic frequency weighting scale in estimating environmental effect. *Workshop on Seismics and Marine Mammals*. 23–25 Jun 1998, London, UK.

Nedwell, J.R., A.W. Turnpenny, J. Lovell, S.J. Parvin, R. Workman, J.A.L. Spinks, and D. Howell. 2007. *A validation of the dB$_{ht}$ as a measure of the behavioural and auditory effects of underwater noise*. Document Number 534R1231 Report prepared by Subacoustech Ltd. for Chevron Ltd, TotalFinaElf Exploration UK PLC, Department of Business, Enterprise and Regulatory Reform, Shell UK Exploration and Production Ltd, The Industry Technology Facilitator, Joint Nature Conservation Committee, and The UK Ministry of Defence. 74 p. https://tethys.pnnl.gov/sites/default/files/publications/Nedwell-et-al-2007.pdf.

Nehls, G., A. Rose, A. Diederichs, M.A. Bellmann, and H. Pehlke. 2016. Noise mitigation during pile driving efficiently reduces disturbance of marine mammals. (Chapter 92) *In* Popper, A.N. and A.D. Hawkins (eds.). *The Effects of Noise on Aquatic Life II*. Volume 875. Springer, NY, USA. pp. 755-762. https://link.springer.com/content/pdf/10.1007%2F978-1-4939-2981-8_92.pdf.

NOAA Fisheries. 2019. *Glossary: Marine Mammal Protection Act* (webpage), 30 Jul 2019. (Accessed 21 Apr 2020).

NOAA Fisheries. 2020a. *Atlantic Salmon (Protected)* (webpage). https://www.fisheries.noaa.gov/species/atlantic-salmon-protected#spotlight. (Accessed 21 May 2020).

NOAA Fisheries. 2020b. *Giant Manta Ray (Manta birostris)* (webpage). https://www.fisheries.noaa.gov/species/giant-manta-ray. (Accessed 11 Jun 2020).

O'Neill, C., D. Leary, and A. McCrodan. 2010. Sound Source Verification. (Chapter 3) *In* Blees, M.K., K.G. Hartin, D.S. Ireland, and D.E. Hannay (eds.). *Marine mammal monitoring and mitigation during open water seismic exploration by Statoil USA E&P Inc. in the Chukchi Sea, August-October 2010: 90-day report*. LGL Report P1119. Prepared by LGL Alaska Research Associates Inc., LGL Ltd., and JASCO Applied Sciences Ltd. for Statoil USA E&P Inc., National Marine Fisheries Service (US), and US Fish and Wildlife Service. pp. 1-34.

Open Ocean. 2020. Metocean data available online. http://www.openocean.fr/en/

Pace, R.M., III, P.J. Corkeron, and S.D. Kraus. 2017. State-space mark-recapture estimates reveal a recent decline in abundance of North Atlantic right whales. *Ecology and Evolution* 7(21): 8730-8741. https://doi.org/10.1002/ece3.3406.

Pettis, H.M. and et al. 2021 in draft. *North Atlantic Right Whale Consortium 2020 Annual Report Card*. Report to the North Atlantic Right Whale Consortium.

Pile Dynamics, Inc. 2010. GRLWEAP. https://www.pile.com/.

Purser, J. and A.N. Radford. 2011. Acoustic noise induces attention shifts and reduces foraging performance in three-spined sticklebacks (*Gasterosteus aculeatus*). *PLOS ONE* 6(2): e17478. https://doi.org/10.1371/journal.pone.0017478.

Racca, R.G., A.N. Rutenko, K. Bröker, and M.E. Austin. 2012a. A line in the water - design and enactment of a closed loop, model based sound level boundary estimation strategy for mitigation of behavioural impacts from a seismic survey. *11th European Conference on Underwater Acoustics*. Volume 34(3), Edinburgh, UK.

Racca, R.G., A.N. Rutenko, K. Bröker, and G. Gailey. 2012b. Model based sound level estimation and in-field adjustment for real-time mitigation of behavioural impacts from a seismic survey and post-event evaluation of sound exposure for individual whales. *In*: McMinn, T. (ed.). *Acoustics 2012*. Fremantle, Australia. http://www.acoustics.asn.au/conference_proceedings/AAS2012/papers/p92.pdf.

Racca, R.G., M.E. Austin, A.N. Rutenko, and K. Bröker. 2015. Monitoring the gray whale sound exposure mitigation zone and estimating acoustic transmission during a 4-D seismic survey, Sakhalin Island, Russia. *Endangered Species Research* 29(2): 131-146. https://doi.org/10.3354/esr00703.

Reiser, C.M., D.W. Funk, R. Rodrigues, and D.E. Hannay. 2010. *Marine mammal monitoring and mitigation during open water seismic exploration by Shell Offshore, Inc. in the Alaskan Chukchi Sea, July–October 2009: 90-day report*. Report Number P1112-1. Technical report by LGL Alaska Research Associates Inc. and JASCO Research Ltd. for Shell Offshore Inc, National Marine Fisheries Service, and US Fish and Wildlife Services. 104 pp, plus appendices.

Reiser, C.M., D.W. Funk, R. Rodrigues, and D.E. Hannay. 2011. *Marine mammal monitoring and mitigation during marine geophysical surveys by Shell Offshore, Inc. in the Alaskan Chukchi and Beaufort seas, July–October 2010: 90-day report*. Report Number P1171E–1. Report by LGL Alaska Research Associates Inc. and JASCO Applied Sciences for Shell Offshore Inc, National Marine Fishery Services, and US Fish and Wildlife Services. 240 + appendices p.

Rhode Island Ocean SAMP. 2011. *Rhode Island Ocean Special Area Management Plan: OCEANSAMP*. Volume 1. Adopted by the Rhode Island Coastal Resources Management Council, 19 Oct 2010. https://tethys.pnnl.gov/sites/default/files/publications/RI-Ocean-SAMP-Volume1.pdf

Richardson, W.J., B. Würsig, and C.R. Greene, Jr. 1986. Reactions of bowhead whales, *Balaena mysticetus*, to seismic exploration in the Canadian Beaufort Sea. *Journal of the Acoustical Society of America* 79(4): 1117-1128. https://doi.org/10.1121/1.393384.

Richardson, W.J., B. Würsig, and C.R. Greene, Jr. 1990. Reactions of bowhead whales, *Balaena mysticetus*, to drilling and dredging noise in the Canadian Beaufort Sea. *Marine Environmental Research* 29(2): 135-160. https://doi.org/10.1016/0141-1136(90)90032-J.

Roberts, J.J., B.D. Best, L. Mannocci, P.N. Halpin, D.L. Palka, L.P. Garrison, K.D. Mullin, T.V.N. Cole, and W.M. McLellan. 2015. *Density Model for Seals (Phocidae) Along the U.S. East Coast, Preliminary Results*. Version 3.2. Marine Geospatial Ecology Lab, Duke University, Durham, NC.

Roberts, J.J., B.D. Best, L. Mannocci, E. Fujioka, P.N. Halpin, D.L. Palka, L.P. Garrison, K.D. Mullin, T.V.N. Cole, et al. 2016. Habitat-based cetacean density models for the U.S. Atlantic and Gulf of Mexico. *Scientific Reports* 6. https://doi.org/10.1038/srep22615.

Roberts, J.J., L. Mannocci, and P.N. Halpin. 2017. *Final Project Report: Marine Species Density Data Gap Assessments and Update for the AFTT Study Area, 2016-2017 (Opt. Year 1)*. Version 1.4. Report by Duke University Marine Geospatial Ecology Lab for Naval Facilities Engineering Command, Atlantic, Durham, NC, USA.

Roberts, J.J., L. Mannocci, R.S. Schick, and P.N. Halpin. 2018. *Final Project Report: Marine Species Density Data Gap Assessments and Update for the AFTT Study Area, 2017-2018 (Opt. Year 2)*. Version 1.2. Report by the Duke University Marine Geospatial Ecology Lab for Naval Facilities Engineering Command, Atlantic Durham, NC, USA.

Roberts, J.J., R.S. Schick, and P.N. Halpin. 2020. *Final Project Report: Marine Species Density Data Gap Assessments and Update for the AFTT Study Area, 2018-2020 (Opt. Year 3)*. Version 1.4. Report by the Duke University Marine Geospatial Ecology Lab for Naval Facilities Engineering Command, Atlantic Durham, NC, USA.

Robinson, S.P., P.D. Theobald, G. Hayman, L.-S. Wang, P.A. Lepper, V.F. Humphrey, and S. Mumford. 2011. *Measurement of Underwater Noise Arising from Marine Aggregate Dredging Operations: Final Report*. Document Number 09/P108. Marine Environment Protection Fund (MEPF). https://webarchive.nationalarchives.gov.uk/20140305134555/http://cefas.defra.gov.uk/alsf/projects/direct-and-indirect-effects/09p108.aspx.

Southall, B.L., A.E. Bowles, W.T. Ellison, J.J. Finneran, R.L. Gentry, C.R. Greene, Jr., D. Kastak, D.R. Ketten, J.H. Miller, et al. 2007. Marine Mammal Noise Exposure Criteria: Initial Scientific Recommendations. *Aquatic Mammals* 33(4): 411-521.

Southall, B.L., W.T. Ellison, C.W. Clark, D.A. Mann, and D.J. Tollit. 2014. *Analytical Framework For Assessing Potential Effects Of Seismic Airgun Surveys On Marine Mammals In The Gulf Of Mexico (Gomex): Expert Working Group (EWG) Final Report*. Southall Environmental Associates, Inc. 133 p.

Southall, B.L., J.J. Finneran, C.J. Reichmuth, P.E. Nachtigall, D.R. Ketten, A.E. Bowles, W.T. Ellison, D.P. Nowacek, and P.L. Tyack. 2019. Marine Mammal Noise Exposure Criteria: Updated Scientific Recommendations for Residual Hearing Effects. *Aquatic Mammals* 45(2): 125-232. https://doi.org/10.1578/AM.45.2.2019.125.

Stadler, J.H. and D.P. Woodbury. 2009. Assessing the effects to fishes from pile driving: Application of new hydroacoustic criteria. *Inter-Noise 2009: Innovations in Practical Noise Control*. 23-29 Aug 2009, Ottawa, Canada.

TetraTech. 2014. *Hydroacoustic Survey Report of Geotechnical Activities Virginia Offshore Wind Technology Advancement Project (VOWTAP)*.

Vortex, 2020. Wind data available online. https://vortexfdc.com/

Waring, G.T., E. Josephson, K. Maze-Foley, and P.E. Rosel. 2011. *U.S. Atlantic and Gulf of Mexico Marine Mammal Stock Assessments—2010*. NOAA Technical Memorandum NMFS-NE-219, Woods Hole, MA, USA. 598 p. https://repository.library.noaa.gov/view/noaa/3831.

Waring, G.T., E. Josephson, K. Maze-Foley, and P.E. Rosel. 2013. *U.S. Atlantic and Gulf of Mexico Marine Mammal Stock Assessments—2012*. Volume 1. NOAA Technical Memorandum NMFS-NE-223, Woods Hole, MA, USA. 419 p. https://repository.library.noaa.gov/view/noaa/4375.

Waring, G.T., E. Josephson, K. Maze-Foley, and P.E. Rosel. 2015. *U.S. Atlantic and Gulf of Mexico Marine Mammal Stock Assessments—2014*. NOAA Technical Memorandum NMFS-NE-232, Woods Hole, MA, USA. 361 p. https://repository.library.noaa.gov/view/noaa/5043.

Waring, G.T., E. Josephson, K. Maze-Foley, and P.E. Rosel. 2016. *U.S. Atlantic and Gulf of Mexico Marine Mammal Stock Assessments—2015*. NOAA Technical Memorandum NMFS-NE-238, Woods Hole, MA, USA. 501 p. https://repository.library.noaa.gov/view/noaa/11985.

Warner, G.A., C. Erbe, and D.E. Hannay. 2010. Underwater Sound Measurements. (Chapter 3) *In* Reiser, C.M., D. Funk, R. Rodrigues, and D.E. Hannay (eds.). *Marine Mammal Monitoring and Mitigation during Open Water Shallow Hazards and Site Clearance Surveys by Shell Offshore Inc. in the Alaskan Chukchi Sea, July-October 2009: 90-Day Report*. LGL Report P1112-1. Report by LGL Alaska Research Associates Inc. and JASCO Applied Sciences for Shell Offshore Inc., National Marine Fisheries Service (US), and Fish and Wildlife Service (US). pp. 1-54.

Warner, G.A., M.E. Austin, and A.O. MacGillivray. 2017. Hydroacoustic measurements and modeling of pile driving operations in Ketchikan, Alaska [Abstract]. *Journal of the Acoustical Society of America* 141(5): 3992. https://doi.org/10.1121/1.4989141.

Whitehead, H. 2018. Sperm Whale: *Physeter macrocephalus*. *In* Würsig, B., J.G.M. Thewissen, and K.M. Kovacs (eds.). *Encyclopedia of Marine Mammals*. 3rd edition. Academic Press. pp. 919-925. https://doi.org/10.1016/B978-0-12-804327-1.00242-9.

Wood, J.D., B.L. Southall, and D.J. Tollit. 2012. *PG&E offshore 3-D Seismic Survey Project Environmental Impact Report–Marine Mammal Technical Draft Report*. Report by SMRU Ltd. 121 p. https://www.coastal.ca.gov/energy/seismic/mm-technical-report-EIR.pdf.

Wysocki, L.E., S. Amoser, and F. Ladich. 2007. Diversity in ambient noise in European freshwater habitats: Noise levels, spectral profiles, and impact on fishes. *Journal of the Acoustical Society of America* 121(5): 2559-2566. https://doi.org/10.1121/1.2713661.

Zhang, Z.Y. and C.T. Tindle. 1995. Improved equivalent fluid approximations for a low shear speed ocean bottom. *Journal of the Acoustical Society of America* 98(6): 3391-3396. https://doi.org/10.1121/1.413789.

Zykov, M.M., L. Bailey, T.J. Deveau, and R.G. Racca. 2013. *South Stream Pipeline – Russian Sector – Underwater Sound Analysis*. Document Number 00691. Technical report by JASCO Applied Sciences for South Stream Transport B.V. https://turkstream.info/r/7607B739-2A1E-4202-86D0-6C6EFE2BC2B6/ssttbv_ru_esia_a123_web_ru_238_en_20140707.pdf.

Zykov, M.M. and J.T. MacDonnell. 2013. *Sound Source Characterizations for the Collaborative Baseline Survey Offshore Massachusetts Final Report: Side Scan Sonar, Sub-Bottom Profiler, and the R/V Small Research Vessel experimental*. Document Number 00413, Version 2.0. Technical report by JASCO Applied Sciences for Fugro GeoServices, Inc. and the (US) Bureau of Ocean Energy Management.

Appendix A. Glossary

1/3-octave
One third of an octave. Note: A one-third octave is approximately equal to one decidecade (1/3 oct ≈ 1.003 ddec; ISO 2017).

1/3-octave-band
Frequency band whose bandwidth is one one-third octave. Note: The bandwidth of a one-third octave-band increases with increasing centre frequency.

absorption
The reduction of acoustic pressure amplitude due to acoustic particle motion energy converting to heat in the propagation medium.

attenuation
The gradual loss of acoustic energy from absorption and scattering as sound propagates through a medium.

azimuth
A horizontal angle relative to a reference direction, which is often magnetic north or the direction of travel. In navigation it is also called bearing.

bandwidth
The range of frequencies over which a sound occurs. Broadband refers to a source that produces sound over a broad range of frequencies (e.g., seismic airguns, vessels) whereas narrowband sources produce sounds over a narrow frequency range (e.g., sonar) (ANSI/ASA S1.13-2005 R2010).

bathymetry
The submarine topography of a region, usually expressed in terms of water depth

broadband sound level
The total sound pressure level measured over a specified frequency range. If the frequency range is unspecified, it refers to the entire measured frequency range.

compressional wave
A mechanical vibration wave in which the direction of particle motion is parallel to the direction of propagation. Also called primary wave or P-wave.

decibel (dB)
One-tenth of a bel. Unit of level when the base of the logarithm is the tenth root of ten, and the quantities concerned are proportional to power (ANSI S1.1-1994 R2004).

frequency
The rate of oscillation of a periodic function measured in cycles-per-unit-time. The reciprocal of the period. Unit: hertz (Hz). Symbol: *f*. 1 Hz is equal to 1 cycle per second.

geoacoustic
Relating to the acoustic properties of the seabed.

hertz (Hz)
A unit of frequency defined as one cycle per second.

impulsive sound
Sound that is typically brief and intermittent with rapid (within a few seconds) rise time and decay back to ambient levels (NOAA 2013, ANSI S12.7-1986 R2006). For example, seismic airguns and impact pile driving.

octave
The interval between a sound and another sound with double or half the frequency. For example, one octave above 200 Hz is 400 Hz, and one octave below 200 Hz is 100 Hz.

parabolic equation method
A computationally efficient solution to the acoustic wave equation that is used to model transmission loss. The parabolic equation approximation omits effects of back-scattered sound, simplifying the computation of transmission loss. The effect of back-scattered sound is negligible for most ocean-acoustic propagation problems.

peak pressure level (PK)
The maximum instantaneous sound pressure level, in a stated frequency band, within a stated period. Also called zero-to-peak pressure level. Unit: decibel (dB).

permanent threshold shift (PTS)
A permanent loss of hearing sensitivity caused by excessive noise exposure. PTS is considered auditory injury.

point source
A source that radiates sound as if from a single point (ANSI S1.1-1994 R2004).

pressure, acoustic
The deviation from the ambient hydrostatic pressure caused by a sound wave. Also called overpressure. Unit: pascal (Pa). Symbol: *p*.

pressure, hydrostatic
The pressure at any given depth in a static liquid that is the result of the weight of the liquid acting on a unit area at that depth, plus any pressure acting on the surface of the liquid. Unit: pascal (Pa).

propagation loss
The decibel reduction in sound level between two stated points that results from sound spreading away from an acoustic source subject to the influence of the surrounding environment. Also called transmission loss.

received level (RL)
The sound level measured (or that would be measured) at a defined location.

rms
root-mean-square.

shear wave
A mechanical vibration wave in which the direction of particle motion is perpendicular to the direction of propagation. Also called secondary wave or S-wave. Shear waves propagate only in solid media, such as sediments or rock. Shear waves in the seabed can be converted to compressional waves in water at the water-seabed interface.

sound
A time-varying pressure disturbance generated by mechanical vibration waves travelling through a fluid medium such as air or water.

sound exposure
Time integral of squared, instantaneous frequency-weighted sound pressure over a stated time interval or event. Unit: pascal-squared second ($Pa^2 \cdot s$) (ANSI S1.1-1994 R2004).

sound exposure level (SEL)
A cumulative measure related to the sound energy in one or more pulses. Unit: dB re 1 $\mu Pa^2 \cdot s$. SEL is expressed over the summation period (e.g., per-pulse SEL [for airguns], single-strike SEL [for pile drivers], 24-hour SEL).

sound field
Region containing sound waves (ANSI S1.1-1994 R2004).

sound pressure level (SPL)
The decibel ratio of the time-mean-square sound pressure, in a stated frequency band, to the square of the reference sound pressure (ANSI S1.1-1994 R2004).

For sound in water, the reference sound pressure is one micropascal (P_0 = 1 μPa) and the unit for SPL is dB re 1 μPa^2:

$$L_p = 10\log_{10}(p^2/p_0^2) = 20\log_{10}(p/p_0)$$

Unless otherwise stated, SPL refers to the root-mean-square (rms) pressure level. See also 90% sound pressure level and fast-average sound pressure level. Non-rectangular time window functions may be applied during calculation of the rms value, in which case the SPL unit should identify the window type.

sound speed profile
The speed of sound in the water column as a function of depth below the water surface.

source level (SL)
The sound level measured in the far-field and scaled back to a standard reference distance of 1 meter from the acoustic centre of the source. Unit: dB re 1 μPa·m (pressure level) or dB re 1 $\mu Pa^2 \cdot s \cdot m$ (exposure level).

temporary threshold shift (TTS)
Temporary loss of hearing sensitivity caused by excessive noise exposure.

Appendix B. Summary of Acoustic Assessment Assumptions

B.1. Impact Pile Driving

The amount of sound generated during pile installation varies with the energy required to drive the piles to the desired depth, which depends on the sediment resistance encountered. Sediment types with greater resistance require pile drivers that deliver higher energy strikes. Maximum sound levels from pile installation usually occur during the last stage of driving (Betke 2008). The representative make and model of impact hammers, and the hammering energy schedule were provided by Mayflower Wind.

Three different foundation types are being considered for the Mayflower Wind Project foundations using three to four piles to secure a jacket structure (Table B-1) and monopile foundations consisting of single piles (Figures 2 and 3). For jacket foundation models, the piles are assumed to be vertical and driven to a penetration depth of 51 m for the realistic WTG scenario and 60 m for the realistic OSP and the maximum OSP and WTG scenarios. For monopile foundation models, the piles are assumed to be vertical and driven to a penetration depth of 35 m for both realistic and maximum scenarios. Pile penetrations across the Lease Area were chosen by Mayflower Wind. The estimated number of strikes required to install piles to completion were obtained from Mayflower Wind in consultation with potential hammer suppliers. All acoustic evaluation was performed assuming that only one pile is driven at a time. Sound from the piling barge was not included in the model.

Table B-1. Impact pile driving: Summary of model inputs, assumptions, and methods.

Parameter	Description
Realistic Scenario Monopile Foundation	
Modeling method	Finite-difference structural model of pile vibration based on thin-shell theory; Hammer forcing functions computed using GRLWEAP
Impact hammer energy	4400 kJ
Ram weight	2157 kN
Helmet weight	2351 kN
Strike rate (min^{-1})	30
Estimated number of strikes to drive pile	5800
Expected penetration	35 m
Modeled seabed penetration	6, 5, and 24 m
Quake (shaft and toe)	2.54 mm (shaft) and 4.5 mm (toe)
Shaft resistance	17, 28, 57% (for each energy level)
Pile length	90.1 m
Pile diameter	11 m
Pile wall thickness	135 mm
L_E accumulation	Per-pulse sound exposures assumed to be equal for a given hammer energy, summed over expected number of strikes
Maximum Scenario Monopile Foundation	
Modeling method	Finite-difference structural model of pile vibration based on thin-shell theory; Hammer forcing functions computed using GRLWEAP
Impact hammer energy	6600 kJ
Ram weight	3257.6 kN

Parameter	Description
Helmet weight	4400 kN
Strike rate (min^{-1})	30
Estimated number of strikes to drive pile	7000
Expected penetration	35 m
Modeled seabed penetration	10, 10, and 15 m
Quake (shaft and toe)	2.54 mm (shaft and toe)
Shaft resistance	44%, 61%, 74% (for each penetration step – a, b, c)
Pile length	105 m
Pile diameter	Tapered 9 to 16 m
Pile wall thickness	110 mm (top) and 166 mm (bottom)
L_E accumulation	Per-pulse sound exposures assumed to be equal for a given hammer energy, summed over expected number of strikes
Realistic Scenario WTG Jacket Foundation (MHU 1900S)	
Modeling method	Finite-difference structural model of pile vibration based on thin-shell theory; Hammer forcing functions computed using GRLWEAP
Impact hammer energy	1900 kJ
Ram weight	932.415 kN
Helmet weight	440 kN
Strike rate (min^{-1})	30
Estimated number of strikes to drive pile	6800
Expected penetration	51 m
Modeled seabed penetration	2, 3, 15 and 31 m
Quake (shaft and toe)	2.54 mm (shaft) and 2.54 mm (toe)
Shaft resistance	14%, 29%, 62%, 81% (for each energy level)
Pile length	54 m
Pile diameter	2.9 m
Pile wall thickness	60 mm
L_E accumulation	Per-pulse sound exposures assumed to be equal for a given hammer energy, summed over expected number of strikes
Realistic Scenario OSP Jacket Foundation (IHC S2000)	
Modeling method	Finite-difference structural model of pile vibration based on thin-shell theory; Hammer forcing functions computed using GRLWEAP
Impact hammer energy	2000 kJ
Ram weight	990.810 kN
Helmet weight	711 kN
Strike rate (min^{-1})	30

Parameter	Description
Estimated number of strikes to drive pile	7000
Expected penetration	60 m
Modeled seabed penetration	20, 20, and 20 m
Quake (shaft and toe)	2.54 mm (shaft) and 2.54 mm (toe)
Shaft resistance	66%, 80%, 86% (for each penetration depth)
Pile length	63 m
Pile diameter	4.5 m
Pile wall thickness	50 mm
L_E accumulation	Per-pulse sound exposures assumed to be equal for a given hammer energy, summed over expected number of strikes
Maximum Scenario OSP/WTG Jacket Foundation (MHU 3500S)	
Modeling method	Finite-difference structural model of pile vibration based on thin-shell theory; Hammer forcing functions computed using GRLWEAP
Impact hammer energy	3500 kJ
Ram weight	1718.947 kN
Helmet weight	1830 kN
Strike rate (min^{-1})	30
Estimated number of strikes to drive pile	4000
Expected penetration	60 m
Modeled seabed penetration	20, 20, and 20 m
Quake (shaft and toe)	2.54 mm (shaft) and 2.54 mm (toe)
Shaft resistance	66%, 80%, 86% (for each penetration depth)
Pile length	63 m
Pile diameter	4.5 m
Pile wall thickness	50 mm
L_E accumulation	Per-pulse sound exposures assumed to be equal for a given hammer energy, summed over expected number of strikes
Environmental parameters for all pile types	
Sound speed profile	GDEM data averaged over region
Bathymetry	SRTM15+ data
Geoacoustics	Elastic seabed properties based on client-supplied description of surficial sediment samples
Shaft damping	0.164 s/m
Toe damping	0.49 s/m
Propagation model for all pile types	
Modeling method	Parabolic-equation propagation model with 2.5° azimuthal resolution; FWRAM full-waveform parabolic equation propagation model for 4 radials

Parameter	Description
Source representation	Vertical line array
Frequency range	10 to 25,000 Hz
Synthetic trace length	300 ms (Jacket), 400 ms (Realistic Monopile), 500 ms (Maximum Monopile)
Maximum modeled range	100 km

Appendix C. Underwater Acoustics

This section provides a detailed description of the acoustic metrics relevant to the modeling study and the modeling methodology.

C.1. Acoustic Metrics

Underwater sound pressure amplitude is measured in decibels (dB) relative to a fixed reference pressure of p_0 = 1 μPa. Because the perceived loudness of sound, especially pulsed sound such as from seismic airguns, pile driving, and sonar, is not generally proportional to the instantaneous acoustic pressure, several sound level metrics are commonly used to evaluate sound and its effects on marine life. Here we provide specific definitions of relevant metrics used in the accompanying report. Where possible, we follow International Organization for Standardization definitions and symbols for sound metrics (e.g., ISO 2017).

The zero-to-peak sound pressure, or peak sound pressure (PK or $L_{p,pk}$; dB re 1 μPa), is the decibel level of the maximum instantaneous acoustic pressure in a stated frequency band attained by an acoustic pressure signal, $p(t)$:

$$L_{p,\mathrm{pk}} = 10\log_{10}\frac{\max|p^2(t)|}{p_0^2} = 20\log_{10}\frac{\max|p(t)|}{p_0} \tag{C-1}$$

PK is often included as a criterion for assessing whether a sound is potentially injurious; however, because it does not account for the duration of an acoustic event, it is generally a poor indicator of perceived loudness.

The peak-to-peak sound pressure (PK-PK or $L_{p,pk\text{-}pk}$; dB re 1 μPa) is the difference between the maximum and minimum instantaneous sound pressure, possibly filtered in a stated frequency band, attained by an impulsive sound, $p(t)$:

$$L_{p,\mathrm{pk\text{-}pk}} = 10\log_{10}\frac{[\max(p(t)) - \min(p(t))]^2}{p_0^2} \tag{C-2}$$

The sound pressure level (SPL or L_p; dB re 1 μPa) is the root-mean-square (rms) pressure level in a stated frequency band over a specified time window (T; s). It is important to note that SPL always refers to an rms pressure level and therefore not instantaneous pressure:

$$L_p = 10\log_{10}\left(\frac{1}{T}\int_T g(t)\,p^2(t)\,dt \Big/ p_0^2\right)\ \mathrm{dB} \tag{C-3}$$

where $g(t)$ is an optional time weighting function. In many cases, the start time of the integration is marched forward in small time steps to produce a time-varying SPL function. For short acoustic events, such as sonar pulses and marine mammal vocalizations, it is important to choose an appropriate time window that matches the duration of the signal. For in-air studies, when evaluating the perceived loudness of sounds with rapid amplitude variations in time, the time weighting function $g(t)$ is often set to a decaying exponential function that emphasizes more recent pressure signals. This function mimics the leaky integration nature of mammalian hearing. For example, human-based fast time-weighted SPL ($L_{p,fast}$) applies an exponential function with time constant 125 ms. A related simpler approach used in underwater acoustics sets $g(t)$ to a boxcar (unity amplitude) function of width 125 ms; the results can be referred to as $L_{p,boxcar\ 125ms}$. Another approach, historically used to evaluate SPL of impulsive signals underwater, defines $g(t)$ as a boxcar function with edges set to the times corresponding to 5% and 95% of the cumulative square pressure function encompassing the duration of an impulsive acoustic event.

This calculation is applied individually to each impulse signal, and the results have been referred to as 90% SPL ($L_{p,90\%}$).

The sound exposure level (SEL or L_E; dB re 1 µPa^2·s) is the time-integral of the squared acoustic pressure over a duration (T):

$$L_E = 10\log_{10}\left(\int_T p^2(t)\,dt \Big/ T_0 p_0^2\right)\ \text{dB} \tag{C-4}$$

where T_0 is a reference time interval of 1 s. SEL continues to increase with time when non-zero pressure signals are present. It is a dose-type measurement, so the integration time applied must be carefully considered for its relevance to impact to the exposed recipients.

SEL can be calculated over a fixed duration, such as the time of a single event or a period with multiple acoustic events. When applied to pulsed sounds, SEL can be calculated by summing the SEL of the N individual pulses. For a fixed duration, the square pressure is integrated over the duration of interest. For multiple events, the SEL can be computed by summing (in linear units) the SEL of the N individual events:

$$L_{E,N} = 10\log_{10}\left(\sum_{i=1}^{N} 10^{\frac{L_{E,i}}{10}}\right)\ \text{dB} \tag{C-5}$$

Because the SPL(T_{90}) and SEL are both computed from the integral of square pressure, these metrics are related numerically by the following expression, which depends only on the duration of the time window T:

$$L_p = L_E - 10\log_{10}(T) \tag{C-6}$$

$$L_{p90} = L_{\mathrm{E}} - 10\log_{10}(T_{90}) - 0.458 \tag{C-7}$$

where the 0.458 dB factor accounts for the 10% of pulse SEL missing from the SPL(T_{90}) integration time window.

Energy equivalent SPL (L_{eq}; dB re 1 µPa) denotes the SPL of a stationary (constant amplitude) sound that generates the same SEL as the signal being examined, $p(t)$, over the same time period, T:

$$L_{\mathrm{eq}} = 10\log_{10}\left(\frac{1}{T}\int_T p^2(t)\,dt \Big/ p_0^2\right) \tag{C-8}$$

The equations for SPL and the energy-equivalent SPL are numerically identical. Conceptually, the difference between the two metrics is that the SPL is typically computed over short periods (typically of 1 s or less) and tracks the fluctuations of a non-steady acoustic signal, whereas the L_{eq} reflects the average SPL of an acoustic signal over time periods typically of 1 min to several hours.

If applied, the frequency weighting of an acoustic event should be specified, as in the case of weighted SEL (e.g., $L_{E,LF,24h}$; see Appendix D.1) or auditory-weighted SPL ($L_{p,ht}$). The use of fast, slow, or impulse exponential-time-averaging or other time-related characteristics should also be specified.

C.2. Decidecade Analysis

The distribution of a sound's power with frequency is described by the sound's spectrum. The sound spectrum can be split into a series of adjacent frequency bands. Splitting a spectrum into 1 Hz wide bands, called passbands, yields the power spectral density of the sound. This splitting of the spectrum into passbands of a constant width of 1 Hz, however, does not represent how animals perceive sound.

Because animals perceive exponential increases in frequency rather than linear increases, analyzing a sound spectrum with passbands that increase exponentially in size better approximates real-world scenarios. In underwater acoustics, a spectrum is commonly split into decidecade bands, which are one tenth of a decade wide. A decidecade is sometimes referred to as a "1/3 octave" because one tenth of a decade is approximately equal to one third of an octave. Each decade represents a factor 10 in sound frequency. Each octave represents a factor 2 in sound frequency. The centre frequency of the ith band, $f_c(i)$, is defined as:

$$f_c(i) = 10^{\frac{i}{10}} \text{ kHz} \tag{C-9}$$

and the low (f_{lo}) and high (f_{hi}) frequency limits of the ith decade band are defined as:

$$f_{lo,i} = 10^{\frac{-1}{20}} f_c(i) \quad \text{and} \quad f_{hi,i} = 10^{\frac{1}{20}} f_c(i) \tag{C-10}$$

The decidecade bands become wider with increasing frequency, and on a logarithmic scale the bands appear equally spaced (Figure C-1). In this report, the acoustic modeling spans from band −24 ($f_c(-24)$ = 0.004 kHz) to band 14 ($f_c(14)$ = 25 kHz).

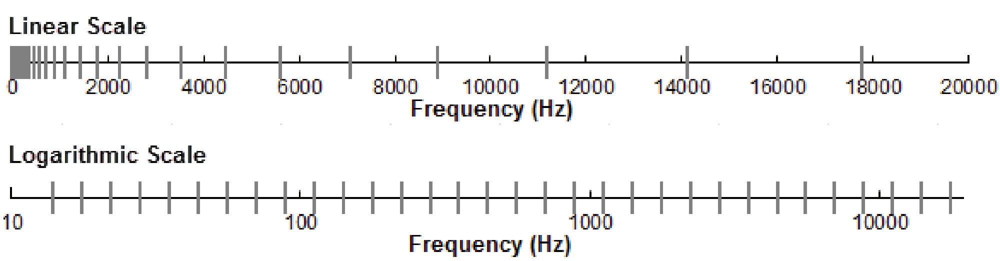

Figure C-1. Decidecade frequency bands (vertical lines) shown on a linear frequency scale and a logarithmic scale.

The sound pressure level in the ith band ($L_{p,i}$) is computed from the spectrum $S(f)$ between $f_{lo,i}$ and $f_{hi,i}$:

$$L_{p,i} = 10 \log_{10} \int_{f_{lo,i}}^{f_{hi,i}} S(f)\, df \tag{C-11}$$

Summing the sound pressure level of all the bands yields the broadband sound pressure level:

$$\text{Broadband SPL} = 10 \log_{10} \sum_i 10^{\frac{L_{p,i}}{10}} \tag{C-12}$$

Figure C-2 shows an example of how the decidecade band sound pressure levels compare to the sound pressure spectral density levels of an ambient noise signal. Because the decidecade bands are wider with increasing frequency, the decidecade band SPL is higher than the spectral levels at higher frequencies. Acoustic modeling of decidecade bands requires less computation time than 1 Hz bands and still resolves the frequency-dependence of the sound source and the propagation environment.

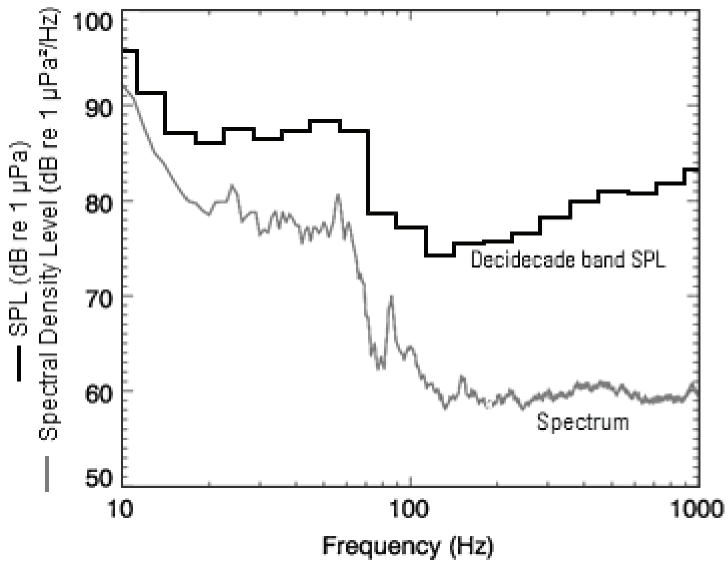

Figure C-2. Sound pressure spectral density levels and the corresponding decidecade band sound pressure levels of example ambient noise shown on a logarithmic frequency scale.

Appendix D. Auditory (Frequency) Weighting Functions

The potential for noise to affect animals of a certain species depends on how well the animals can hear it. Noises are less likely to disturb or injure an animal if they are at frequencies that the animal cannot hear well. An exception occurs when the sound pressure is so high that it can physically injure an animal by non-auditory means (i.e., barotrauma). For sound levels below such extremes, the importance of sound components at particular frequencies can be scaled by frequency weighting relevant to an animal's sensitivity to those frequencies (Nedwell and Turnpenny 1998, Nedwell et al. 2007).

D.1. Frequency Weighting Functions - Technical Guidance (NMFS 2018)

In 2015, a US Navy technical report by Finneran (2015) recommended new auditory weighting functions. The auditory weighting functions for marine mammals are applied in a similar way as A-weighting for noise level assessments for humans. The new frequency-weighting functions are expressed as:

$$G(f) = K + 10\log_{10}\left\{\frac{(f/f_1)^{2a}}{[1+(f/f_1)^2]^a[1+(f/f_2)^2]^b}\right\} \quad \text{(D-1)}$$

Finneran (2015) proposed five functional hearing groups for marine mammals in water: low-, mid- and high-frequency cetaceans (LF, MF, and HF cetaceans, respectively), phocid pinnipeds, and otariid pinnipeds. The parameters for these frequency-weighting functions were further modified the following year (Finneran 2016) and were adopted in NOAA's technical guidance that assesses acoustic impacts on marine mammals (NMFS 2018). The updates did not affect the content related to either the definitions of M-weighting functions or the threshold values. Table D-1 lists the frequency-weighting parameters for each hearing group. Figure D-1 shows the resulting frequency-weighting curves.

Table D-1. Parameters for the auditory weighting functions recommended by NMFS (2018).

Functional hearing group	a	b	f_1 (Hz)	f_2 (Hz)	K (dB)
Low-frequency cetaceans	1.0	2	200	19,000	0.13
Mid-frequency cetaceans	1.6	2	8,800	110,000	1.20
High-frequency cetaceans	1.8	2	12,000	140,000	1.36
Phocid pinnipeds in water	1.0	2	1,900	30,000	0.75
Otariid pinnipeds in water	2.0	2	940	25,000	0.64

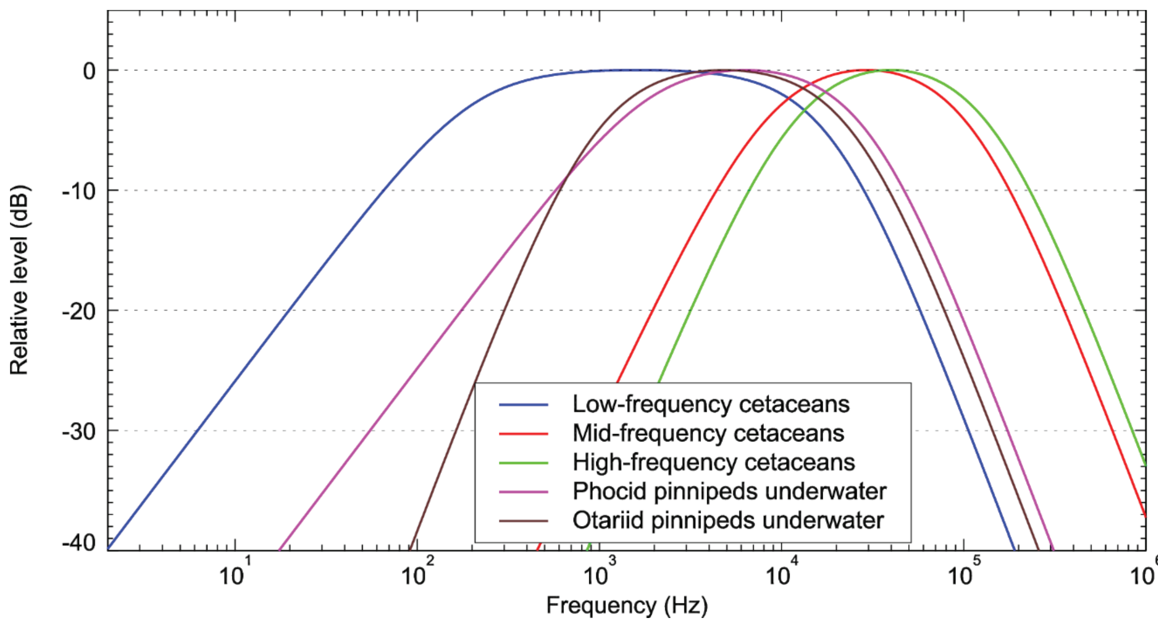

Figure D-1. Auditory weighting functions for the functional marine mammal hearing groups as recommended by NMFS (2018).

D.2. Southall et al. (2007) Frequency Weighting Functions

Auditory weighting functions for marine mammals—called M-weighting functions—were proposed by Southall et al. (2007). These M-weighting functions are applied in a similar way as A-weighting for noise level assessments for humans. Functions were defined for five hearing groups of marine mammals:

- Low-frequency (LF) cetaceans—mysticetes (baleen whales)
- Mid-frequency (MF) cetaceans—some odontocetes (toothed whales)
- High-frequency (HF) cetaceans—odontocetes specialized for using high-frequencies
- Pinnipeds in water (Pw)—seals, sea lions, and walrus
- Pinnipeds in air (not addressed here)

The M-weighting functions have unity gain (0 dB) through the passband and their high- and low-frequency roll-offs are approximately –12 dB per octave. The amplitude response in the frequency domain of each M-weighting function is defined by:

$$G(f) = -20\log_{10}\left[\left(1+\frac{a^2}{f^2}\right)\left(1+\frac{f^2}{b^2}\right)\right] \tag{D-2}$$

where G is the weighting function amplitude (in dB) at the frequency f (in Hz), and a and b are the estimated lower and upper hearing limits, respectively, which control the roll-off and passband of the weighting function. The parameters a and b are defined uniquely for each hearing group (Table D-2). Figure D-1 shows the auditory weighting functions.

Table D-2. Parameters for the auditory weighting functions recommended by Southall et al. (2007).

Functional hearing group	*a* (Hz)	*b* (Hz)
Low-frequency cetaceans	7	22,000
Mid-frequency cetaceans	150	160,000
High-frequency cetaceans	200	180,000
Pinnipeds in water	75	75,000

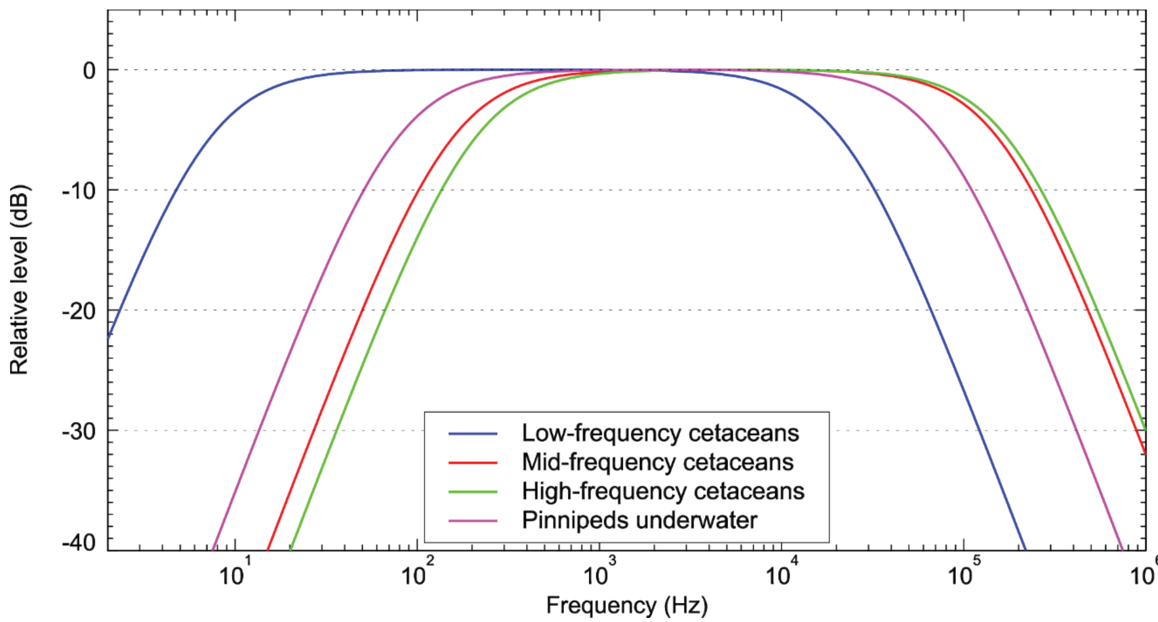

Figure D-2. Auditory weighting functions for the functional marine mammal hearing groups as recommended by Southall et al. (2007).

Appendix E. Sound Propagation Modeling

E.1. Pile Driving Source Model (PDSM)

A physical model of pile vibration and near-field sound radiation is used to calculate source levels of piles. The physical model employed in this study computes the underwater vibration and sound radiation of a pile by solving the theoretical equations of motion for axial and radial vibrations of a cylindrical shell. These equations of motion are solved subject to boundary conditions, which describe the forcing function of the hammer at the top of the pile and the soil resistance at the base of the pile (Figure E-1). Damping of the pile vibration due to radiation loading is computed for Mach waves emanating from the pile wall. The equations of motion are discretised using the finite difference (FD) method and are solved on a discrete time and depth mesh.

To model the sound emissions from the piles, the force of the pile driving hammers also had to be modeled. The force at the top of each pile was computed using the GRLWEAP 2010 wave equation model (GRLWEAP, Pile Dynamics 2010), which includes a large database of simulated hammers—both impact and vibratory—based on the manufacturer's specifications. The forcing functions from GRLWEAP were used as inputs to the FD model to compute the resulting pile vibrations.

The sound radiating from the pile itself is simulated using a vertical array of discrete point sources. The point sources are centered on the pile axis. Their amplitudes are derived using an inverse technique, such that their collective particle velocity, calculated using a near-field wave-number integration model, matches the particle velocity in the water at the pile wall. The sound field propagating away from the vertical source array is then calculated using a time-domain acoustic propagation model (see Appendix E.4). MacGillivray (2014) describes the theory behind the physical model in more detail.

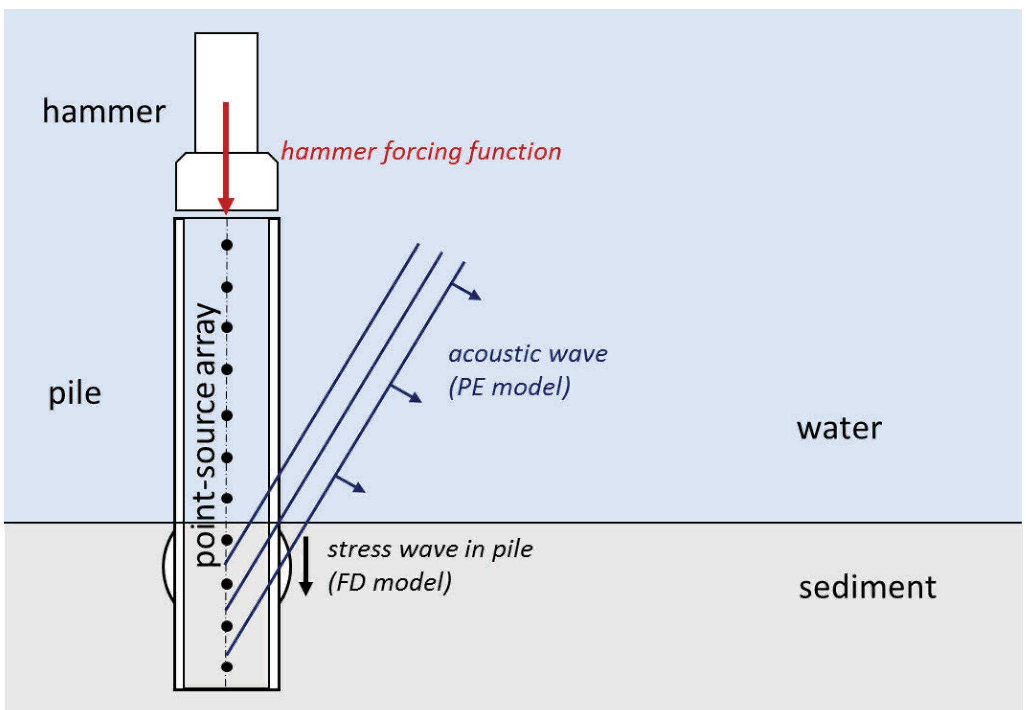

Figure E-1. Physical model geometry for impact driving of a cylindrical pile (vertical cross-section). The hammer forcing function is used with the finite difference (FD) model to compute the stress wave vibration in the pile. A vertical array of point sources is used with the parabolic equation (PE) model to compute the acoustic waves that the pile wall radiates.

E.2. Environmental Parameters

E.2.1. Bathymetry

A bathymetry grid for the acoustic propagation model was compiled based on data obtained from the Shuttle Radar Topography Mission (SRTM) referred to as SRTM-TOPO15+ (Becker et al. 2009).

E.2.2. Geoacoustics

In shallow water environments where there is increased interaction with the seafloor, the properties of the substrate have a large influence over the sound propagation. The dominant soil type in the area is expected to be sand. Table E-1 shows the sediment layer geoacoustic property profile based on the sediment type and generic porosity-depth profile using a sediment grain-shearing model (Buckingham 2005).

Table E-1. Estimated geoacoustic properties used for modeling. Within each depth range, each parameter varies linearly within the stated range. The compressional wave is the primary wave. The shear wave is the secondary wave.

Depth below seafloor (m)	Material	Density (g/cm^3)	Compressional wave		Shear wave	
			Speed (m/s)	Attenuation (dB/λ)	Speed (m/s)	Attenuation (dB/λ)
0–3.33	Medium sand	2.09	1770.1–1774.4	0.88–0.879	300.0	3.65
3.33–6.67		2.09–2.095	1774.4–1778.8	0.879–0.878		
6.67–10.0		2.095–2.099	1778.8–1783.1	0.878–0.877		
10.0–50.0		2.099–2.152	1783.1–1833.5	0.877–0.865		
50.0–100.0		2.152–2.216	1833.5–1893.3	0.865–0.848		
100.0–200.0		2.216–2.337	1893.3–2003.3	0.848–0.807		
200.0–500.0		2.337–2.634	2003.3–2268.9	0.807–0.664		

E.2.3. Sound Speed Profile

The speed of sound in sea-water is a function of temperature, salinity and pressure (depth) (Coppens 1981). Sound speed profiles were obtained from the US Navy's Generalized Digital Environmental Model (GDEM; NAVO 2003). Considering the greater area around the proposed construction area and deep waters, we see that the shape of the sound speed profiles do not change much month to month, during the summer months (June to August) (Figure E-2). Water depths in the Mayflower Wind are less than 60 m; sound speed profile for the shallow water are provided in (Figure E-3). An average summer profile, obtained by calculating the mean of all profiles shown in Figure E-2 was assumed representative of the area for modeling purposes.

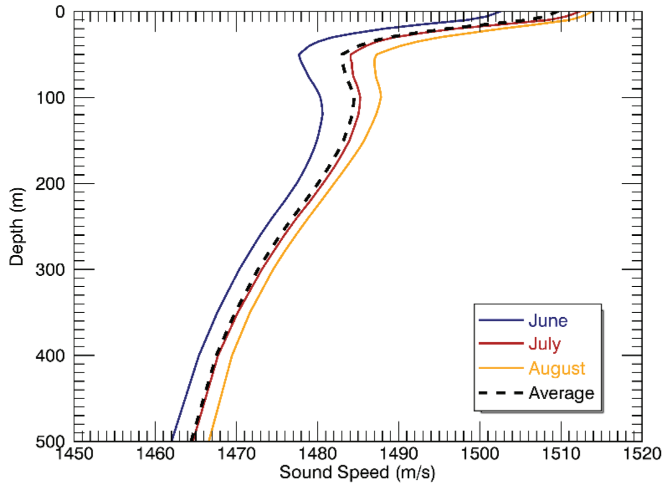

Figure E-2. Sound speed profiles for the months of June through August for Mayflower Wind, and the mean profile used in the modeling and obtained by taking the average of all profiles.

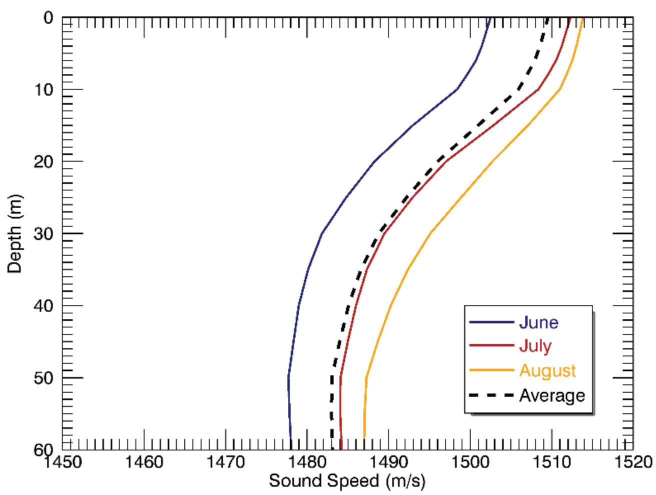

Figure E-3. Sound speed profiles up to 60 m depth for the months of June through August for Mayflower Wind, and the mean profile used in the modeling and obtained by taking the average of all profiles.

E.3. Transmission Loss

The propagation of sound through the environment was modeled by predicting the acoustic transmission loss—a measure, in decibels, of the decrease in sound level between a source and a receiver some distance away. Geometric spreading of acoustic waves is the predominant way by which transmission loss occurs. Transmission loss also happens when the sound is absorbed and scattered by the seawater, and absorbed scattered, and reflected at the water surface and within the seabed. Transmission loss depends on the acoustic properties of the ocean and seabed; its value changes with frequency.

If the acoustic source level (SL), expressed in dB re 1 µPa²m²s, and transmission loss (TL), in units of dB, at a given frequency are known, then the received level (RL) at a receiver location can be calculated in dB re 1 µPa²s by:

$$\mathrm{RL} = \mathrm{SL} - \mathrm{TL} \tag{E-1}$$

E.4. Sound Propagation with MONM

Transmission loss (i.e., sound propagation) can be predicted with JASCO's Marine Operations Noise Model (MONM). MONM computes received sound energy, the sound exposure level (L_E or SEL), for directional sources. MONM uses a wide-angle parabolic equation solution to the acoustic wave equation (Collins 1993) based on a version of the US Naval Research Laboratory's Range-dependent Acoustic Model (RAM), which has been modified to account for a solid seabed (Zhang and Tindle 1995). The parabolic equation method has been extensively benchmarked and is widely employed in the underwater acoustics community (Collins et al. 1996). MONM's predictions have been validated against experimental data from several underwater acoustic measurement programs conducted by JASCO (Hannay and Racca 2005, Aerts et al. 2008, Funk et al. 2008, Ireland et al. 2009, O'Neill et al. 2010, Warner et al. 2010, Racca et al. 2012a, Racca et al. 2012b). MONM accounts for the additional reflection loss at the seabed due to partial conversion of incident compressional waves to shear waves at the seabed and sub-bottom interfaces, and it includes wave attenuations in all layers. MONM incorporates site-specific environmental properties, such as bathymetry, underwater sound speed as a function of depth, and a geoacoustic profile the seafloor.

MONM treats frequency dependence by computing acoustic transmission loss at the center frequencies of decidecades. At each center frequency, the transmission loss is modeled as a function of depth and range from the source. Composite broadband received SEL are then computed by summing the received decidecade levels across the modeled frequency range.

For computational efficiency, MONM and similar models such as PE-RAM, do not track temporal aspects of the propagating signal (as opposed to models that can output time-domain pressure signals, see Appendix E.5). It is the total sound energy transmission loss that is calculated. For our purposes, that is equivalent to propagating the L_E acoustic metric. For continuous, steady-state signals SPL is readily obtained from the SEL.

Acoustic fields in three dimensions are generated by modeling propagation loss within two-dimensional (2-D) vertical planes aligned along radials covering a 360° swath from the source, an approach commonly referred to as N×2-D (Figure E-4). These vertical radial planes are separated by an angular step size of $\Delta\theta$, yielding $N = 360°/\Delta\theta$ planes.

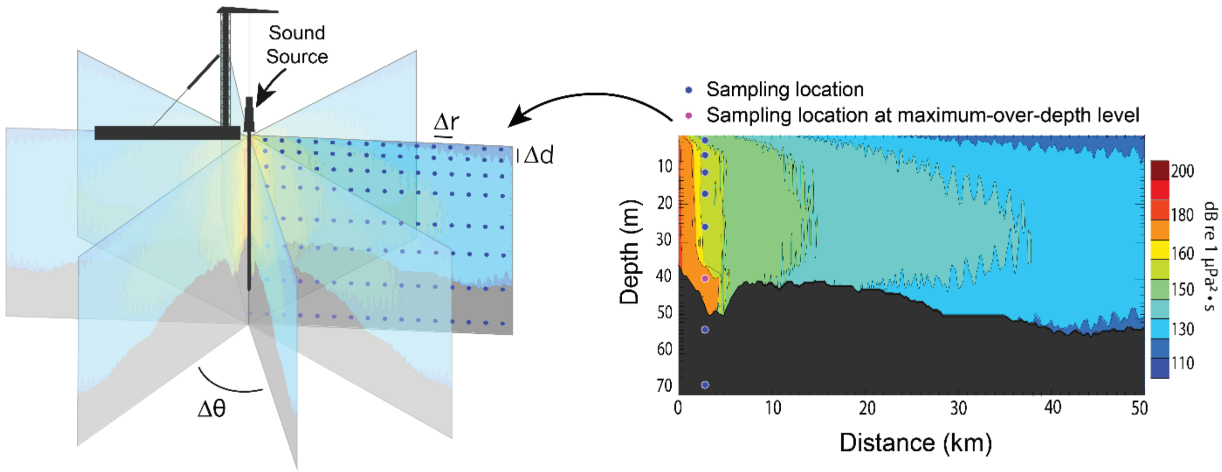

Figure E-4. Modeled three-dimensional sound field (N×2-D method) and maximum-over-depth modeling approach. Sampling locations are shown as blue dots on both figures. On the right panel, the pink dot represents the sampling location where the sound level is maximum over the water column. This maximum-over-depth level is used in calculating distances to sound level thresholds for some marine animals.

E.5. Sound Propagation with FWRAM

For impulsive sounds from impact pile driving, time-domain representations of the pressure waves generated in the water are required for calculating SPL and peak pressure level. Furthermore, the pile must be represented as a distributed source to accurately characterize vertical directivity effects in the near-field zone. For this study, synthetic pressure waveforms were computed using FWRAM, which is a time-domain acoustic model based on the same wide-angle parabolic equation (PE) algorithm as MONM. FWRAM computes synthetic pressure waveforms versus range and depth for range-varying marine acoustic environments, and it takes the same environmental inputs as MONM (bathymetry, water sound speed profile, and seabed geoacoustic profile). Unlike MONM, FWRAM computes pressure waveforms via Fourier synthesis of the modeled acoustic transfer function in closely spaced frequency bands. FWRAM employs the array starter method to accurately model sound propagation from a spatially distributed source (MacGillivray and Chapman 2012).

Synthetic pressure waveforms were modeled over the frequency range 10 to 2048 Hz, inside a 1 s window (e.g., Figure E-5). The synthetic pressure waveforms were post-processed, after applying a travel time correction, to calculate standard SPL and SEL metrics versus range and depth from the source.

Besides providing direct calculations of the peak pressure level and SPL, the synthetic waveforms from FWRAM can also be used to convert the SEL values from MONM to SPL.

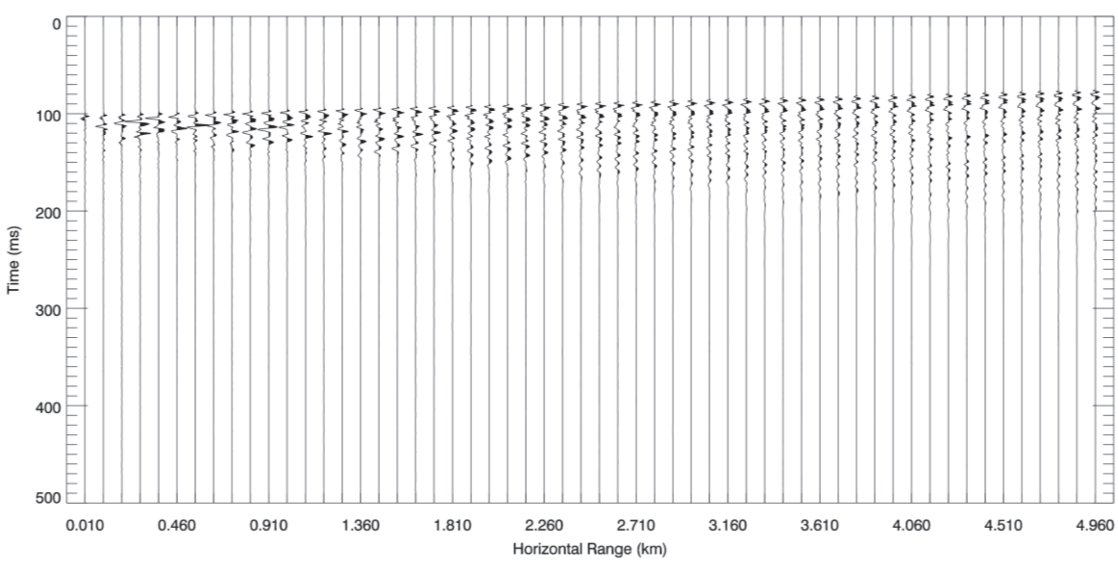

Figure E-5. Example of synthetic pressure waveforms computed by FWRAM at multiple range offsets. Receiver depth is 35 m and the amplitudes of the pressure traces have been normalised for display purposes.

E.6. Estimating Acoustic Range to Threshold Levels

A maximum-over depth approach is used to determine acoustic ranges to the defined thresholds (ranges to isopleths). That is, at each horizontal sampling range, the maximum received level that occurs within the water column is used as the value at that range. The ranges to a threshold typically differ along different radii and may not be continuous because sound levels may drop below threshold at some ranges and then exceed threshold at farther ranges. Figure E-6 shows an example of an area with sound levels above threshold and two methods of reporting the injury or behavioral disruption range: (1) R_{max}, the maximum range at which the sound level was encountered in the modeled maximum-over-depth sound field, and (2) $R_{95\%}$, the maximum range at which the sound level was encountered after the 5 percent farthest such points were excluded. $R_{95\%}$ is used because, regardless of the shape of the maximum-over-depth footprint, the predicted range encompasses at least 95 percent of the horizontal area that would be exposed to sound at or above the specified level. The difference between R_{max} and $R_{95\%}$ depends on the source directivity and the heterogeneity of the acoustic environment. $R_{95\%}$ excludes ends of protruding areas or small isolated acoustic foci not representative of the nominal ensonification zone.

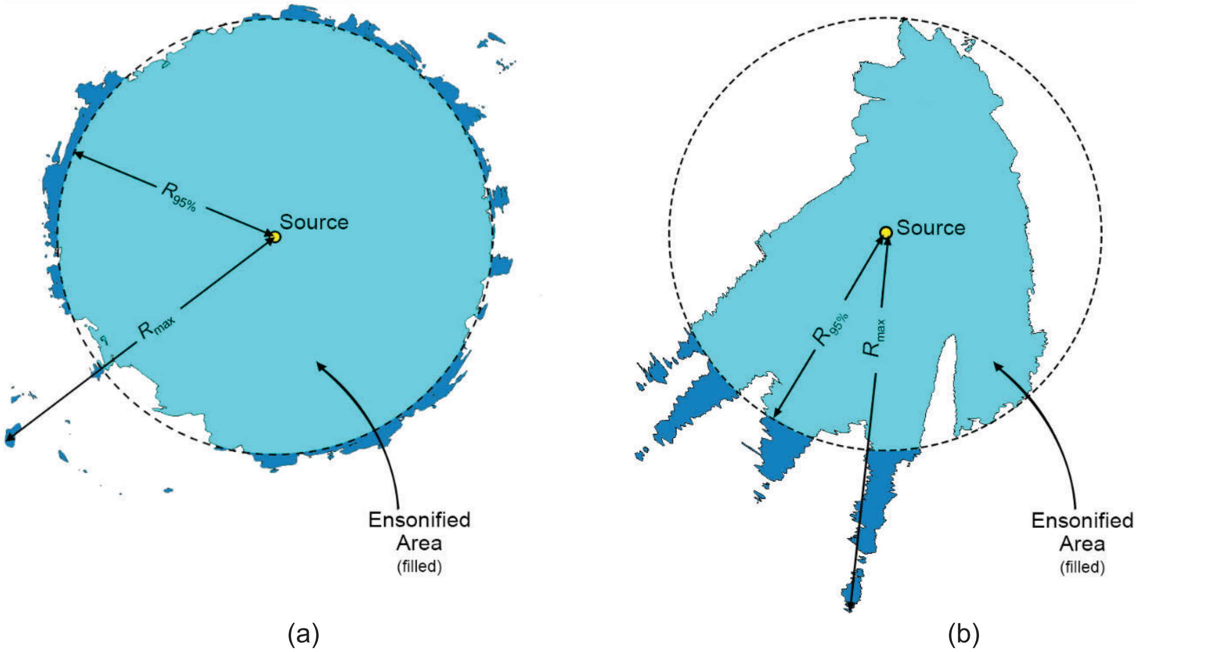

Figure E-6. Sample areas ensonified to an arbitrary sound level with R_{max} and $R_{95\%}$ ranges shown for two different scenarios. (a) Largely symmetric sound level contour with small protrusions. (b) Strongly asymmetric sound level contour with long protrusions. Light blue indicates the ensonified areas bounded by $R_{95\%}$; darker blue indicates the areas outside this boundary which determine R_{max}.

E.7. Model Validation Information

Predictions from JASCO's propagation models (MONM and FWRAM) have been validated against experimental data from a number of underwater acoustic measurement programs conducted by JASCO globally, including the United States and Canadian Arctic, Canadian and southern United States waters, Greenland, Russia and Australia (Hannay and Racca 2005, Aerts et al. 2008, Funk et al. 2008, Ireland et al. 2009, O'Neill et al. 2010, Warner et al. 2010, Racca et al. 2012a, Racca et al. 2012b, Matthews and MacGillivray 2013, Martin et al. 2015, Racca et al. 2015, Martin et al. 2017a, Martin et al. 2017b, Warner et al. 2017, MacGillivray 2018, McPherson et al. 2018, McPherson and Martin 2018).

In addition, JASCO has conducted measurement programs associated with a significant number of anthropogenic activities which have included internal validation of the modeling (including McCrodan et al. 2011, Austin and Warner 2012, McPherson and Warner 2012, Austin and Bailey 2013, Austin et al. 2013, Zykov and MacDonnell 2013, Austin 2014, Austin et al. 2015, Austin and Li 2016, Martin and Popper 2016).

Appendix F. Acoustic Radial Isopleths

The following subsections contain tables of ranges to nominal SEL isopleths from impact pile driving of realistic and maximum jacket and monopile foundation scenarios. An example map of the unweighted single-strike SEL is provided for source location L01 (Figure F-1).

F.1. Ranges to Single-strike SEL Thresholds

The following tables present single-strike SEL isopleth ranges. R_{max} is the maximum range at which the sound level was encountered in the modeled maximum-over-depth sound field and $R_{95\%}$ is the maximum range at which the sound level was encountered after the 5% percent farthest such points were excluded (Appendix E.6). Ranges are calculated on unweighted and weighted sound fields described in Appendix D.1. Weightings used are designated as follows: Flat is unweighted, LFC is low-frequency cetaceans, MFC is mid-frequency cetaceans, HFC is high-frequency cetaceans, PPW is pinnipeds in water, and TUW is turtles in water. TUW weighting functions are from the US Navy (Finneran et al. 2017), the rest are from the Technical Guidance (NMFS 2018). All calculations use an average summer sound speed profile.

F.1.1. Location L01

F.1.1.1. Realistic Scenarios

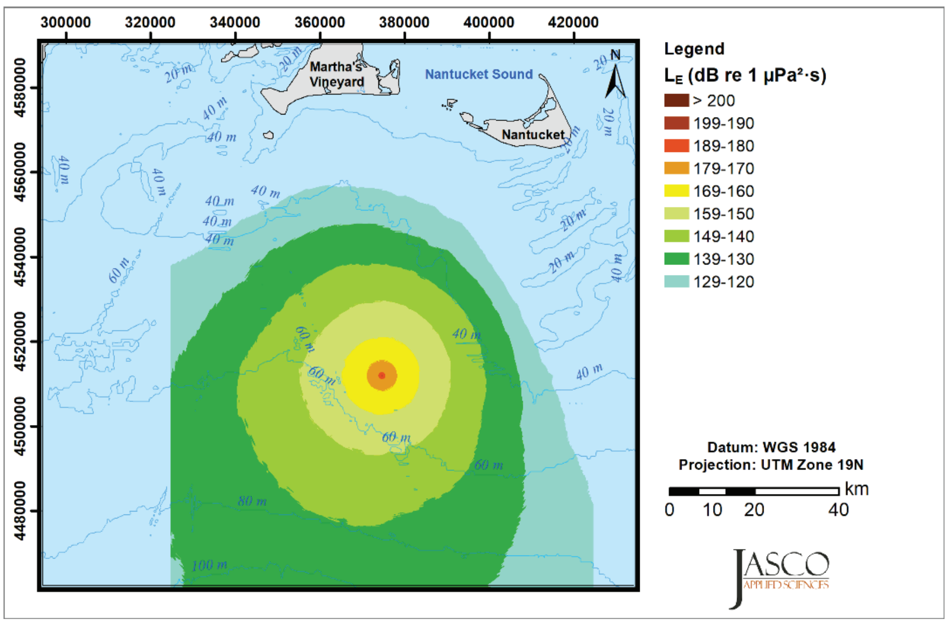

Figure F-1. Unweighted single-strike sound exposure level (SEL) for an 11 m pile at Site L01, average summer sound speed profile and energy level of 4400 kJ.

Table F-1. Distance (km) to the single strike sound exposure level (SEL) for a 2.9 m pin pile at location L01 using a Menck MHU1900S hammer operating at 475 kJ.

Level (SEL)	Flat R_{max}	Flat $R_{95\%}$	LFC R_{max}	LFC $R_{95\%}$	MFC R_{max}	MFC $R_{95\%}$	HFC R_{max}	HFC $R_{95\%}$	PPW R_{max}	PPW $R_{95\%}$	TUW R_{max}	TUW $R_{95\%}$
200	-	-	-	-	-	-	-	-	-	-	-	-
190	-	-	-	-	-	-	-	-	-	-	-	-
180	0.09	0.09	0.05	0.05	-	-	-	-	-	-	0.07	0.07
170	0.50	0.48	0.25	0.24	-	-	-	-	0.03	0.03	0.43	0.41
160	2.68	2.43	1.66	1.61	0.03	0.03	-	-	0.23	0.23	2.13	2.06
150	8.63	7.85	6.91	6.03	0.11	0.10	0.06	0.06	2.34	1.63	7.91	7.08
140	21.54	18.11	17.06	14.86	0.91	0.86	0.47	0.46	7.71	6.32	19.44	16.66
130	45.42	38.49	38.26	32.62	5.29	3.79	3.10	2.33	17.50	14.53	40.86	35.38
120	70.68	55.83	70.68	54.65	11.27	8.98	7.71	6.15	37.18	29.43	70.68	55.14

A dash (-) indicates that the threshold distance was not reached.

Table F-2. Distance (km) to the single strike sound exposure level (SEL) for a 2.9 m pin pile at location L01 using a Menck MHU1900S hammer operating at 950 kJ.

Level (SEL)	Flat R_{max}	Flat $R_{95\%}$	LFC R_{max}	LFC $R_{95\%}$	MFC R_{max}	MFC $R_{95\%}$	HFC R_{max}	HFC $R_{95\%}$	PPW R_{max}	PPW $R_{95\%}$	TUW R_{max}	TUW $R_{95\%}$
200	-	-	-	-	-	-	-	-	-	-	-	-
190	0.02	0.02	-	-	-	-	-	-	-	-	-	-
180	0.13	0.13	0.08	0.08	-	-	-	-	-	-	0.11	0.11
170	0.84	0.81	0.53	0.50	-	-	-	-	0.08	0.08	0.72	0.67
160	4.06	3.78	3.11	2.42	0.03	0.03	0.03	0.03	0.47	0.46	3.26	3.12
150	11.25	10.05	9.22	7.99	0.22	0.20	0.11	0.10	3.83	3.04	9.93	9.00
140	26.09	22.50	22.51	18.54	1.64	1.55	0.85	0.80	10.19	8.32	23.61	20.56
130	55.85	47.43	48.44	40.48	6.76	5.20	4.58	3.17	21.90	17.82	51.84	43.94
120	70.68	57.15	70.68	56.60	14.15	11.01	9.78	7.80	45.37	36.11	70.68	56.97

A dash (-) indicates that the threshold distance was not reached.

Table F-3. Distance (km) to the single strike sound exposure level (SEL) for a 2.9 m pin pile at location L01 using a Menck MHU1900S hammer operating at 1900 kJ (a, 20 m penetration depth, see Section 3.1.1).

Level (SEL)	Flat R_{max}	Flat $R_{95\%}$	LFC R_{max}	LFC $R_{95\%}$	MFC R_{max}	MFC $R_{95\%}$	HFC R_{max}	HFC $R_{95\%}$	PPW R_{max}	PPW $R_{95\%}$	TUW R_{max}	TUW $R_{95\%}$
200	-	-	-	-	-	-	-	-	-	-	-	-
190	0.05	0.05	0.03	0.03	-	-	-	-	-	-	0.03	0.03
180	0.29	0.28	0.15	0.15	-	-	-	-	0.03	0.03	0.20	0.20
170	1.65	1.60	0.89	0.86	-	-	-	-	0.13	0.13	1.31	1.22
160	6.35	5.81	4.82	4.46	0.08	0.08	0.04	0.04	1.56	0.87	5.33	4.99
150	16.20	14.38	12.70	11.43	0.52	0.47	0.23	0.22	6.05	4.60	14.98	13.16
140	35.13	30.75	29.59	25.33	3.82	2.86	1.64	1.55	14.42	11.56	32.15	28.41
130	70.68	54.47	65.12	51.97	9.07	7.10	6.09	4.84	29.17	23.41	67.72	53.71
120	70.68	57.02	70.68	57.19	18.22	14.11	12.72	10.14	57.40	47.73	70.68	57.12

A dash (-) indicates that the threshold distance was not reached.

Table F-4. Distance (km) to the single strike sound exposure level (SEL) for a 2.9 m pin pile at location L01 using a Menck MHU1900S hammer operating at 1900 kJ (b, 51 m penetration, see Section 3.1.1).

Level (SEL)	Flat R_{max}	Flat $R_{95\%}$	LFC R_{max}	LFC $R_{95\%}$	MFC R_{max}	MFC $R_{95\%}$	HFC R_{max}	HFC $R_{95\%}$	PPW R_{max}	PPW $R_{95\%}$	TUW R_{max}	TUW $R_{95\%}$
200	-	-	-	-	-	-	-	-	-	-	-	-
190	-	-	-	-	-	-	-	-	-	-	0.00	-
180	0.03	0.03	-	-	-	-	-	-	-	-	0.02	0.02
170	0.17	0.17	0.11	0.11	-	-	-	-	-	-	0.13	0.13
160	1.18	1.09	0.80	0.76	-	-	-	-	0.10	0.09	0.84	0.82
150	5.14	4.48	3.85	3.23	0.05	0.05	0.03	0.03	0.80	0.78	4.32	3.81
140	13.39	11.78	10.90	9.44	0.38	0.37	0.13	0.13	4.77	3.78	11.82	10.52
130	29.75	25.84	26.07	21.46	3.08	2.07	1.59	1.18	12.00	9.80	27.73	23.76
120	64.72	51.76	56.84	46.76	7.56	6.04	5.32	3.89	25.82	20.39	58.19	48.94

A dash (-) indicates that the threshold distance was not reached.

Table F-5. Distance (km) to the single strike sound exposure level (SEL) for a 2.9 m pin pile at location L01 using a Menck MHU1900S hammer operating at 475 kJ, with 2 dB shift for post-piling installation (OSP foundation).

Level (SEL)	Flat R_{max}	Flat $R_{95\%}$	LFC R_{max}	LFC $R_{95\%}$	MFC R_{max}	MFC $R_{95\%}$	HFC R_{max}	HFC $R_{95\%}$	PPW R_{max}	PPW $R_{95\%}$	TUW R_{max}	TUW $R_{95\%}$
200	-	-	-	-	-	-	-	-	-	-	-	-
190	0.02	0.02	-	-	-	-	-	-	-	-	-	-
180	0.12	0.12	0.07	0.07	-	-	-	-	-	-	0.10	0.10
170	0.82	0.78	0.45	0.43	-	-	-	-	0.06	0.06	0.53	0.51
160	3.83	3.23	2.42	2.33	0.03	0.03	0.02	0.02	0.38	0.36	3.10	2.70
150	10.44	9.43	8.34	7.43	0.16	0.16	0.10	0.10	3.11	2.38	9.32	8.34
140	24.14	21.05	21.49	17.26	1.61	1.53	0.79	0.58	9.49	7.64	22.52	19.41
130	52.77	45.03	45.42	37.86	6.08	4.61	3.84	3.04	20.46	16.66	48.11	40.99
120	70.68	57.07	70.68	55.83	13.48	10.38	9.08	7.26	41.95	33.79	70.68	56.36

A dash (-) indicates that the threshold distance was not reached.

Table F-6. Distance (km) to the single strike sound exposure level (SEL) for a 2.9 m pin pile at location L01 using a Menck MHU1900S hammer operating at 950 kJ, with 2 dB shift for post-piling installation (OSP foundation) .

Level (SEL)	Flat R_{max}	Flat $R_{95\%}$	LFC R_{max}	LFC $R_{95\%}$	MFC R_{max}	MFC $R_{95\%}$	HFC R_{max}	HFC $R_{95\%}$	PPW R_{max}	PPW $R_{95\%}$	TUW R_{max}	TUW $R_{95\%}$
200	-	-	-	-	-	-	-	-	-	-	-	-
190	0.03	0.03	-	-	-	-	-	-	-	-	0.02	0.02
180	0.17	0.17	0.12	0.11	-	-	-	-	-	-	0.14	0.14
170	1.22	1.17	0.81	0.78	-	-	-	-	0.10	0.09	0.85	0.83
160	5.19	4.63	3.88	3.29	0.05	0.05	0.03	0.03	0.81	0.78	4.38	3.91
150	13.66	12.09	10.96	9.57	0.38	0.37	0.14	0.14	4.78	3.79	12.23	10.78
140	30.14	26.28	26.10	21.71	3.09	2.09	1.60	1.51	12.59	9.86	27.82	24.23
130	65.01	52.17	56.89	47.13	7.57	6.06	5.33	3.92	25.89	20.53	58.67	49.41
120	70.68	57.20	70.68	57.14	15.76	12.50	11.24	8.94	53.50	41.98	70.68	57.28

A dash (-) indicates that the threshold distance was not reached.

Table F-7. Distance (km) to the single strike sound exposure level (SEL) for a 2.9 m pin pile at location L01 using a Menck MHU1900S hammer operating at 1900 kJ, with 2 dB shift for post-piling installation (OSP foundation) (a, 20 m penetration depth, see Section 3.1.1).

Level (SEL)	Flat R_{max}	Flat $R_{95\%}$	LFC R_{max}	LFC $R_{95\%}$	MFC R_{max}	MFC $R_{95\%}$	HFC R_{max}	HFC $R_{95\%}$	PPW R_{max}	PPW $R_{95\%}$	TUW R_{max}	TUW $R_{95\%}$
200	-	-	-	-	-	-	-	-	-	-	-	-
190	0.07	0.07	0.03	0.03	-	-	-	-	-	-	0.06	0.06
180	0.42	0.41	0.21	0.20	-	-	-	-	0.03	0.03	0.35	0.34
170	2.40	2.27	1.62	1.57	0.02	0.02	-	-	0.19	0.19	2.04	1.63
160	7.79	7.24	6.11	5.29	0.10	0.10	0.05	0.05	1.63	1.57	6.86	6.27
150	19.07	16.66	15.76	13.62	0.80	0.78	0.39	0.38	7.19	5.76	17.60	15.36
140	41.90	35.52	34.80	30.11	4.59	3.56	3.08	2.06	16.68	13.40	37.39	32.37
130	70.68	55.12	70.68	54.48	10.51	8.26	7.43	5.86	34.59	27.14	70.68	54.63
120	70.68	56.96	70.68	57.02	20.38	15.94	14.70	11.49	66.80	51.86	70.68	56.96

A dash (-) indicates that the threshold distance was not reached.

Table F-8. Distance (km) to the single strike sound exposure level (SEL) for a 2.9 m pin pile at location L01 using a Menck MHU1900S hammer operating at 1900 kJ, with 2 dB shift for post-piling installation (OSP foundation) (51 m penetration depth, see Section 3.1.1).

Level (SEL)	Flat R_{max}	Flat $R_{95\%}$	LFC R_{max}	LFC $R_{95\%}$	MFC R_{max}	MFC $R_{95\%}$	HFC R_{max}	HFC $R_{95\%}$	PPW R_{max}	PPW $R_{95\%}$	TUW R_{max}	TUW $R_{95\%}$
200	-	-	-	-	-	-	-	-	-	-	-	-
190	-	-	-	-	-	-	-	-	-	-	-	-
180	0.04	0.04	0.02	0.02	0	0	0	0	0	0	0.028	0.028
170	0.243	0.241	0.146	0.144	0	0	0	0	0.02	0.02	0.181	0.179
160	1.632	1.581	0.882	0.853	0	0	0	0	0.134	0.134	1.246	1.2
150	6.164	5.535	4.808	4.36	0.08	0.08	0.04	0.04	1.558	0.871	5.28	4.754
140	15.81	13.977	12.684	11.271	0.522	0.468	0.234	0.224	6.045	4.598	14.936	12.715
130	34.79	30.256	29.584	25.06	3.824	2.856	1.644	1.548	14.406	11.536	32.025	27.818
120	70.682	54.455	65.046	51.768	9.066	7.088	6.085	4.824	28.661	23.349	67.635	53.408

A dash (-) indicates that the threshold distance was not reached.

Table F-9. Distance (km) to the single strike sound exposure level (SEL) for an 11 m pile at location L01 using a Menck MHU4400 hammer operating at 1100 kJ.

Level (SEL)	Flat R_{max}	Flat $R_{95\%}$	LFC R_{max}	LFC $R_{95\%}$	MFC R_{max}	MFC $R_{95\%}$	HFC R_{max}	HFC $R_{95\%}$	PPW R_{max}	PPW $R_{95\%}$	TUW R_{max}	TUW $R_{95\%}$
200	-	-	-	-	-	-	-	-	-	-	-	-
190	0.06	0.06	-	-	-	-	-	-	-	-	0.03	0.03
180	0.33	0.32	0.09	0.09	-	-	-	-	-	-	0.23	0.22
170	1.83	1.78	0.46	0.44	-	-	-	-	0.03	0.03	1.33	1.30
160	6.32	5.86	2.44	2.34	-	-	-	-	0.14	0.14	5.16	4.76
150	14.08	12.69	8.03	7.29	0.04	0.04	0.03	0.03	0.90	0.88	12.51	11.41
140	26.25	23.71	17.35	15.67	0.23	0.22	0.11	0.10	4.78	3.96	24.32	22.17
130	48.20	42.14	33.70	30.08	2.34	1.57	0.90	0.84	12.61	10.46	45.44	39.94
120	70.68	55.16	64.95	52.35	6.82	5.29	4.59	3.61	25.84	21.47	70.68	54.89

A dash (-) indicates that the threshold distance was not reached.

Table F-10. Distance (km) to the single strike sound exposure level (SEL) for an 11 m pile at location L01 using a Menck MHU4400 hammer operating at 2200 kJ.

Level (SEL)	Flat R_{max}	Flat $R_{95\%}$	LFC R_{max}	LFC $R_{95\%}$	MFC R_{max}	MFC $R_{95\%}$	HFC R_{max}	HFC $R_{95\%}$	PPW R_{max}	PPW $R_{95\%}$	TUW R_{max}	TUW $R_{95\%}$
200	-	-	-	-	-	-	-	-	-	-	-	-
190	0.06	0.06	-	-	-	-	-	-	-	-	0.05	0.05
180	0.40	0.39	0.11	0.11	-	-	-	-	-	-	0.31	0.30
170	2.34	2.20	0.65	0.62	-	-	-	-	0.03	0.03	1.69	1.57
160	7.19	6.62	3.43	3.06	-	-	-	-	0.24	0.23	6.14	5.63
150	15.74	14.33	9.71	8.80	0.10	0.10	0.04	0.04	1.62	1.56	14.85	13.22
140	30.08	26.91	20.68	18.72	0.53	0.52	0.24	0.23	6.76	5.56	28.36	25.61
130	57.13	48.36	41.07	35.89	3.83	2.99	2.32	1.56	15.72	13.31	54.84	47.02
120	70.68	56.51	70.68	54.67	9.48	7.28	6.10	5.02	33.07	26.80	70.68	56.13

A dash (-) indicates that the threshold distance was not reached.

Table F-11. Distance (km) to the single strike sound exposure level (SEL) for an 11 m pile at location L01 using a Menck MHU4400 hammer operating at 4400 kJ.

Level (SEL)	Flat R_{max}	Flat $R_{95\%}$	LFC R_{max}	LFC $R_{95\%}$	MFC R_{max}	MFC $R_{95\%}$	HFC R_{max}	HFC $R_{95\%}$	PPW R_{max}	PPW $R_{95\%}$	TUW R_{max}	TUW $R_{95\%}$
200	0.02	0.02	-	-	-	-	-	-	-	-	-	-
190	0.14	0.13	0.03	0.03	-	-	-	-	-	-	0.09	0.09
180	0.84	0.80	0.20	0.20	-	-	-	-	-	-	0.56	0.53
170	3.74	3.52	1.31	1.28	-	-	-	-	0.07	0.07	2.84	2.62
160	9.72	8.90	5.14	4.66	0.03	0.03	-	-	0.45	0.43	8.57	7.79
150	19.77	17.80	12.75	11.54	0.11	0.11	0.08	0.08	3.08	2.37	18.37	16.57
140	36.93	32.76	26.13	23.42	1.03	0.86	0.47	0.46	8.88	7.57	34.90	31.30
130	68.63	53.92	52.37	45.50	5.30	3.82	3.11	2.34	19.37	16.68	66.87	52.95
120	70.68	57.23	70.68	56.33	11.54	9.05	8.15	6.25	39.77	33.19	70.68	57.27

A dash (-) indicates that the threshold distance was not reached.

F.1.1.2. Maximum Scenarios

Table F-12. Distance (km) to the single strike sound exposure level (SEL) for a 4.5 m pile at location L01 using an IHC S2000 hammer operating at 2000 kJ (a, 20 m penetration depth, see Section 3.1.1).

Level (SEL)	Flat R_{max}	Flat $R_{95\%}$	LFC R_{max}	LFC $R_{95\%}$	MFC R_{max}	MFC $R_{95\%}$	HFC R_{max}	HFC $R_{95\%}$	PPW R_{max}	PPW $R_{95\%}$	TUW R_{max}	TUW $R_{95\%}$
200	-	-	-	-	-	-	-	-	-	-	-	-
190	0.09	0.09	0.03	0.03	-	-	-	-	-	-	0.06	0.06
180	0.49	0.47	0.21	0.20	-	-	-	-	0.03	0.03	0.41	0.40
170	2.67	2.46	1.62	1.57	0.02	0.02	-	-	0.18	0.18	2.14	2.04
160	8.57	7.75	6.07	5.24	0.10	0.09	0.05	0.05	1.62	1.56	7.79	6.97
150	19.67	17.37	15.76	13.66	0.78	0.57	0.39	0.37	6.84	5.40	18.18	16.15
140	42.11	36.06	34.77	29.86	4.58	3.10	3.06	1.98	15.72	13.07	38.17	33.34
130	70.68	55.11	70.68	54.41	9.85	8.04	6.83	5.40	34.55	26.29	70.68	54.67
120	70.68	56.96	70.68	57.04	19.56	15.45	14.15	11.14	65.01	50.90	70.68	56.97

A dash (-) indicates that the threshold distance was not reached.

Table F-13. Distance (km) to the single strike sound exposure level (SEL) for a 4.5 m pile at location L01 using an IHC S2000 hammer operating at 2000 kJ (b, 40 m penetration depth, see Section 3.1.1).

Level (SEL)	Flat R_{max}	Flat $R_{95\%}$	LFC R_{max}	LFC $R_{95\%}$	MFC R_{max}	MFC $R_{95\%}$	HFC R_{max}	HFC $R_{95\%}$	PPW R_{max}	PPW $R_{95\%}$	TUW R_{max}	TUW $R_{95\%}$
200	-	-	-	-	-	-	-	-	-	-	-	-
190	0.06	0.06	0.03	0.03	-	-	-	-	-	-	0.05	0.05
180	0.37	0.36	0.17	0.16	-	-	-	-	0.02	0.02	0.30	0.29
170	2.07	1.96	1.16	0.91	-	-	-	-	0.13	0.13	1.61	1.57
160	7.17	6.58	5.16	4.52	0.06	0.06	0.04	0.04	0.90	0.87	6.21	5.74
150	17.23	15.40	13.56	11.89	0.47	0.46	0.23	0.22	5.57	4.58	16.28	14.34
140	37.35	32.02	30.13	26.01	3.82	2.75	1.64	1.55	14.40	11.47	34.02	30.07
130	70.68	54.50	67.30	52.31	9.00	6.92	6.08	4.66	28.64	23.26	69.57	54.28
120	70.68	57.00	70.68	57.19	18.20	13.92	12.59	9.99	57.01	47.48	70.68	57.08

A dash (-) indicates that the threshold distance was not reached.

Table F-14. Distance (km) to the single strike sound exposure level (SEL) for a 4.5 m pile at location L01 using an IHC S2000 hammer operating at 2000 kJ (c, 60 m penetration depth, see Section 3.1.1).

Level (SEL)	Flat R_{max}	Flat $R_{95\%}$	LFC R_{max}	LFC $R_{95\%}$	MFC R_{max}	MFC $R_{95\%}$	HFC R_{max}	HFC $R_{95\%}$	PPW R_{max}	PPW $R_{95\%}$	TUW R_{max}	TUW $R_{95\%}$
200	-	-	-	-	-	-	-	-	-	-	-	-
190	-	-	-	-	-	-	-	-	-	-	-	-
180	0.06	0.06	0.03	0.03	-	-	-	-	-	-	0.04	0.04
170	0.34	0.33	0.15	0.15	-	-	-	-	0.02	0.02	0.25	0.24
160	1.79	1.68	0.89	0.86	-	-	-	-	0.13	0.13	1.59	1.54
150	6.85	6.09	4.79	4.11	0.05	0.05	0.03	0.03	0.88	0.85	5.74	5.28
140	16.64	14.66	12.68	11.32	0.44	0.44	0.21	0.20	5.52	4.48	15.80	13.65
130	36.05	30.92	29.51	24.96	3.11	2.35	1.63	1.53	13.52	11.03	33.07	28.99
120	70.68	54.45	63.73	51.11	8.90	6.73	6.06	4.52	27.36	22.43	68.03	53.83

A dash (-) indicates that the threshold distance was not reached.

Table F-15. Distance (km) to the single strike sound exposure level (SEL) for a 4.5 m pile at location L01 using an IHC S2000 hammer operating at 2000 kJ, with 2 dB shift for post-piling installation (OSP foundation) (a, 20 m penetration depth, see Section 3.1.1).

Level (SEL)	Flat R_{max}	Flat $R_{95\%}$	LFC R_{max}	LFC $R_{95\%}$	MFC R_{max}	MFC $R_{95\%}$	HFC R_{max}	HFC $R_{95\%}$	PPW R_{max}	PPW $R_{95\%}$	TUW R_{max}	TUW $R_{95\%}$
200	0.02	0.02	-	-	-	-	-	-	-	-	-	-
190	0.12	0.12	0.06	0.06	-	-	-	-	-	-	0.10	0.10
180	0.80	0.75	0.35	0.34	-	-	-	-	0.03	0.03	0.51	0.50
170	3.52	3.21	2.30	2.06	0.03	0.03	-	-	0.25	0.24	3.08	2.67
160	10.10	9.22	7.30	6.64	0.12	0.11	0.10	0.10	2.36	2.25	8.91	8.25
150	23.07	20.17	18.15	15.88	1.58	0.89	0.52	0.47	8.29	6.70	21.55	18.77
140	49.14	41.67	40.98	34.54	5.32	3.87	3.11	2.37	18.40	14.97	45.34	38.59
130	70.68	56.36	70.68	54.91	11.81	9.22	8.18	6.48	37.21	30.33	70.68	55.67
120	70.68	56.98	70.68	56.97	22.88	17.32	15.76	12.54	70.68	54.20	70.68	56.94

A dash (-) indicates that the threshold distance was not reached.

Table F-16. Distance (km) to the single strike sound exposure level (SEL) for a 4.5 m pile at location L01 using an IHC S2000 hammer operating at 2000 kJ, with 2 dB shift for post-piling installation (OSP foundation) (b, 40 m penetration depth, see Section 3.1.1).

Level (SEL)	Flat R_{max}	Flat $R_{95\%}$	LFC R_{max}	LFC $R_{95\%}$	MFC R_{max}	MFC $R_{95\%}$	HFC R_{max}	HFC $R_{95\%}$	PPW R_{max}	PPW $R_{95\%}$	TUW R_{max}	TUW $R_{95\%}$
200	-	-	-	-	-	-	-	-	-	-	-	-
190	0.09	0.09	0.03	0.03	-	-	-	-	-	-	0.07	0.07
180	0.52	0.50	0.22	0.22	-	-	-	-	0.03	0.03	0.43	0.42
170	2.76	2.59	1.63	1.58	0.02	0.02	-	-	0.19	0.19	2.21	2.11
160	8.75	7.95	6.17	5.57	0.10	0.09	0.05	0.05	1.63	1.57	8.07	7.22
150	20.57	17.84	15.92	14.05	0.79	0.77	0.39	0.38	7.06	5.56	18.65	16.61
140	44.03	37.05	35.16	30.62	4.58	3.14	3.08	2.04	15.76	13.31	39.28	34.50
130	70.68	55.33	70.68	54.49	10.36	8.19	7.42	5.70	34.58	26.93	70.68	54.83
120	70.68	56.95	70.68	57.01	19.57	15.71	14.68	11.34	66.76	51.58	70.68	56.96

A dash (-) indicates that the threshold distance was not reached.

Table F-17. Distance (km) to the single strike sound exposure level (SEL) for a 4.5 m pile at location L01 using an IHC S2000 hammer operating at 2000 kJ, with 2 dB shift for post-piling installation (OSP foundation) (c, 60 m penetration depth, see Section 3.1.1).

Level (SEL)	Flat R_{max}	Flat $R_{95\%}$	LFC R_{max}	LFC $R_{95\%}$	MFC R_{max}	MFC $R_{95\%}$	HFC R_{max}	HFC $R_{95\%}$	PPW R_{max}	PPW $R_{95\%}$	TUW R_{max}	TUW $R_{95\%}$
200	-	-	-	-	-	-	-	-	-	-	-	-
190	-	-	-	-	-	-	-	-	-	-	-	-
180	0.08	0.08	0.03	0.03	-	-	-	-	-	-	0.06	0.06
170	0.48	0.47	0.20	0.20	-	-	-	-	0.03	0.03	0.39	0.38
160	2.46	2.35	1.60	1.56	0.02	0.02	-	-	0.17	0.17	2.06	1.93
150	8.36	7.50	5.59	5.09	0.10	0.09	0.05	0.05	1.61	1.55	7.54	6.72
140	19.53	16.93	15.16	13.51	0.58	0.56	0.38	0.36	6.82	5.33	17.75	15.86
130	41.13	35.62	34.75	29.57	3.85	3.07	2.35	1.66	15.69	12.78	37.48	33.05
120	70.68	55.05	70.43	54.35	9.83	7.90	6.82	5.32	33.08	25.90	70.68	54.67

A dash (-) indicates that the threshold distance was not reached.

Table F-18. Distance (km) to the single strike sound exposure level (SEL) for a 4.5 m pile at location L01 using a Menck MHU3500S hammer operating at 3500 kJ (a, 20 m penetration depth, see Section 3.1.1).

Level (SEL)	Flat R_{max}	Flat $R_{95\%}$	LFC R_{max}	LFC $R_{95\%}$	MFC R_{max}	MFC $R_{95\%}$	HFC R_{max}	HFC $R_{95\%}$	PPW R_{max}	PPW $R_{95\%}$	TUW R_{max}	TUW $R_{95\%}$
200	-	-	-	-	-	-	-	-	-	-	-	-
190	0.06	0.06	0.02	0.02	-	-	-	-	-	-	0.05	0.05
180	0.36	0.35	0.14	0.13	-	-	-	-	-	-	0.27	0.26
170	1.96	1.90	0.86	0.83	-	-	-	-	0.10	0.10	1.58	1.54
160	6.87	6.33	4.09	3.87	0.05	0.05	0.03	0.03	0.81	0.79	5.80	5.43
150	15.95	14.48	11.76	10.45	0.38	0.36	0.13	0.13	4.78	3.80	14.99	13.38
140	33.45	29.46	26.76	23.03	3.08	2.06	1.59	1.18	12.59	9.89	30.96	27.55
130	68.06	53.77	58.08	48.21	7.56	6.02	5.32	3.88	25.88	20.59	63.64	51.71
120	70.68	57.15	70.68	57.16	15.75	12.42	11.07	8.88	52.97	42.00	70.68	57.25

A dash (-) indicates that the threshold distance was not reached.

Table F-19. Distance (km) to the single strike sound exposure level (SEL) for a 4.5 m pile at location L01 using a Menck MHU3500S hammer operating at 3500 kJ (b,40 m penetration depth, see Section 3.1.1).

Level (SEL)	Flat R_{max}	Flat $R_{95\%}$	LFC R_{max}	LFC $R_{95\%}$	MFC R_{max}	MFC $R_{95\%}$	HFC R_{max}	HFC $R_{95\%}$	PPW R_{max}	PPW $R_{95\%}$	TUW R_{max}	TUW $R_{95\%}$
200	-	-	-	-	-	-	-	-	-	-	-	-
190	0.05	0.05	-	-	-	-	-	-	-	-	0.03	0.03
180	0.27	0.26	0.11	0.11	-	-	-	-	-	-	0.18	0.17
170	1.59	1.54	0.71	0.67	-	-	-	-	0.08	0.08	1.12	1.09
160	5.72	5.24	3.27	3.13	0.03	0.03	0.03	0.03	0.52	0.50	5.13	4.50
150	14.22	12.81	10.18	9.01	0.22	0.21	0.11	0.10	3.84	3.07	13.07	11.69
140	29.30	26.16	23.35	20.28	2.31	1.55	0.86	0.81	10.48	8.53	27.85	24.58
130	61.24	50.45	51.78	43.33	6.77	5.23	4.58	3.51	21.93	18.22	57.82	48.54
120	70.68	57.26	70.68	56.93	14.15	11.10	9.82	7.88	46.23	36.88	70.68	57.15

A dash (-) indicates that the threshold distance was not reached.

Table F-20. Distance (km) to the single strike sound exposure level (SEL) for a 4.5 m pile at location L01 using a Menck MHU3500S hammer operating at 3500 kJ (c, 60 m penetration depth, see Section 3.1.1).

Level (SEL)	Flat R_{max}	Flat $R_{95\%}$	LFC R_{max}	LFC $R_{95\%}$	MFC R_{max}	MFC $R_{95\%}$	HFC R_{max}	HFC $R_{95\%}$	PPW R_{max}	PPW $R_{95\%}$	TUW R_{max}	TUW $R_{95\%}$
200	-	-	-	-	-	-	-	-	-	-	-	-
190	0.03	0.03	-	-	-	-	-	-	-	-	-	-
180	0.15	0.14	0.05	0.05	-	-	-	-	-	-	0.10	0.10
170	0.87	0.83	0.27	0.27	-	-	-	-	0.03	0.03	0.51	0.49
160	3.73	3.54	1.65	1.60	0.02	0.02	-	-	0.18	0.18	2.90	2.69
150	10.10	9.19	6.33	5.79	0.10	0.09	0.05	0.05	1.62	1.55	8.82	8.15
140	21.58	19.20	16.16	14.22	0.58	0.55	0.38	0.36	6.82	5.35	20.50	17.80
130	44.38	37.89	34.83	30.41	3.85	3.06	2.35	1.64	15.70	12.90	40.10	35.53
120	70.68	55.27	70.68	54.44	9.83	7.87	6.82	5.31	33.08	26.04	70.68	54.85

A dash (-) indicates that the threshold distance was not reached.

Table F-21. Distance (km) to the single strike sound exposure level (SEL) for a 4.5 m pile at location L01 using a Menck MHU3500S hammer operating at 3500 kJ, with 2 dB shift for post-piling installation (OSP foundation) (a, 20 m penetration depth, see Section 3.1.1).

Level (SEL)	Flat R_{max}	Flat $R_{95\%}$	LFC R_{max}	LFC $R_{95\%}$	MFC R_{max}	MFC $R_{95\%}$	HFC R_{max}	HFC $R_{95\%}$	PPW R_{max}	PPW $R_{95\%}$	TUW R_{max}	TUW $R_{95\%}$
200	-	-	-	-	-	-	-	-	-	-	-	-
190	0.09	0.09	0.03	0.03	-	-	-	-	-	-	0.06	0.06
180	0.50	0.48	0.18	0.18	-	-	-	-	0.03	0.03	0.39	0.37
170	2.73	2.60	1.24	1.18	-	-	-	-	0.14	0.13	2.14	1.94
160	8.38	7.65	5.22	4.81	0.08	0.08	0.04	0.04	1.57	0.88	7.35	6.68
150	18.58	16.67	14.05	12.50	0.52	0.46	0.23	0.22	6.05	4.61	17.24	15.46
140	38.60	33.60	31.83	26.87	3.82	2.84	1.64	1.55	14.42	11.64	36.11	31.40
130	70.68	54.61	67.64	52.91	9.04	7.04	6.09	4.76	29.17	23.61	70.46	54.42
120	70.68	56.99	70.68	57.17	18.22	14.04	12.72	10.08	57.42	47.86	70.68	57.06

A dash (-) indicates that the threshold distance was not reached.

Table F-22. Distance (km) to the single strike sound exposure level (SEL) for a 4.5 m pile at location L01 using a Menck MHU3500S hammer operating at 3500 kJ, with 2 dB shift for post-piling installation (OSP foundation) (b,40 m penetration depth, see Section 3.1.1).

Level (SEL)	Flat R_{max}	Flat $R_{95\%}$	LFC R_{max}	LFC $R_{95\%}$	MFC R_{max}	MFC $R_{95\%}$	HFC R_{max}	HFC $R_{95\%}$	PPW R_{max}	PPW $R_{95\%}$	TUW R_{max}	TUW $R_{95\%}$
200	-	-	-	-	-	-	-	-	-	-	-	-
190	0.06	0.06	0.02	0.02	-	-	-	-	-	-	0.05	0.05
180	0.37	0.36	0.15	0.14	-	-	-	-	0.02	0.02	0.28	0.27
170	2.01	1.92	0.88	0.85	-	-	-	-	0.11	0.11	1.60	1.55
160	7.05	6.48	4.10	3.90	0.05	0.05	0.03	0.03	0.82	0.80	6.12	5.57
150	16.64	14.77	11.86	10.73	0.39	0.37	0.15	0.14	4.79	3.84	15.75	13.72
140	34.75	30.20	27.82	23.67	3.09	2.25	1.60	1.51	12.62	10.17	31.76	28.37
130	69.09	54.15	59.12	49.07	7.58	6.08	5.33	4.21	25.92	20.99	65.19	52.71
120	70.68	57.11	70.68	57.20	16.33	12.57	11.24	8.98	53.53	42.95	70.68	57.21

A dash (-) indicates that the threshold distance was not reached.

Table F-23. Distance (km) to the single strike sound exposure level (SEL) for a 4.5 m pile at location L01 using a Menck MHU3500S hammer operating at 3500 kJ, with 2 dB shift for post-piling installation (OSP foundation) (c, 60 m penetration depth, see Section 3.1.1).

Level (SEL)	Flat R_{max}	Flat $R_{95\%}$	LFC R_{max}	LFC $R_{95\%}$	MFC R_{max}	MFC $R_{95\%}$	HFC R_{max}	HFC $R_{95\%}$	PPW R_{max}	PPW $R_{95\%}$	TUW R_{max}	TUW $R_{95\%}$
200	-	-	-	-	-	-	-	-	-	-	-	-
190	0.03	0.03	-	-	-	-	-	-	-	-	0.02	0.02
180	0.21	0.20	0.07	0.07	-	-	-	-	-	-	0.13	0.13
170	1.17	1.12	0.42	0.41	-	-	-	-	0.03	0.03	0.84	0.80
160	4.59	4.28	2.41	2.31	0.03	0.03	-	-	0.25	0.24	3.80	3.56
150	11.64	10.75	7.72	7.20	0.11	0.10	0.07	0.07	2.35	1.66	10.48	9.62
140	24.79	21.98	19.06	16.49	1.02	0.86	0.47	0.46	8.19	6.62	23.05	20.45
130	51.65	43.80	41.10	35.10	5.30	3.81	3.11	2.33	18.18	14.84	47.06	40.82
120	70.68	56.49	70.68	54.94	11.28	9.02	7.72	6.22	37.20	30.06	70.68	55.85

A dash (-) indicates that the threshold distance was not reached.

Table F-24. Distance (km) to the single strike sound exposure level (SEL) for a 16 m pile at location L01 using a theoretical 6600 kJ hammer operating at 6600 kJ (a, 10 m penetration depth, see Section 3.1.1).

Level (SEL)	Flat R_{max}	Flat $R_{95\%}$	LFC R_{max}	LFC $R_{95\%}$	MFC R_{max}	MFC $R_{95\%}$	HFC R_{max}	HFC $R_{95\%}$	PPW R_{max}	PPW $R_{95\%}$	TUW R_{max}	TUW $R_{95\%}$
200	0.05	0.05	-	-	-	-	-	-	-	-	0.03	0.03
190	0.30	0.29	0.05	0.05	-	-	-	-	-	-	0.16	0.16
180	1.63	1.58	0.34	0.34	-	-	-	-	0.02	0.02	1.07	1.04
170	5.72	5.20	1.85	1.79	-	-	-	-	0.11	0.11	4.44	4.09
160	12.22	11.28	6.76	6.07	0.03	0.03	0.02	0.02	0.79	0.58	10.93	9.83
150	23.16	21.04	15.01	13.74	0.15	0.14	0.10	0.09	3.86	3.18	21.47	19.49
140	42.47	37.30	29.39	26.58	1.61	1.52	0.78	0.56	10.49	8.99	39.87	35.38
130	70.68	54.54	58.59	49.02	6.07	4.54	3.84	3.02	21.97	19.03	70.63	54.41
120	70.68	57.12	70.68	57.06	12.78	10.18	9.04	7.10	45.04	37.01	70.68	57.18

A dash (-) indicates that the threshold distance was not reached.

Table F-25. Distance (km) to the single strike sound exposure level (SEL) for a 16 m pile at location L01 using a theoretical 6600 kJ hammer operating at 6600 kJ (b, 20 m penetration depth, see Section 3.1.1.).

Level (SEL)	Flat R_{max}	Flat $R_{95\%}$	LFC R_{max}	LFC $R_{95\%}$	MFC R_{max}	MFC $R_{95\%}$	HFC R_{max}	HFC $R_{95\%}$	PPW R_{max}	PPW $R_{95\%}$	TUW R_{max}	TUW $R_{95\%}$
200	0.05	0.05	-	-	-	-	-	-	-	-	0.03	0.03
190	0.30	0.29	0.06	0.06	-	-	-	-	-	-	0.18	0.18
180	1.63	1.59	0.35	0.34	-	-	-	-	0.02	0.02	1.09	1.06
170	5.78	5.35	1.94	1.87	-	-	-	-	0.12	0.12	4.47	4.21
160	12.72	11.65	6.87	6.38	0.03	0.03	0.02	0.02	0.82	0.79	11.13	10.27
150	23.92	21.74	15.80	14.32	0.17	0.16	0.10	0.10	4.00	3.45	22.28	20.20
140	44.19	38.73	30.91	27.77	1.62	1.53	0.79	0.77	10.92	9.46	41.45	36.81
130	70.68	54.76	61.15	50.33	6.09	4.68	3.85	3.05	23.20	19.75	70.68	54.59
120	70.68	57.05	70.68	57.17	13.71	10.49	9.49	7.38	47.53	38.72	70.68	57.09

A dash (-) indicates that the threshold distance was not reached.

Table F-26. Distance (km) to the single strike sound exposure level (SEL) for a 16 m pile at location L01 using a theoretical 6600 hammer operating at 6600 kJ (c, 35 m penetration depth, see Section 3.1.1.).

Level (SEL)	Flat R_{max}	Flat $R_{95\%}$	LFC R_{max}	LFC $R_{95\%}$	MFC R_{max}	MFC $R_{95\%}$	HFC R_{max}	HFC $R_{95\%}$	PPW R_{max}	PPW $R_{95\%}$	TUW R_{max}	TUW $R_{95\%}$
200	0.06	0.06	-	-	-	-	-	-	-	-	0.03	0.03
190	0.32	0.31	0.07	0.07	-	-	-	-	-	-	0.20	0.19
180	1.86	1.81	0.40	0.38	-	-	-	-	0.03	0.03	1.11	1.08
170	5.93	5.52	2.23	2.14	-	-	-	-	0.14	0.13	4.73	4.33
160	13.38	12.07	7.76	6.99	0.04	0.04	0.03	0.03	0.90	0.88	11.66	10.78
150	25.23	22.79	17.58	15.55	0.23	0.23	0.12	0.11	4.78	3.90	24.10	21.43
140	48.37	41.84	34.97	30.82	2.34	1.58	0.91	0.85	12.61	10.50	46.82	40.18
130	70.68	55.44	68.84	53.96	6.83	5.33	4.72	3.65	25.89	21.83	70.68	55.26
120	70.68	56.95	70.68	57.15	14.71	11.48	9.85	8.15	52.83	43.86	70.68	56.96

A dash (-) indicates that the threshold distance was not reached.

F.1.2. Location L02

F.1.2.1. Realistic Scenarios

Table F-27. Distance (km) to the single strike sound exposure level (SEL) for a 2.9 m pin pile at location L02 using a Menck MHU1900S hammer operating at 475 kJ.

Level (SEL)	Flat R_{max}	Flat $R_{95\%}$	LFC R_{max}	LFC $R_{95\%}$	MFC R_{max}	MFC $R_{95\%}$	HFC R_{max}	HFC $R_{95\%}$	PPW R_{max}	PPW $R_{95\%}$	TUW R_{max}	TUW $R_{95\%}$
200	-	-	-	-	-	-	-	-	-	-	-	-
190	-	-	-	-	-	-	-	-	-	-	-	-
180	0.05	0.05	0.02	0.02	-	-	-	-	-	-	0.03	0.03
170	0.30	0.28	0.16	0.15	-	-	-	-	0.02	0.02	0.23	0.23
160	1.67	1.47	1.12	0.91	-	-	-	-	0.13	0.13	1.37	1.27
150	5.25	4.74	3.83	3.46	0.09	0.09	0.03	0.03	1.20	1.15	4.62	4.11
140	12.67	10.85	10.56	9.04	0.63	0.60	0.28	0.26	4.16	3.66	11.34	9.89
130	23.78	20.40	21.29	17.77	3.07	2.36	1.75	1.65	10.47	8.92	22.23	18.98
120	39.95	34.23	37.06	31.05	7.74	6.01	5.03	4.16	20.70	17.22	37.99	32.10

A dash (-) indicates that the threshold distance was not reached.

Table F-28. Distance (km) to the single strike sound exposure level (SEL) for a 2.9 m pin pile at location L02 using a Menck MHU1900S hammer operating at 950 kJ.

Level (SEL)	Flat R_{max}	Flat $R_{95\%}$	LFC R_{max}	LFC $R_{95\%}$	MFC R_{max}	MFC $R_{95\%}$	HFC R_{max}	HFC $R_{95\%}$	PPW R_{max}	PPW $R_{95\%}$	TUW R_{max}	TUW $R_{95\%}$
200	-	-	-	-	-	-	-	-	-	-	-	-
190	-	-	-	-	-	-	-	-	-	-	-	-
180	0.08	0.08	0.05	0.05	-	-	-	-	-	-	0.06	0.06
170	0.54	0.50	0.29	0.28	-	-	-	-	0.04	0.04	0.36	0.35
160	2.32	2.18	1.70	1.41	0.03	0.03	-	-	0.26	0.24	1.98	1.79
150	6.91	6.15	5.40	4.79	0.13	0.13	0.09	0.09	1.77	1.68	6.46	5.51
140	15.11	13.20	13.10	11.26	1.20	1.12	0.63	0.60	5.85	5.00	13.79	12.16
130	27.96	24.24	25.73	21.49	4.12	3.37	2.82	2.21	13.19	11.16	26.13	22.69
120	46.84	40.11	42.92	36.44	9.76	7.55	6.50	5.35	24.83	20.48	43.78	37.44

A dash (-) indicates that the threshold distance was not reached.

Table F-29. Distance (km) to the single strike sound exposure level (SEL) for a 2.9 m pin pile at location L02 using a Menck MHU1900S hammer operating at 1900 kJ (a, 20 m penetration depth, see Section 3.1.1).

Level (SEL)	Flat R_{max}	Flat $R_{95\%}$	LFC R_{max}	LFC $R_{95\%}$	MFC R_{max}	MFC $R_{95\%}$	HFC R_{max}	HFC $R_{95\%}$	PPW R_{max}	PPW $R_{95\%}$	TUW R_{max}	TUW $R_{95\%}$
200	-	-	-	-	-	-	-	-	-	-	-	-
190	0.03	0.03	-	-	-	-	-	-	-	-	0.02	0.02
180	0.18	0.18	0.11	0.11	-	-	-	-	-	-	0.14	0.14
170	1.16	1.09	0.66	0.63	-	-	-	-	0.09	0.09	0.83	0.79
160	3.82	3.56	2.90	2.69	0.06	0.06	0.03	0.03	0.66	0.63	3.21	3.03
150	9.97	9.00	8.46	7.25	0.58	0.54	0.17	0.17	3.41	2.79	9.67	8.05
140	20.08	17.35	17.60	15.17	2.28	1.79	1.66	1.14	9.08	7.34	18.52	16.06
130	35.14	30.24	32.84	27.46	5.91	4.98	4.14	3.44	18.34	14.85	32.55	28.42
120	59.39	50.77	54.99	46.23	12.23	9.98	9.09	7.35	30.89	26.04	55.30	47.02

A dash (-) indicates that the threshold distance was not reached.

Table F-30. Distance (km) to the single strike sound exposure level (SEL) for a 2.9 m pin pile at location L02 using a Menck MHU1900S hammer operating at 1900 kJ (b, 51 m penetration depth, see Section 3.1.1).

Level (SEL)	Flat R_{max}	Flat $R_{95\%}$	LFC R_{max}	LFC $R_{95\%}$	MFC R_{max}	MFC $R_{95\%}$	HFC R_{max}	HFC $R_{95\%}$	PPW R_{max}	PPW $R_{95\%}$	TUW R_{max}	TUW $R_{95\%}$
200	-	-	-	-	-	-	-	-	-	-	-	-
190	-	-	-	-	-	-	-	-	-	-	-	-
180	0.02	0.02	-	-	-	-	-	-	-	-	-	-
170	0.16	0.16	0.09	-	-	-	-	-	-	-	0.12	0.12
160	0.90	0.87	0.62	-	-	-	-	-	0.07	0.07	0.76	0.67
150	3.57	3.25	2.86	2.38	0.03	0.03	0.03	0.03	0.65	0.61	3.07	2.75
140	9.80	8.46	7.64	6.77	0.52	0.27	0.13	0.13	2.90	2.74	8.84	7.64
130	19.30	16.67	16.57	14.44	2.25	1.67	1.20	1.12	8.44	6.86	17.68	15.46
120	33.87	29.22	32.06	26.36	5.57	4.57	3.92	3.21	16.83	14.14	32.12	27.48

A dash (-) indicates that the threshold distance was not reached.

Table F-31. Distance (km) to the single strike sound exposure level (SEL) for a 2.9 m pin pile at location L02 using a Menck MHU1900S hammer operating at 475 kJ, with 2 dB shift for post-piling installation (OSP foundation).

Level (SEL)	Flat R_{max}	Flat $R_{95\%}$	LFC R_{max}	LFC $R_{95\%}$	MFC R_{max}	MFC $R_{95\%}$	HFC R_{max}	HFC $R_{95\%}$	PPW R_{max}	PPW $R_{95\%}$	TUW R_{max}	TUW $R_{95\%}$
200	-	-	-	-	-	-	-	-	-	-	-	-
190	-	-	-	-	-	-	-	-	-	-	-	-
180	0.06	0.06	0.03	0.03	-	-	-	-	-	-	0.05	0.05
170	0.42	0.40	0.23	0.23	-	-	-	-	0.03	0.03	0.32	0.31
160	2.09	1.94	1.44	1.36	0.02	0.02	-	-	0.21	0.20	1.78	1.61
150	6.50	5.69	4.80	4.24	0.10	0.10	0.08	0.08	1.74	1.62	5.83	5.07
140	14.16	12.32	12.05	10.45	1.16	1.04	0.61	0.58	5.14	4.44	12.80	11.35
130	26.51	22.87	23.75	20.12	3.88	3.01	2.30	2.13	12.45	10.31	24.62	21.38
120	44.07	37.93	40.02	34.43	9.06	6.99	5.90	4.93	23.27	19.26	41.04	35.42

A dash (-) indicates that the threshold distance was not reached.

Table F-32. Distance (km) to the single strike sound exposure level (SEL) for a 2.9 m pin pile at location L02 using a Menck MHU1900S hammer operating at 950 kJ, with 2 dB shift for post-piling installation (OSP foundation) .

Level (SEL)	Flat R_{max}	Flat $R_{95\%}$	LFC R_{max}	LFC $R_{95\%}$	MFC R_{max}	MFC $R_{95\%}$	HFC R_{max}	HFC $R_{95\%}$	PPW R_{max}	PPW $R_{95\%}$	TUW R_{max}	TUW $R_{95\%}$
200	-	-	-	-	-	-	-	-	-	-	-	-
190	-	-	-	-	-	-	-	-	-	-	-	-
180	0.12	0.12	0.06	0.06	-	-	-	-	-	-	0.09	0.09
170	0.68	0.65	0.40	0.39	-	-	-	-	0.06	0.06	0.55	0.53
160	2.91	2.72	2.28	1.95	0.03	0.03	0.02	0.02	0.60	0.56	2.53	2.28
150	8.15	7.31	6.55	5.84	0.22	0.21	0.10	0.09	2.33	2.21	7.26	6.61
140	17.32	15.03	14.88	12.92	1.74	1.60	1.13	0.77	7.16	5.98	15.83	13.90
130	32.06	26.89	27.98	24.11	4.78	3.98	3.37	2.76	15.36	12.75	29.22	25.27
120	52.37	44.51	47.40	40.46	10.44	8.62	7.80	6.17	27.31	22.80	48.37	41.39

A dash (-) indicates that the threshold distance was not reached.

Table F-33. Distance (km) to the single strike sound exposure level (SEL) for a 2.9 m pin pile at location L02 using a Menck MHU1900S hammer operating at 1900 kJ, with 2 dB shift for post-piling installation (OSP foundation) (a, 20 m penetration depth, see Section 3.1.1).

Level (SEL)	Flat R_{max}	Flat $R_{95\%}$	LFC R_{max}	LFC $R_{95\%}$	MFC R_{max}	MFC $R_{95\%}$	HFC R_{max}	HFC $R_{95\%}$	PPW R_{max}	PPW $R_{95\%}$	TUW R_{max}	TUW $R_{95\%}$
200	-	-	-	-	-	-	-	-	-	-	-	-
190	0.04	0.04	0.02	0.02	-	-	-	-	-	-	0.03	0.03
180	0.27	0.27	0.15	0.14	-	-	-	-	0.02	0.02	0.20	0.19
170	1.45	1.39	0.89	0.84	-	-	-	-	0.13	0.13	1.13	1.07
160	4.90	4.41	3.57	3.29	0.09	0.09	0.03	0.03	1.19	1.13	4.32	3.78
150	12.02	10.33	9.91	8.63	0.63	0.60	0.27	0.25	3.99	3.48	10.97	9.36
140	22.99	19.63	20.50	17.22	3.05	2.27	1.75	1.64	10.27	8.66	21.38	18.18
130	38.99	33.38	36.06	30.37	7.15	5.83	4.79	4.04	20.65	16.78	37.06	31.25
120	64.85	53.71	60.86	51.41	13.17	11.17	9.80	8.38	34.60	28.73	60.70	51.78

A dash (-) indicates that the threshold distance was not reached.

Table F-34. Distance (km) to the single strike sound exposure level (SEL) for a 2.9 m pin pile at location L02 using a Menck MHU1900S hammer operating at 1900 kJ, with 2 dB shift for post-piling installation (OSP foundation) (b, 51 m penetration depth, see Section 3.1.1).

Level (SEL)	Flat R_{max}	Flat $R_{95\%}$	LFC R_{max}	LFC $R_{95\%}$	MFC R_{max}	MFC $R_{95\%}$	HFC R_{max}	HFC $R_{95\%}$	PPW R_{max}	PPW $R_{95\%}$	TUW R_{max}	TUW $R_{95\%}$
200	-	-	-	-	-	-	-	-	-	-	-	-
190	-	-	-	-	-	-	-	-	-	-	-	-
180	0.04	0.04	-	-	-	-	-	-	-	-	0.03	0.03
170	0.23	0.23	0.13	0.13	-	-	-	-	0.02	0.02	0.17	0.17
160	1.37	1.22	0.81	0.77	-	-	-	-	0.12	0.12	1.04	0.89
150	4.46	4.03	3.42	2.92	0.08	0.08	0.03	0.03	1.12	0.78	3.83	3.51
140	11.29	9.78	9.19	8.13	0.62	0.59	0.23	0.22	3.90	3.26	10.58	9.03
130	22.20	18.83	19.10	16.43	2.81	2.19	1.74	1.42	9.77	8.14	20.09	17.51
120	38.00	32.17	34.73	29.23	6.52	5.45	4.46	3.71	19.86	16.01	34.74	30.26

A dash (-) indicates that the threshold distance was not reached.

Table F-35. Distance (km) to the single strike sound exposure level (SEL) for an 11 m pile at location L02 using a Menck MHU4400 hammer operating at 1100 kJ.

Level (SEL)	Flat R_{max}	Flat $R_{95\%}$	LFC R_{max}	LFC $R_{95\%}$	MFC R_{max}	MFC $R_{95\%}$	HFC R_{max}	HFC $R_{95\%}$	PPW R_{max}	PPW $R_{95\%}$	TUW R_{max}	TUW $R_{95\%}$
200	-	-	-	-	-	-	-	-	-	-	-	-
190	0.05	0.05	-	-	-	-	-	-	-	-	0.03	0.03
180	0.27	0.27	0.05	0.05	-	-	-	-	-	-	0.17	0.17
170	1.54	1.43	0.31	0.30	-	-	-	-	-	-	0.94	0.90
160	4.10	3.85	1.69	1.58	-	-	-	-	0.12	0.12	3.27	3.06
150	8.56	7.84	4.76	4.43	0.03	0.03	0.02	0.02	0.67	0.64	7.42	6.85
140	15.02	13.55	10.17	9.34	0.23	0.22	0.10	0.10	2.92	2.75	13.95	12.54
130	24.27	21.59	18.89	16.64	1.75	1.64	1.14	0.81	7.84	6.90	23.15	20.47
120	36.84	32.41	31.77	27.36	5.02	4.12	3.39	2.83	16.12	13.82	35.30	31.09

A dash (-) indicates that the threshold distance was not reached.

Table F-36. Distance (km) to the single strike sound exposure level (SEL) for an 11 m pile at location L02 using a Menck MHU4400 hammer operating at 2200 kJ.

Level (SEL)	Flat R_{max}	Flat $R_{95\%}$	LFC R_{max}	LFC $R_{95\%}$	MFC R_{max}	MFC $R_{95\%}$	HFC R_{max}	HFC $R_{95\%}$	PPW R_{max}	PPW $R_{95\%}$	TUW R_{max}	TUW $R_{95\%}$
200	-	-	-	-	-	-	-	-	-	-	-	-
190	0.05	0.05	-	-	-	-	-	-	-	-	0.03	0.03
180	0.30	0.29	0.06	0.06	-	-	-	-	-	-	0.19	0.19
170	1.55	1.46	0.40	0.39	-	-	-	-	0.02	0.02	1.06	1.02
160	4.42	4.11	2.03	1.88	-	-	-	-	0.15	0.15	3.78	3.47
150	9.40	8.58	5.65	5.19	0.06	0.06	0.03	0.03	1.17	1.10	8.57	7.85
140	16.96	15.19	12.18	10.95	0.59	0.56	0.19	0.18	3.96	3.36	16.22	14.41
130	27.62	24.47	22.18	19.36	2.30	1.87	1.67	1.15	9.77	8.39	26.62	23.58
120	41.99	36.66	35.62	30.97	6.44	5.06	4.15	3.51	19.12	16.07	40.49	35.41

A dash (-) indicates that the threshold distance was not reached.

Table F-37. Distance (km) to the single strike sound exposure level (SEL) for an 11 m pile at location L02 using a Menck MHU4400 hammer operating at 4400 kJ.

Level (SEL)	Flat R_{max}	Flat $R_{95\%}$	LFC R_{max}	LFC $R_{95\%}$	MFC R_{max}	MFC $R_{95\%}$	HFC R_{max}	HFC $R_{95\%}$	PPW R_{max}	PPW $R_{95\%}$	TUW R_{max}	TUW $R_{95\%}$
200	-	-	-	-	-	-	-	-	-	-	-	-
190	0.12	0.12	0.02	0.02	-	-	-	-	-	-	0.06	0.06
180	0.61	0.59	0.14	0.13	-	-	-	-	-	-	0.38	0.37
170	2.50	2.31	0.78	0.76	-	-	-	-	0.05	0.05	1.87	1.76
160	6.04	5.55	3.03	2.84	0.02	0.02	-	-	0.28	0.27	5.28	4.81
150	11.91	10.76	7.64	6.99	0.10	0.09	0.06	0.06	1.76	1.65	11.01	9.94
140	20.41	18.12	15.29	13.51	1.11	0.73	0.58	0.54	5.30	4.69	19.38	17.31
130	31.96	28.43	26.50	23.02	3.38	2.77	2.26	1.70	12.48	10.57	31.12	27.38
120	48.64	42.48	41.77	36.04	8.40	6.49	5.51	4.52	22.92	19.32	46.80	40.86

A dash (-) indicates that the threshold distance was not reached.

F.1.2.2. Maximum Scenarios

Table F-38. Distance (km) to the single strike sound exposure level (SEL) for a 4.5 m pile at location L02 using an IHC S2000 hammer operating at 2000 kJ (a, 20 m penetration depth, see Section 3.1.1).

Level (SEL)	Flat R_{max}	Flat $R_{95\%}$	LFC R_{max}	LFC $R_{95\%}$	MFC R_{max}	MFC $R_{95\%}$	HFC R_{max}	HFC $R_{95\%}$	PPW R_{max}	PPW $R_{95\%}$	TUW R_{max}	TUW $R_{95\%}$
200	-	-	-	-	-	-	-	-	-	-	-	-
190	0.06	0.06	0.02	0.02	-	-	-	-	-	-	0.04	0.04
180	0.36	0.34	0.17	0.16	-	-	-	-	0.02	0.02	0.27	0.26
170	1.80	1.70	1.15	1.07	-	-	-	-	0.13	0.13	1.43	1.37
160	5.70	5.03	4.01	3.57	0.09	0.09	0.03	0.03	1.20	1.15	5.13	4.52
150	12.73	11.15	10.60	9.18	0.63	0.60	0.28	0.26	4.16	3.66	12.02	10.38
140	24.52	20.92	21.35	18.04	3.07	2.34	1.75	1.65	10.47	8.92	22.96	19.66
130	40.24	34.76	37.08	31.34	7.16	5.98	5.02	4.15	20.70	17.23	38.04	32.87
120	66.76	54.46	61.66	52.24	13.89	11.38	10.26	8.57	34.64	29.31	61.93	52.88

A dash (-) indicates that the threshold distance was not reached.

Table F-39. Distance (km) to the single strike sound exposure level (SEL) for a 4.5 m pile at location L02 using an IHC S2000 hammer operating at 2000 kJ (b, 40 m penetration depth, see Section 3.1.1).

Level (SEL)	Flat R_{max}	Flat $R_{95\%}$	LFC R_{max}	LFC $R_{95\%}$	MFC R_{max}	MFC $R_{95\%}$	HFC R_{max}	HFC $R_{95\%}$	PPW R_{max}	PPW $R_{95\%}$	TUW R_{max}	TUW $R_{95\%}$
200	-	-	-	-	-	-	-	-	-	-	-	-
190	0.05	0.05	0.02	0.02	-	-	-	-	-	-	0.04	0.04
180	0.31	0.30	0.14	0.13	-	-	-	-	-	-	0.24	0.24
170	1.70	1.62	0.81	0.78	-	-	-	-	0.10	0.10	1.39	1.31
160	5.27	4.78	3.42	3.04	0.06	0.06	0.03	0.03	0.66	0.64	4.70	4.21
150	11.95	10.44	9.07	8.02	0.57	0.54	0.17	0.16	3.42	2.80	11.25	9.76
140	22.22	19.33	18.49	16.09	2.28	1.75	1.66	1.14	9.08	7.44	20.85	18.30
130	37.08	31.88	32.95	28.35	5.90	4.92	4.14	3.41	18.34	14.97	34.61	30.50
120	60.75	51.92	55.33	47.07	12.23	9.93	9.09	7.30	31.59	26.17	56.47	49.23

A dash (-) indicates that the threshold distance was not reached.

Table F-40. Distance (km) to the single strike sound exposure level (SEL) for a 4.5 m pile at location L02 using an IHC S2000 hammer operating at 2000 kJ (c, 60 m penetration depth, see Section 3.1.1).

Level (SEL)	Flat R_{max}	Flat $R_{95\%}$	LFC R_{max}	LFC $R_{95\%}$	MFC R_{max}	MFC $R_{95\%}$	HFC R_{max}	HFC $R_{95\%}$	PPW R_{max}	PPW $R_{95\%}$	TUW R_{max}	TUW $R_{95\%}$
200	-	-	-	-	-	-	-	-	-	-	-	-
190	-	-	-	-	-	-	-	-	-	-	-	-
180	0.05	0.05	-	-	-	-	-	-	-	-	0.03	0.03
170	0.28	0.27	0.13	0.13	-	-	-	-	-	-	0.20	0.20
160	1.44	1.38	0.78	0.73	-	-	-	-	0.11	0.11	1.11	1.06
150	4.69	4.26	3.27	2.88	0.06	0.06	0.03	0.03	0.79	0.73	4.20	3.79
140	11.32	10.02	9.07	8.00	0.60	0.57	0.21	0.20	3.45	3.07	10.62	9.28
130	22.20	19.04	18.89	16.24	2.30	2.13	1.69	1.18	9.11	7.76	20.77	17.92
120	37.11	32.04	33.83	28.78	6.48	5.13	4.22	3.57	19.10	15.43	35.24	30.49

A dash (-) indicates that the threshold distance was not reached.

Table F-41. Distance (km) to the single strike sound exposure level (SEL) for a 4.5 m pile at location L02 using an IHC S2000 hammer operating at 2000 kJ, with 2 dB shift for post-piling installation (OSP foundation) (a, 20 m penetration depth, see Section 3.1.1).

Level (SEL)	Flat R_{max}	Flat $R_{95\%}$	LFC R_{max}	LFC $R_{95\%}$	MFC R_{max}	MFC $R_{95\%}$	HFC R_{max}	HFC $R_{95\%}$	PPW R_{max}	PPW $R_{95\%}$	TUW R_{max}	TUW $R_{95\%}$
200	-	-	-	-	-	-	-	-	-	-	-	-
190	0.09	0.09	0.04	0.04	-	-	-	-	-	-	0.06	0.06
180	0.54	0.52	0.26	0.25	-	-	-	-	0.03	0.03	0.36	0.35
170	2.36	2.19	1.45	1.37	0.02	0.02	-	-	0.21	0.20	1.98	1.78
160	6.56	6.04	5.10	4.45	0.10	0.10	0.08	0.08	1.74	1.62	5.94	5.44
150	14.61	12.76	12.37	10.65	1.15	0.83	0.61	0.58	5.13	4.44	13.42	11.82
140	26.80	23.36	24.18	20.45	3.62	3.00	2.30	2.10	12.45	10.31	25.35	22.06
130	44.98	38.49	40.29	34.69	8.46	6.97	5.90	4.90	23.27	19.28	42.00	36.22
120	70.68	55.02	68.40	54.72	15.71	12.67	11.57	9.59	37.58	32.01	68.59	55.01

A dash (-) indicates that the threshold distance was not reached.

Table F-42. Distance (km) to the single strike sound exposure level (SEL) for a 4.5 m pile at location L02 using an IHC S2000 hammer operating at 2000 kJ, with 2 dB shift for post-piling installation (OSP foundation) (b, 40 m penetration depth, see Section 3.1.1).

Level (SEL)	Flat R_{max}	Flat $R_{95\%}$	LFC R_{max}	LFC $R_{95\%}$	MFC R_{max}	MFC $R_{95\%}$	HFC R_{max}	HFC $R_{95\%}$	PPW R_{max}	PPW $R_{95\%}$	TUW R_{max}	TUW $R_{95\%}$
200	-	-	-	-	-	-	-	-	-	-	-	-
190	0.09	0.09	0.03	0.03	-	-	-	-	-	-	0.06	0.06
180	0.47	0.45	0.19	0.19	-	-	-	-	0.02	0.02	0.34	0.33
170	2.21	2.09	1.19	1.13	-	-	-	-	0.13	0.13	1.84	1.72
160	6.32	5.64	4.08	3.75	0.09	0.09	0.03	0.03	1.20	1.13	5.74	5.08
150	13.37	11.97	10.62	9.43	0.63	0.60	0.26	0.24	4.14	3.55	12.71	11.18
140	24.67	21.60	21.35	18.17	2.83	2.25	1.75	1.64	10.27	8.73	23.67	20.55
130	40.57	35.05	37.05	31.17	7.15	5.80	4.78	4.01	20.66	16.90	38.07	33.37
120	65.95	54.37	60.94	51.86	13.15	11.12	9.80	8.34	34.60	28.84	61.79	52.91

A dash (-) indicates that the threshold distance was not reached.

Table F-43. Distance (km) to the single strike sound exposure level (SEL) for a 4.5 m pile at location L02 using an IHC S2000 hammer operating at 2000 kJ, with 2 dB shift for post-piling installation (OSP foundation) (c, 60 m penetration depth, see Section 3.1.1).

Level (SEL)	Flat R_{max}	Flat $R_{95\%}$	LFC R_{max}	LFC $R_{95\%}$	MFC R_{max}	MFC $R_{95\%}$	HFC R_{max}	HFC $R_{95\%}$	PPW R_{max}	PPW $R_{95\%}$	TUW R_{max}	TUW $R_{95\%}$
200	-	-	-	-	-	-	-	-	-	-	-	-
190	-	-	-	-	-	-	-	-	-	-	-	-
180	0.08	0.08	0.03	0.03	-	-	-	-	-	-	0.05	0.05
170	0.38	0.36	0.17	0.17	-	-	-	-	0.02	0.02	0.28	0.28
160	1.96	1.78	1.19	1.12	-	-	-	-	0.14	0.13	1.46	1.40
150	5.85	5.19	4.07	3.68	0.09	0.09	0.03	0.03	1.21	1.15	5.28	4.71
140	13.14	11.48	10.62	9.44	0.63	0.60	0.29	0.26	4.46	3.70	12.08	10.77
130	24.62	21.40	22.10	18.38	3.07	2.38	1.75	1.65	10.82	9.01	23.64	20.22
120	40.87	35.34	37.11	31.72	7.78	6.03	5.03	4.18	21.25	17.38	38.92	33.45

A dash (-) indicates that the threshold distance was not reached.

Table F-44. Distance (km) to the single strike sound exposure level (SEL) for a 4.5 m pile at location L02 using a Menck MHU3500S hammer operating at 3500 kJ (a, 20 m penetration depth, see Section 3.1.1).

Level (SEL)	Flat R_{max}	Flat $R_{95\%}$	LFC R_{max}	LFC $R_{95\%}$	MFC R_{max}	MFC $R_{95\%}$	HFC R_{max}	HFC $R_{95\%}$	PPW R_{max}	PPW $R_{95\%}$	TUW R_{max}	TUW $R_{95\%}$
200	-	-	-	-	-	-	-	-	-	-	-	-
190	0.04	0.04	-	-	-	-	-	-	-	-	0.03	0.03
180	0.26	0.26	0.11	0.11	-	-	-	-	-	-	0.18	0.18
170	1.43	1.35	0.64	0.62	-	-	-	-	0.07	0.07	1.05	0.99
160	4.35	4.03	2.89	2.65	0.03	0.03	0.03	0.03	0.64	0.60	3.69	3.48
150	10.47	9.16	7.68	6.96	0.27	0.25	0.13	0.13	2.89	2.61	9.81	8.48
140	20.02	17.31	16.58	14.56	2.20	1.65	1.19	1.10	7.82	6.65	18.55	16.28
130	34.15	29.56	30.93	26.27	5.34	4.42	3.88	3.04	16.79	13.79	32.24	28.17
120	56.43	48.61	51.35	43.66	10.98	9.23	8.44	6.67	29.18	24.39	52.60	45.53

A dash (-) indicates that the threshold distance was not reached.

Table F-45. Distance (km) to the single strike sound exposure level (SEL) for a 4.5 m pile at location L02 using a Menck MHU3500S hammer operating at 3500 kJ (b, 40 m penetration depth, see Section 3.1.1).

Level (SEL)	Flat R_{max}	Flat $R_{95\%}$	LFC R_{max}	LFC $R_{95\%}$	MFC R_{max}	MFC $R_{95\%}$	HFC R_{max}	HFC $R_{95\%}$	PPW R_{max}	PPW $R_{95\%}$	TUW R_{max}	TUW $R_{95\%}$
200	-	-	-	-	-	-	-	-	-	-	-	-
190	0.05	0.05	-	-	-	-	-	-	-	-	0.03	0.03
180	0.26	0.25	0.09	0.09	-	-	-	-	-	-	0.19	0.18
170	1.43	1.35	0.57	0.54	-	-	-	-	0.06	0.06	1.05	0.99
160	4.36	4.00	2.40	2.25	0.03	0.03	-	-	0.53	0.31	3.69	3.49
150	9.97	9.02	6.95	6.27	0.16	0.15	0.10	0.09	2.30	2.13	9.24	8.30
140	18.59	16.59	15.27	13.27	1.67	1.15	0.77	0.61	6.52	5.58	17.81	15.72
130	32.03	27.88	27.89	23.99	4.44	3.60	3.07	2.36	14.63	12.08	30.16	26.67
120	51.38	44.40	46.15	39.42	9.77	8.04	7.15	5.73	26.49	21.79	48.55	42.08

A dash (-) indicates that the threshold distance was not reached.

Table F-46. Distance (km) to the single strike sound exposure level (SEL) for a 4.5 m pile at location L02 using a Menck MHU3500S hammer operating at 3500 kJ (c, 60 m penetration depth, see Section 3.1.1).

Level (SEL)	Flat R_{max}	Flat $R_{95\%}$	LFC R_{max}	LFC $R_{95\%}$	MFC R_{max}	MFC $R_{95\%}$	HFC R_{max}	HFC $R_{95\%}$	PPW R_{max}	PPW $R_{95\%}$	TUW R_{max}	TUW $R_{95\%}$
200	-	-	-	-	-	-	-	-	-	-	-	-
190	-	-	-	-	-	-	-	-	-	-	-	-
180	0.06	0.06	-	-	-	-	-	-	-	-	0.02	0.02
170	0.25	0.24	0.08	0.08	-	-	-	-	-	-	0.13	0.13
160	1.19	1.14	0.46	0.44	-	-	-	-	0.06	0.06	0.75	0.73
150	3.68	3.46	2.28	2.09	0.03	0.03	0.02	0.02	0.55	0.32	3.14	2.93
140	9.13	8.10	6.54	5.95	0.17	0.17	0.10	0.09	2.30	2.18	8.17	7.39
130	17.83	15.74	14.66	12.98	1.69	1.17	0.78	0.63	6.53	5.65	16.91	14.87
120	31.77	27.34	27.89	23.90	4.46	3.64	3.08	2.45	14.65	12.21	29.99	26.06

A dash (-) indicates that the threshold distance was not reached.

Table F-47. Distance (km) to the single strike sound exposure level (SEL) for a 4.5 m pile at location L02 using a Menck MHU3500S hammer operating at 3500 kJ, with 2 dB shift for post-piling installation (OSP foundation) (a, 20 m penetration depth, see Section 3.1.1).

Level (SEL)	Flat R_{max}	Flat $R_{95\%}$	LFC R_{max}	LFC $R_{95\%}$	MFC R_{max}	MFC $R_{95\%}$	HFC R_{max}	HFC $R_{95\%}$	PPW R_{max}	PPW $R_{95\%}$	TUW R_{max}	TUW $R_{95\%}$
200	-	-	-	-	-	-	-	-	-	-	-	-
190	0.08	0.08	0.02	0.02	-	-	-	-	-	-	0.04	0.04
180	0.38	0.37	0.15	0.14	-	-	-	-	-	-	0.25	0.24
170	1.84	1.73	0.85	0.82	-	-	-	-	0.11	0.11	1.40	1.33
160	5.32	4.91	3.45	3.17	0.06	0.06	0.03	0.03	0.81	0.76	4.66	4.21
150	12.02	10.51	9.66	8.33	0.61	0.57	0.22	0.20	3.58	3.17	11.26	9.75
140	22.91	19.47	18.93	16.53	2.77	2.16	1.71	1.21	9.76	7.89	20.87	18.36
130	38.00	32.45	34.12	29.09	6.49	5.21	4.43	3.60	19.11	15.61	35.30	30.85
120	61.79	52.70	57.53	48.76	12.53	10.38	9.76	7.69	32.04	27.13	58.17	50.45

A dash (-) indicates that the threshold distance was not reached.

Table F-48. Distance (km) to the single strike sound exposure level (SEL) for a 4.5 m pile at location L02 using a Menck MHU3500S hammer operating at 3500 kJ, with 2 dB shift for post-piling installation (OSP foundation) (b, 40 m penetration depth, see Section 3.1.1).

Level (SEL)	Flat R_{max}	Flat $R_{95\%}$	LFC R_{max}	LFC $R_{95\%}$	MFC R_{max}	MFC $R_{95\%}$	HFC R_{max}	HFC $R_{95\%}$	PPW R_{max}	PPW $R_{95\%}$	TUW R_{max}	TUW $R_{95\%}$
200	-	-	-	-	-	-	-	-	-	-	-	-
190	0.07	0.07	-	-	-	-	-	-	-	-	0.04	0.04
180	0.38	0.36	0.13	0.13	-	-	-	-	-	-	0.25	0.24
170	1.85	1.74	0.74	0.69	-	-	-	-	0.07	0.07	1.43	1.35
160	5.29	4.84	3.02	2.79	0.03	0.03	0.03	0.03	0.64	0.60	4.63	4.21
150	11.33	10.27	8.16	7.42	0.26	0.23	0.12	0.12	2.89	2.38	10.62	9.62
140	20.91	18.55	17.28	15.09	1.75	1.65	1.17	1.08	7.82	6.62	20.08	17.58
130	34.70	30.43	31.56	26.62	5.12	4.26	3.61	2.97	16.12	13.70	33.00	29.23
120	57.10	49.16	51.32	43.66	10.95	9.09	8.42	6.57	28.66	24.21	53.52	46.38

A dash (-) indicates that the threshold distance was not reached.

Table F-49. Distance (km) to the single strike sound exposure level (SEL) for a 4.5 m pile at location L02 using a Menck MHU3500S hammer operating at 3500 kJ, with 2 dB shift for post-piling installation (OSP foundation) (c, 60 m penetration depth, see Section 3.1.1).

Level (SEL)	Flat R_{max}	Flat $R_{95\%}$	LFC R_{max}	LFC $R_{95\%}$	MFC R_{max}	MFC $R_{95\%}$	HFC R_{max}	HFC $R_{95\%}$	PPW R_{max}	PPW $R_{95\%}$	TUW R_{max}	TUW $R_{95\%}$
200	-	-	-	-	-	-	-	-	-	-	-	-
190	-	-	-	-	-	-	-	-	-	-	-	-
180	0.09	0.09	-	-	-	-	-	-	-	-	0.03	0.03
170	0.33	0.33	0.11	0.11	-	-	-	-	-	-	0.19	0.19
160	1.54	1.46	0.65	0.63	-	-	-	-	0.07	0.07	1.08	1.04
150	4.47	4.16	2.90	2.68	0.03	0.03	0.03	0.03	0.64	0.60	3.78	3.54
140	10.59	9.39	7.86	7.10	0.27	0.25	0.13	0.13	2.89	2.68	9.94	8.73
130	20.12	17.70	16.89	14.81	2.20	1.65	1.19	1.10	7.83	6.67	19.26	16.77
120	34.62	30.00	31.58	26.58	5.34	4.43	3.88	3.05	16.80	13.87	32.71	28.70

A dash (-) indicates that the threshold distance was not reached.

Table F-50. Distance (km) to the single strike sound exposure level (SEL) for a 16 m pile at location L02 using a theoretical 6600 kJ hammer operating at 6600 kJ (a, 10 m penetration depth, see Section 3.1.1).

Level (SEL)	Flat R_{max}	Flat $R_{95\%}$	LFC R_{max}	LFC $R_{95\%}$	MFC R_{max}	MFC $R_{95\%}$	HFC R_{max}	HFC $R_{95\%}$	PPW R_{max}	PPW $R_{95\%}$	TUW R_{max}	TUW $R_{95\%}$
200	0.05	0.05	-	-	-	-	-	-	-	-	-	-
190	0.21	0.20	0.03	0.03	-	-	-	-	-	-	0.08	0.08
180	1.05	1.00	0.18	0.17	-	-	-	-	-	-	0.49	0.47
170	3.06	2.87	0.95	0.91	-	-	-	-	0.06	0.06	2.20	2.04
160	6.55	6.06	3.34	3.14	0.02	0.02	-	-	0.31	0.30	5.66	5.20
150	12.50	11.31	8.10	7.41	0.10	0.09	0.06	0.06	1.76	1.66	11.76	10.61
140	21.32	18.95	15.94	14.13	0.78	0.63	0.56	0.53	5.49	4.84	20.45	18.14
130	32.94	29.31	27.17	23.73	3.36	2.72	2.25	1.68	12.53	10.76	32.07	28.45
120	49.67	43.60	42.03	36.65	7.81	6.37	5.34	4.47	22.92	19.44	47.79	42.15

A dash (-) indicates that the threshold distance was not reached.

Table F-51. Distance (km) to the single strike sound exposure level (SEL) for a 16 m pile at location L02 using a theoretical 6600 hammer operating at 6600 kJ (b, 20 m penetration depth, see Section 3.1.1).

Level (SEL)	Flat R_{max}	Flat $R_{95\%}$	LFC R_{max}	LFC $R_{95\%}$	MFC R_{max}	MFC $R_{95\%}$	HFC R_{max}	HFC $R_{95\%}$	PPW R_{max}	PPW $R_{95\%}$	TUW R_{max}	TUW $R_{95\%}$
200	0.04	0.04	-	-	-	-	-	-	-	-	0.02	0.02
190	0.23	0.22	0.04	0.04	-	-	-	-	-	-	0.13	0.13
180	1.28	1.20	0.23	0.22	-	-	-	-	-	-	0.69	0.67
170	3.61	3.36	1.30	1.23	-	-	-	-	0.06	0.06	2.73	2.59
160	7.61	7.02	4.03	3.77	-	-	-	-	0.39	0.38	6.58	6.05
150	13.77	12.38	8.93	8.17	0.10	0.09	0.06	0.06	1.97	1.83	12.63	11.41
140	22.30	19.86	16.58	14.75	0.77	0.62	0.55	0.52	5.89	5.18	21.19	18.86
130	33.75	29.96	27.49	24.32	3.35	2.69	2.25	1.67	12.56	11.02	32.87	29.05
120	50.60	44.50	43.07	37.40	7.80	6.30	5.34	4.42	22.98	19.64	48.80	43.15

A dash (-) indicates that the threshold distance was not reached.

Table F-52. Distance (km) to the single strike sound exposure level (SEL) for a 16 m pile at location L02 using a theoretical 6600 hammer operating at 6600 kJ (c, 35 m penetration depth, see Section 3.1.1).

Level (SEL)	Flat R_{max}	Flat $R_{95\%}$	LFC R_{max}	LFC $R_{95\%}$	MFC R_{max}	MFC $R_{95\%}$	HFC R_{max}	HFC $R_{95\%}$	PPW R_{max}	PPW $R_{95\%}$	TUW R_{max}	TUW $R_{95\%}$
200	0.05	0.05	-	-	-	-	-	-	-	-	0.03	0.03
190	0.28	0.27	0.05	0.05	-	-	-	-	-	-	0.16	0.15
180	1.46	1.38	0.28	0.27	-	-	-	-	-	-	0.86	0.82
170	4.04	3.74	1.53	1.44	-	-	-	-	0.09	0.09	3.06	2.88
160	8.24	7.53	4.44	4.15	0.03	0.03	-	-	0.60	0.57	7.07	6.49
150	14.49	13.06	9.79	8.88	0.13	0.12	0.09	0.09	2.39	2.24	13.37	12.09
140	23.55	20.99	17.82	15.96	1.20	1.11	0.63	0.60	6.61	5.98	22.67	20.10
130	35.66	31.74	30.08	26.23	3.93	3.30	2.81	2.19	14.63	12.29	34.65	30.87
120	54.47	48.05	46.86	40.76	9.09	7.38	6.48	5.22	25.74	21.70	52.64	46.49

A dash (-) indicates that the threshold distance was not reached.

F.2. Ranges to SPL Thresholds

The following tables present single-strike SPL isopleth ranges. R_{max} is the maximum range at which the sound level was encountered in the modeled maximum-over-depth sound field and $R_{95\%}$ is the maximum range at which the sound level was encountered after the 5 percent farthest such points were excluded (Appendix E.6). Ranges are calculated on unweighted and weighted sound fields described in Appendix D.2. Weightings used are designated as follows: Flat is unweighted, LFC is low-frequency cetaceans, MFC is mid-frequency cetaceans, HFC is high-frequency cetaceans, PPW is pinnipeds in water (Southall et al. 2007). R_{max} is the maximum range at which the sound level was encountered in the modeled maximum-over-depth sound field and $R_{95\%}$ is the maximum range at which the sound level was encountered after the 5 percent farthest such points were excluded. All calculations use an average summer sound speed profile.

F.2.1. Location L01

F.2.1.1. Realistic Scenarios

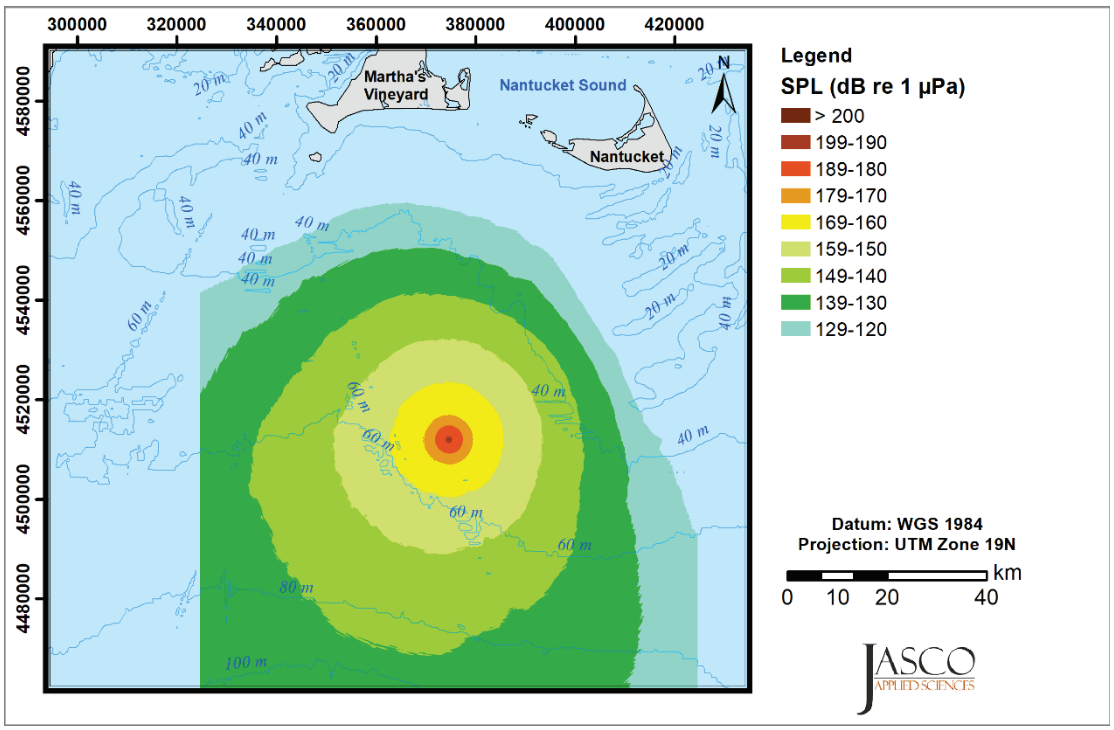

Figure F-2. Unweighted single-strike sound pressure level (SPL) for an 11 m pile at Site L01, average summer sound speed profile and energy level of 4400 kJ.

Table F-53. Distance (km) to the single strike sound pressure level (SPL) for a 2.9 m pin pile at location L01 using a Menck MHU1900S hammer operating at 475 kJ.

Level (SPL)	Flat R_{max}	Flat $R_{95\%}$	LFC R_{max}	LFC $R_{95\%}$	MFC R_{max}	MFC $R_{95\%}$	HFC R_{max}	HFC $R_{95\%}$	PPW R_{max}	PPW $R_{95\%}$
200	-	-	-	-	-	-	-	-	-	-
190	0.07	0.07	0.07	0.07	0.03	0.03	0.02	0.02	0.05	0.05
180	0.44	0.42	0.44	0.42	0.18	0.18	0.15	0.14	0.31	0.30
170	2.39	2.16	2.39	2.14	1.59	1.28	0.90	0.87	1.67	1.61
160	5.91	5.22	5.87	5.20	4.05	3.79	3.84	3.53	5.19	4.60
150	15.75	13.63	15.75	13.61	11.68	10.08	10.88	9.15	13.66	12.14
140	33.56	29.44	33.56	29.40	26.75	22.76	25.14	20.68	31.47	26.75
130	69.46	54.27	69.42	54.26	60.99	48.92	55.75	45.46	67.65	53.18
120	70.68	57.07	70.68	57.07	70.68	57.21	70.68	57.11	70.68	57.15

A dash (-) indicates that the threshold distance was not reached.

Table F-54. Distance (km) to the single strike sound pressure level (SPL) for a 2.9 m pin pile at location L01 using a Menck MHU1900S hammer operating at 950 kJ.

Level (SPL)	Flat R_{max}	Flat $R_{95\%}$	LFC R_{max}	LFC $R_{95\%}$	MFC R_{max}	MFC $R_{95\%}$	HFC R_{max}	HFC $R_{95\%}$	PPW R_{max}	PPW $R_{95\%}$
200	-	-	-	-	-	-	-	-	-	-
190	0.12	0.11	0.12	0.11	0.06	0.06	0.04	0.04	0.09	0.09
180	0.77	0.74	0.76	0.73	0.33	0.32	0.25	0.24	0.53	0.51
170	3.24	3.12	3.23	3.11	2.37	2.14	1.66	1.61	2.68	2.44
160	7.69	7.01	7.69	6.99	5.60	4.95	5.31	4.53	6.90	6.02
150	18.92	16.47	18.92	16.45	14.65	12.75	13.56	11.55	17.06	15.00
140	41.88	35.37	41.86	35.34	33.67	28.46	30.12	25.29	38.24	32.68
130	70.68	55.11	70.68	55.10	69.13	54.15	67.58	52.42	70.68	54.66
120	70.68	56.96	70.68	56.96	70.68	57.06	70.68	57.18	70.68	56.97

A dash (-) indicates that the threshold distance was not reached.

Table F-55. Distance (km) to the single strike sound pressure level (SPL) for a 2.9 m pin pile at location L01 using a Menck MHU1900S hammer operating at 1900 kJ (a, 20 m penetration depth, see Section 3.1.1).

Level (SPL)	Flat R_{max}	Flat $R_{95\%}$	LFC R_{max}	LFC $R_{95\%}$	MFC R_{max}	MFC $R_{95\%}$	HFC R_{max}	HFC $R_{95\%}$	PPW R_{max}	PPW $R_{95\%}$
200	0.03	0.03	0.03	0.03	-	-	-	-	0.03	0.03
190	0.22	0.22	0.22	0.21	0.12	0.12	0.09	0.09	0.16	0.16
180	1.59	1.53	1.59	1.53	0.82	0.80	0.57	0.56	1.09	0.88
170	3.81	3.58	3.81	3.57	3.26	3.15	3.17	2.91	3.57	3.39
160	10.20	9.20	10.20	9.18	7.62	6.66	7.04	6.00	9.08	8.03
150	23.63	20.58	23.63	20.55	18.89	15.93	17.02	14.53	22.51	18.69
140	51.85	43.93	51.85	43.88	42.11	35.29	38.23	32.15	48.13	40.37
130	70.68	57.00	70.68	57.00	70.68	55.18	70.68	54.58	70.68	56.48
120	70.68	57.04	70.68	57.04	70.68	56.96	70.68	56.99	70.68	57.00

A dash (-) indicates that the threshold distance was not reached.

Table F-56. Distance (km) to the single strike sound pressure level (SPL) for a 2.9 m pin pile at location L01 using a Menck MHU1900S hammer operating at 1900 kJ (b, 51 m penetration depths, see Section 3.1.1).

Level (SPL)	Flat R_{max}	Flat $R_{95\%}$	LFC R_{max}	LFC $R_{95\%}$	MFC R_{max}	MFC $R_{95\%}$	HFC R_{max}	HFC $R_{95\%}$	PPW R_{max}	PPW $R_{95\%}$
200	-	-	-	-	-	-	-	-	-	-
190	0.03	0.03	0.02	0.02	-	-	-	-	0.02	0.02
180	0.15	0.14	0.15	0.14	0.08	0.08	0.07	0.07	0.12	0.12
170	0.88	0.86	0.88	0.85	0.54	0.52	0.38	0.35	0.81	0.78
160	3.06	2.86	3.05	2.86	2.46	2.37	2.40	2.31	2.87	2.76
150	6.83	6.08	6.83	6.06	4.82	4.50	4.55	3.86	5.86	5.21
140	17.06	14.99	17.06	14.97	13.39	11.49	12.09	10.46	15.77	13.61
130	37.42	32.10	37.41	32.07	30.12	25.49	27.78	23.11	34.78	30.02
120	70.68	54.59	70.68	54.58	67.59	52.54	61.04	49.55	70.68	54.47

A dash (-) indicates that the threshold distance was not reached.

Table F-57. Distance (km) to the single strike sound pressure level (SPL) for a 2.9 m pin pile at location L01 using a Menck MHU1900S hammer operating at 475 kJ, with 2 dB shift for post-piling installation (OSP foundation).

Level (SPL)	Flat R_{max}	Flat $R_{95\%}$	LFC R_{max}	LFC $R_{95\%}$	MFC R_{max}	MFC $R_{95\%}$	HFC R_{max}	HFC $R_{95\%}$	PPW R_{max}	PPW $R_{95\%}$
200	-	-	-	-	-	-	-	-	-	-
190	0.10	0.10	0.10	0.10	0.05	0.05	0.03	0.03	0.08	0.08
180	0.58	0.53	0.55	0.53	0.26	0.25	0.21	0.20	0.48	0.46
170	3.11	2.72	3.10	2.71	1.67	1.62	1.63	1.59	2.43	2.34
160	7.24	6.64	7.24	6.64	5.35	4.62	4.80	4.01	6.35	5.72
150	18.12	15.81	18.12	15.78	13.60	12.10	12.66	10.93	16.22	14.34
140	39.04	33.82	39.04	33.78	32.57	26.75	28.76	24.04	36.16	31.28
130	70.68	54.77	70.68	54.77	67.82	53.57	64.99	50.76	70.68	54.51
120	70.68	56.97	70.68	56.97	70.68	57.12	70.68	57.23	70.68	56.99

A dash (-) indicates that the threshold distance was not reached.

Table F-58. Distance (km) to the single strike sound pressure level (SPL) for a 2.9 m pin pile at location L01 using a Menck MHU1900S hammer operating at 950 kJ, with 2 dB shift for post-piling installation (OSP foundation).

Level (SPL)	Flat R_{max}	Flat $R_{95\%}$	LFC R_{max}	LFC $R_{95\%}$	MFC R_{max}	MFC $R_{95\%}$	HFC R_{max}	HFC $R_{95\%}$	PPW R_{max}	PPW $R_{95\%}$
200	0.03	0.03	0.03	0.03	-	-	-	-	0.02	0.02
190	0.15	0.15	0.15	0.14	0.09	0.09	0.07	0.07	0.12	0.12
180	0.89	0.86	0.89	0.86	0.54	0.52	0.39	0.37	0.83	0.80
170	3.60	3.45	3.60	3.45	3.11	2.44	2.42	2.34	3.32	3.18
160	9.33	8.36	9.33	8.35	7.10	6.13	6.35	5.45	8.36	7.46
150	22.53	19.24	22.53	19.22	17.17	14.99	15.72	13.63	21.50	17.45
140	48.31	40.96	48.15	40.92	39.05	33.23	36.00	30.31	45.42	37.99
130	70.68	56.48	70.68	56.47	70.68	54.71	70.68	54.49	70.68	55.85
120	70.68	56.99	70.68	56.99	70.68	56.97	70.68	57.01	70.68	56.97

A dash (-) indicates that the threshold distance was not reached.

Table F-59. Distance (km) to the single strike sound pressure level (SPL) for a 2.9 m pin pile at location L01 using a Menck MHU1900S hammer operating at 1900 kJ, with 2 dB shift for post-piling installation (OSP foundation) (a, 20 m penetration depth, see Section 3.1.1).

Level (SPL)	Flat R_{max}	Flat $R_{95\%}$	LFC R_{max}	LFC $R_{95\%}$	MFC R_{max}	MFC $R_{95\%}$	HFC R_{max}	HFC $R_{95\%}$	PPW R_{max}	PPW $R_{95\%}$
200	0.06	0.06	0.06	0.06	0.03	0.03	0.02	0.02	0.03	0.03
190	0.35	0.34	0.35	0.34	0.15	0.15	0.13	0.13	0.22	0.21
180	2.07	1.79	2.06	1.77	0.90	0.87	0.85	0.83	1.62	1.57
170	4.49	4.11	4.49	4.08	3.56	3.34	3.33	3.19	3.88	3.64
160	12.47	10.97	12.47	10.94	9.45	8.07	8.29	7.29	10.96	9.62
150	27.84	24.13	27.83	24.10	22.53	18.60	19.88	16.88	25.71	21.86
140	60.95	49.42	60.94	49.39	49.64	40.84	45.48	37.30	55.82	46.96
130	70.68	57.24	70.68	57.24	70.68	56.74	70.68	55.68	70.68	57.14
120	70.68	57.26	70.68	57.26	70.68	57.04	70.68	56.99	70.68	57.18

Table F-60. Distance (km) to the single strike sound pressure level (SPL) for a 2.9 m pin pile at location L01 using a Menck MHU1900S hammer operating at 1900 kJ, with 2 dB shift for post-piling installation (OSP foundation) (b, 51 m penetration depth, See Section 3.1.1).

Level (SPL)	Flat R_{max}	Flat $R_{95\%}$	LFC R_{max}	LFC $R_{95\%}$	MFC R_{max}	MFC $R_{95\%}$	HFC R_{max}	HFC $R_{95\%}$	PPW R_{max}	PPW $R_{95\%}$
200	-	-	-	-	-	-	-	-	-	-
190	0.03	0.03	0.03	0.03	-	-	-	-	0.03	0.03
180	0.20	0.19	0.19	0.19	0.12	0.11	0.09	0.09	0.15	0.15
170	1.28	1.22	1.27	1.22	0.82	0.79	0.57	0.55	0.90	0.87
160	3.23	3.12	3.23	3.12	2.90	2.79	2.56	2.45	3.13	2.96
150	8.36	7.53	8.36	7.51	6.32	5.40	5.58	4.76	7.21	6.58
140	20.54	17.39	20.54	17.37	15.77	13.65	14.64	12.41	18.13	15.87
130	45.34	37.33	45.32	37.29	35.97	30.43	33.42	27.26	41.00	34.77
120	70.68	55.63	70.68	55.62	70.68	54.50	68.25	53.87	70.68	55.05

A dash (-) indicates that the threshold distance was not reached.

Table F-61. Distance (km) to the single strike sound pressure level (SPL) for an 11 m pile at location L01 using a Menck MHU4400 hammer operating at 1100 kJ.

Level (SPL)	Flat R_{max}	Flat $R_{95\%}$	LFC R_{max}	LFC $R_{95\%}$	MFC R_{max}	MFC $R_{95\%}$	HFC R_{max}	HFC $R_{95\%}$	PPW R_{max}	PPW $R_{95\%}$
200	0.05	0.05	0.05	0.05	-	-	-	-	-	-
190	0.30	0.29	0.29	0.28	0.03	0.03	0.02	0.02	0.10	0.10
180	1.60	1.56	1.59	1.55	0.21	0.21	0.12	0.12	0.61	0.58
170	3.70	3.56	3.69	3.55	1.32	1.29	0.80	0.73	2.93	2.75
160	9.14	8.32	8.96	8.28	3.57	3.43	3.17	2.97	5.78	5.37
150	18.45	16.69	18.34	16.62	8.75	8.01	6.78	5.94	14.14	12.63
140	33.66	30.17	33.58	30.10	19.40	17.41	15.76	14.20	27.13	24.58
130	61.04	50.75	60.96	50.69	38.82	34.20	33.45	29.11	52.12	45.61
120	70.68	57.05	70.68	57.04	70.68	54.52	67.69	53.37	70.68	55.99

A dash (-) indicates that the threshold distance was not reached.

Table F-62. Distance (km) to the single strike sound pressure level (SPL) for an 11 m pile at location L01 using a Menck MHU4400 hammer operating at 2200 kJ.

Level (SPL)	Flat R_{max}	Flat $R_{95\%}$	LFC R_{max}	LFC $R_{95\%}$	MFC R_{max}	MFC $R_{95\%}$	HFC R_{max}	HFC $R_{95\%}$	PPW R_{max}	PPW $R_{95\%}$
200	0.05	0.05	0.05	0.05	-	-	-	-	0.02	0.02
190	0.35	0.34	0.35	0.34	0.05	0.05	0.03	0.03	0.13	0.13
180	1.84	1.79	1.83	1.78	0.38	0.37	0.17	0.17	0.93	0.83
170	3.77	3.62	3.76	3.61	1.83	1.73	1.12	1.08	3.15	3.04
160	9.74	8.96	9.74	8.92	3.87	3.62	3.45	3.28	6.79	6.12
150	19.89	18.10	19.87	18.04	10.29	9.49	8.35	7.51	15.73	14.18
140	37.17	33.18	37.16	33.12	23.11	20.37	19.11	16.86	30.58	27.68
130	68.85	54.04	68.77	54.01	47.19	40.44	40.98	34.71	59.79	50.00
120	70.68	57.24	70.68	57.24	70.68	55.66	70.68	54.68	70.68	57.14

A dash (-) indicates that the threshold distance was not reached.

Table F-63. Distance (km) to the single strike sound pressure level (SPL) for an 11 m pile at location L01 using a Menck MHU4400 hammer operating at 4400 kJ.

Level (SPL)	Flat R_{max}	Flat $R_{95\%}$	LFC R_{max}	LFC $R_{95\%}$	MFC R_{max}	MFC $R_{95\%}$	HFC R_{max}	HFC $R_{95\%}$	PPW R_{max}	PPW $R_{95\%}$
200	0.12	0.12	0.11	0.11	-	-	-	-	0.05	0.05
190	0.69	0.66	0.67	0.65	0.10	0.10	0.06	0.06	0.27	0.26
180	2.87	2.74	2.85	2.72	0.59	0.56	0.39	0.38	1.58	1.54
170	5.19	4.82	5.16	4.79	2.69	2.59	1.90	1.80	3.47	3.30
160	12.08	11.15	12.07	11.10	5.20	4.81	3.84	3.53	8.76	7.99
150	23.86	21.53	23.84	21.48	13.38	12.08	10.32	9.57	19.12	17.21
140	44.96	39.37	44.92	39.29	28.00	24.93	24.12	20.81	37.30	33.07
130	70.68	54.95	70.68	54.94	58.01	48.63	51.56	42.67	70.13	54.40
120	70.68	57.01	70.68	57.02	70.68	57.10	70.68	56.34	70.68	57.14

A dash (-) indicates that the threshold distance was not reached.

F.2.1.2. Maximum Scenarios

Table F-64. Distance (km) to the single strike sound pressure level (SPL) for a 4.5 m pile at location L01 using an IHC S2000 hammer operating at 2000 kJ (a, 20 m penetration depth, see Section 3.1.1).

Level (SPL)	Flat R_{max}	Flat $R_{95\%}$	LFC R_{max}	LFC $R_{95\%}$	MFC R_{max}	MFC $R_{95\%}$	HFC R_{max}	HFC $R_{95\%}$	PPW R_{max}	PPW $R_{95\%}$
200	0.07	0.07	0.07	0.07	0.03	0.03	0.02	0.02	0.05	0.05
190	0.42	0.41	0.42	0.40	0.15	0.15	0.13	0.13	0.25	0.24
180	2.39	2.11	2.38	2.10	0.90	0.87	0.84	0.82	1.63	1.58
170	4.12	3.85	4.09	3.84	3.30	3.17	3.22	3.10	3.56	3.43
160	11.45	10.30	11.45	10.27	7.70	6.81	7.08	6.05	9.70	8.60
150	25.72	22.13	25.71	22.10	18.95	16.29	17.06	14.71	22.59	19.62
140	53.29	45.90	53.27	45.86	44.04	35.81	38.33	32.43	49.25	41.74
130	70.68	57.06	70.68	57.06	70.68	55.27	70.68	54.60	70.68	56.62
120	70.68	57.05	70.68	57.05	70.68	56.96	70.68	56.98	70.68	57.00

Table F-65. Distance (km) to the single strike sound pressure level (SPL) for a 4.5 m pile at location L01 using an IHC S2000 hammer operating at 2000 kJ (b, 40 m penetration depth, see Section 3.1.1).

Level (SPL)	Flat R_{max}	Flat $R_{95\%}$	LFC R_{max}	LFC $R_{95\%}$	MFC R_{max}	MFC $R_{95\%}$	HFC R_{max}	HFC $R_{95\%}$	PPW R_{max}	PPW $R_{95\%}$
200	0.05	0.05	0.05	0.05	0.02	0.02	-	-	0.03	0.03
190	0.32	0.31	0.31	0.30	0.13	0.13	0.10	0.10	0.18	0.18
180	1.66	1.60	1.66	1.60	0.83	0.81	0.57	0.56	1.22	1.17
170	3.51	3.38	3.51	3.37	3.11	2.86	2.83	2.51	3.27	3.15
160	9.38	8.69	9.38	8.66	6.35	5.67	5.59	4.92	8.34	7.34
150	22.51	19.33	22.51	19.30	16.22	14.18	14.65	12.69	19.56	16.98
140	46.47	39.95	46.46	39.90	36.14	31.16	33.56	27.90	43.08	36.50
130	70.68	55.96	70.68	55.96	70.68	54.53	68.43	53.98	70.68	55.34
120	70.68	56.96	70.68	56.96	70.68	57.00	70.68	57.09	70.68	56.96

A dash (-) indicates that the threshold distance was not reached.

Table F-66. Distance (km) to the single strike sound pressure level (SPL) for a 4.5 m pile at location L01 using an IHC S2000 hammer operating at 2000 kJ (c, 60 m penetration depth, see Section 3.1.1).

Level (SPL)	Flat R_{max}	Flat $R_{95\%}$	LFC R_{max}	LFC $R_{95\%}$	MFC R_{max}	MFC $R_{95\%}$	HFC R_{max}	HFC $R_{95\%}$	PPW R_{max}	PPW $R_{95\%}$
200	-	-	-	-	-	-	-	-	-	-
190	0.05	0.05	0.05	0.05	-	-	-	-	0.03	0.03
180	0.27	0.27	0.27	0.26	0.12	0.11	0.09	0.09	0.17	0.16
170	1.61	1.56	1.61	1.56	0.81	0.78	0.56	0.54	1.18	1.10
160	3.10	2.92	3.10	2.90	2.54	2.45	2.44	2.35	2.80	2.70
150	8.76	7.96	8.75	7.94	5.61	5.10	5.32	4.57	7.33	6.68
140	21.50	18.03	21.49	18.00	15.16	13.39	13.60	11.93	18.16	15.99
130	45.30	37.70	45.30	37.66	34.76	29.55	32.50	26.00	40.35	34.54
120	70.68	55.52	70.68	55.51	70.68	54.38	67.66	52.98	70.68	54.91

A dash (-) indicates that the threshold distance was not reached.

Table F-67. Distance (km) to the single strike sound pressure level (SPL) for a 4.5 m pile at location L01 using an IHC S2000 hammer operating at 2000 kJ, with 2 dB shift for post-piling installation (OSP foundation) (a, 20 m penetration depth, see Section 3.1.1).

Level (SPL)	Flat R_{max}	Flat $R_{95\%}$	LFC R_{max}	LFC $R_{95\%}$	MFC R_{max}	MFC $R_{95\%}$	HFC R_{max}	HFC $R_{95\%}$	PPW R_{max}	PPW $R_{95\%}$
200	0.11	0.11	0.11	0.11	0.03	0.03	0.03	0.03	0.07	0.07
190	0.64	0.56	0.59	0.54	0.21	0.20	0.17	0.16	0.41	0.40
180	2.79	2.67	2.79	2.66	1.62	1.57	1.56	0.94	2.36	2.08
170	5.22	4.80	5.22	4.79	3.48	3.34	3.34	3.21	4.07	3.82
160	13.66	12.25	13.66	12.21	9.47	8.29	8.36	7.42	11.45	10.30
150	28.94	25.70	28.94	25.66	22.55	19.05	20.48	17.08	26.75	22.88
140	61.25	50.51	61.24	50.48	49.70	41.51	46.30	37.59	56.89	47.97
130	70.68	57.27	70.68	57.27	70.68	56.80	70.68	55.73	70.68	57.16
120	70.68	57.27	70.68	57.27	70.68	57.04	70.68	56.99	70.68	57.19

Table F-68. Distance (km) to the single strike sound pressure level (SPL) for a 4.5 m pile at location L01 using an IHC S2000 hammer operating at 2000 kJ, with 2 dB shift for post-piling installation (OSP foundation) (b, 40 m penetration depth, see Section 3.1.1).

Level (SPL)	Flat R_{max}	Flat $R_{95\%}$	LFC R_{max}	LFC $R_{95\%}$	MFC R_{max}	MFC $R_{95\%}$	HFC R_{max}	HFC $R_{95\%}$	PPW R_{max}	PPW $R_{95\%}$
200	0.072	0.072	0.072	0.072	0.028	0.028	0.02	0.02	0.045	0.045
190	0.444	0.431	0.442	0.427	0.161	0.161	0.134	0.134	0.279	0.269
180	2.389	2.137	2.384	2.125	1.119	0.892	0.852	0.829	1.642	1.59
170	4.239	3.843	4.106	3.836	3.244	3.132	3.165	3.014	3.496	3.327
160	11.471	10.379	11.467	10.35	7.826	6.917	7.113	6.106	9.796	8.733
150	25.765	22.367	25.761	22.331	19.071	16.482	17.148	14.848	23.083	19.841
140	53.451	46.348	53.437	46.311	45.24	36.185	38.928	32.741	51.211	42.338
130	70.682	57.078	70.682	57.077	70.682	55.375	70.682	54.638	70.682	56.715
120	70.682	57.06	70.682	57.059	70.682	56.96	70.682	56.98	70.682	57.009

Table F-69. Distance (km) to the single strike sound pressure level (SPL) for a 4.5 m pile at location L01 using an IHC S2000 hammer operating at 2000 kJ, with 2 dB shift for post-piling installation (OSP foundation) (c, 60 m penetration depth, see Section 3.1.1).

Level (SPL)	Flat R_{max}	Flat $R_{95\%}$	LFC R_{max}	LFC $R_{95\%}$	MFC R_{max}	MFC $R_{95\%}$	HFC R_{max}	HFC $R_{95\%}$	PPW R_{max}	PPW $R_{95\%}$
200	-	-	-	-	-	-	-	-	-	-
190	0.06	0.06	0.06	0.06	0.02	0.02	0.02	0.02	0.04	0.04
180	0.41	0.40	0.40	0.39	0.15	0.15	0.13	0.13	0.23	0.22
170	2.03	1.90	1.99	1.88	0.89	0.86	0.83	0.81	1.61	1.56
160	3.82	3.45	3.82	3.42	2.77	2.67	2.59	2.50	3.10	2.89
150	10.46	9.52	10.46	9.49	7.19	6.48	6.35	5.61	9.07	8.05
140	24.12	20.86	24.10	20.83	17.97	15.57	16.66	14.03	21.61	18.67
130	51.82	43.92	51.81	43.86	40.36	34.27	37.14	30.94	48.05	39.88
120	70.68	56.83	70.68	56.82	70.68	54.88	70.68	54.52	70.68	56.18

A dash (-) indicates that the threshold distance was not reached.

Table F-70. Distance (km) to the single strike sound pressure level (SPL) for a 4.5 m pile at location L01 using a Menck MHU3500S hammer operating at 3500 kJ (a, 20 m penetration depth, see Section 3.1.1).

Level (SPL)	Flat R_{max}	Flat $R_{95\%}$	LFC R_{max}	LFC $R_{95\%}$	MFC R_{max}	MFC $R_{95\%}$	HFC R_{max}	HFC $R_{95\%}$	PPW R_{max}	PPW $R_{95\%}$
200	0.05	0.05	0.05	0.05	-	-	-	-	0.03	0.03
190	0.31	0.30	0.30	0.30	0.10	0.10	0.07	0.07	0.16	0.15
180	1.75	1.61	1.66	1.60	0.56	0.54	0.47	0.46	0.94	0.88
170	3.51	3.38	3.50	3.37	2.77	2.54	2.44	2.34	3.20	3.08
160	8.92	8.26	8.91	8.24	5.34	4.74	4.79	3.94	6.91	6.46
150	20.56	17.95	20.55	17.91	13.98	12.38	12.63	10.89	17.17	15.34
140	41.86	36.08	41.14	36.03	32.51	26.98	27.86	23.94	37.42	32.32
130	70.68	54.98	70.68	54.97	67.71	53.41	61.72	50.27	70.68	54.56
120	70.68	56.97	70.68	56.97	70.68	57.14	70.68	57.25	70.68	56.99

A dash (-) indicates that the threshold distance was not reached.

Table F-71. Distance (km) to the single strike sound pressure level (SPL) for a 4.5 m pile at location L01 using a Menck MHU3500S hammer operating at 3500 kJ (b, 40 m penetration depth, see Section 3.1.1).

Level (SPL)	Flat R_{max}	Flat $R_{95\%}$	LFC R_{max}	LFC $R_{95\%}$	MFC R_{max}	MFC $R_{95\%}$	HFC R_{max}	HFC $R_{95\%}$	PPW R_{max}	PPW $R_{95\%}$
200	0.03	0.03	0.03	0.03	-	-	-	-	0.02	0.02
190	0.23	0.22	0.22	0.22	0.07	0.07	0.06	0.06	0.13	0.13
180	1.32	1.29	1.32	1.28	0.46	0.45	0.29	0.28	0.83	0.80
170	3.09	2.96	3.09	2.95	2.40	2.30	1.68	1.62	2.78	2.67
160	7.74	7.08	7.73	7.03	4.08	3.86	3.84	3.22	5.66	5.08
150	17.66	15.69	17.64	15.65	11.83	10.48	10.88	9.22	15.12	13.45
140	36.19	31.81	36.19	31.77	27.80	23.34	25.10	20.79	33.39	28.65
130	70.68	54.47	70.68	54.46	60.97	49.14	53.56	45.39	68.09	53.77
120	70.68	57.04	70.68	57.04	70.68	57.21	70.68	57.10	70.68	57.13

A dash (-) indicates that the threshold distance was not reached.

Table F-72. Distance (km) to the single strike sound pressure level (SPL) for a 4.5 m pile at location L01 using a Menck MHU3500S hammer operating at 3500 kJ (c, 60 m penetration depth, see Section 3.1.1).

Level (SPL)	Flat R_{max}	Flat $R_{95\%}$	LFC R_{max}	LFC $R_{95\%}$	MFC R_{max}	MFC $R_{95\%}$	HFC R_{max}	HFC $R_{95\%}$	PPW R_{max}	PPW $R_{95\%}$
200	0.02	0.02	0.02	0.02	-	-	-	-	-	-
190	0.12	0.12	0.12	0.12	0.03	0.03	0.02	0.02	0.06	0.06
180	0.74	0.71	0.73	0.70	0.17	0.16	0.13	0.13	0.35	0.34
170	2.68	2.60	2.67	2.59	1.09	0.90	0.84	0.82	1.80	1.67
160	5.21	4.83	5.20	4.80	2.88	2.78	2.77	2.67	3.34	3.16
150	12.52	11.49	12.50	11.45	7.60	6.69	6.83	5.80	9.90	9.02
140	26.08	23.29	26.07	23.25	18.16	16.02	16.69	14.28	23.06	19.99
130	53.39	46.29	53.36	46.24	41.11	34.85	37.25	31.27	49.12	41.45
120	70.68	56.99	70.68	56.98	70.68	54.95	70.68	54.53	70.68	56.32

A dash (-) indicates that the threshold distance was not reached.

Table F-73. Distance (km) to the single strike sound pressure level (SPL) for a 4.5 m pile at location L01 using a Menck MHU3500S hammer operating at 3500 kJ, with 2 dB shift for post-piling installation (OSP foundation) (a, 20 m penetration depth, see Section 3.1.1).

Level (SPL)	Flat R_{max}	Flat $R_{95\%}$	LFC R_{max}	LFC $R_{95\%}$	MFC R_{max}	MFC $R_{95\%}$	HFC R_{max}	HFC $R_{95\%}$	PPW R_{max}	PPW $R_{95\%}$
200	0.07	0.07	0.07	0.07	0.02	0.02	-	-	0.03	0.03
190	0.42	0.41	0.41	0.40	0.13	0.13	0.11	0.11	0.23	0.22
180	2.40	2.17	2.39	2.14	0.84	0.82	0.74	0.57	1.58	1.52
170	4.07	3.76	4.06	3.74	3.13	2.94	3.04	2.77	3.36	3.24
160	10.61	9.80	10.60	9.77	6.77	5.84	5.61	5.00	8.58	7.81
150	23.13	20.62	23.13	20.57	16.69	14.52	14.75	12.91	20.57	17.80
140	48.34	41.55	48.31	41.50	37.39	31.66	33.63	28.39	45.30	37.40
130	70.68	56.15	70.68	56.14	70.68	54.54	68.84	54.07	70.68	55.49
120	70.68	56.96	70.68	56.96	70.68	56.99	70.68	57.08	70.68	56.96

A dash (-) indicates that the threshold distance was not reached.

Table F-74. Distance (km) to the single strike sound pressure level (SPL) for a 4.5 m pile at location L01 using a Menck MHU3500S hammer operating at 3500 kJ, with 2 dB shift for post-piling installation (OSP foundation) (b, 40 m penetration depth, see Section 3.1.1).

Level (SPL)	Flat R_{max}	Flat $R_{95\%}$	LFC R_{max}	LFC $R_{95\%}$	MFC R_{max}	MFC $R_{95\%}$	HFC R_{max}	HFC $R_{95\%}$	PPW R_{max}	PPW $R_{95\%}$
200	0.05	0.05	0.05	0.05	-	-	-	-	0.03	0.03
190	0.33	0.32	0.32	0.31	0.11	0.11	0.08	0.08	0.17	0.16
180	1.77	1.64	1.76	1.62	0.57	0.56	0.50	0.48	1.09	0.95
170	3.28	3.16	3.27	3.15	2.65	2.48	2.43	2.34	2.92	2.81
160	9.25	8.30	8.93	8.28	5.38	4.81	4.80	3.97	7.18	6.57
150	20.59	18.13	20.58	18.10	14.04	12.56	12.66	11.07	17.60	15.55
140	42.18	36.63	42.16	36.58	33.36	27.46	28.75	24.23	38.21	32.80
130	70.68	55.11	70.68	55.10	67.79	53.65	63.66	50.61	70.68	54.62
120	70.68	56.96	70.68	56.96	70.68	57.12	70.68	57.24	70.68	56.98

A dash (-) indicates that the threshold distance was not reached.

Table F-75. Distance (km) to the single strike sound pressure level (SPL) for a 4.5 m pile at location L01 using a Menck MHU3500S hammer operating at 3500 kJ, with 2 dB shift for post-piling installation (OSP foundation) (c, 60 m penetration depth, see Section 3.1.1).

Level (SPL)	Flat R_{max}	Flat $R_{95\%}$	LFC R_{max}	LFC $R_{95\%}$	MFC R_{max}	MFC $R_{95\%}$	HFC R_{max}	HFC $R_{95\%}$	PPW R_{max}	PPW $R_{95\%}$
200	0.03	0.03	0.03	0.03	-	-	-	-	-	-
190	0.17	0.17	0.17	0.16	0.03	0.03	0.03	0.03	0.08	0.08
180	1.05	0.98	0.98	0.95	0.23	0.22	0.17	0.17	0.47	0.46
170	2.83	2.74	2.82	2.73	1.63	1.58	1.21	1.13	2.41	2.33
160	6.24	5.85	6.22	5.81	3.21	3.09	3.10	2.84	4.38	3.97
150	14.97	13.38	14.96	13.33	9.44	8.17	7.99	7.09	11.84	10.70
140	30.28	26.72	30.25	26.68	22.52	18.72	19.08	16.59	26.77	23.22
130	61.28	50.61	61.28	50.57	48.39	40.18	45.27	36.29	55.87	47.62
120	70.68	57.26	70.68	57.26	70.68	56.35	70.68	55.35	70.68	57.13

A dash (-) indicates that the threshold distance was not reached.

Table F-76. Distance (km) to the single strike sound pressure level (SPL) for a 16 m pile at location L01 using a theoretical 6600 hammer operating at 6600 kJ (a, 10 m penetration depth, see Section 3.1.1).

Level (SPL)	Flat R_{max}	Flat $R_{95\%}$	LFC R_{max}	LFC $R_{95\%}$	MFC R_{max}	MFC $R_{95\%}$	HFC R_{max}	HFC $R_{95\%}$	PPW R_{max}	PPW $R_{95\%}$
200	0.26	0.26	0.25	0.24	0.03	0.03	-	-	0.08	0.08
190	1.45	1.41	1.40	1.31	0.14	0.14	0.09	0.09	0.46	0.44
180	3.25	3.14	3.24	3.12	0.94	0.84	0.51	0.48	2.29	2.20
170	7.26	6.68	7.11	6.61	3.04	2.91	2.56	2.35	4.35	3.89
160	14.99	13.72	14.96	13.66	6.41	5.86	4.63	4.29	10.91	9.81
150	27.54	25.01	27.52	24.94	15.69	13.87	12.61	11.17	22.19	19.93
140	51.64	44.81	51.45	44.70	31.53	27.82	26.75	23.41	42.49	37.13
130	70.68	55.59	70.68	55.58	63.67	51.32	55.85	46.92	70.68	54.68
120	70.68	56.98	70.68	56.98	70.68	57.26	70.68	57.05	70.68	57.04

A dash (-) indicates that the threshold distance was not reached.

Table F-77. Distance (km) to the single strike sound pressure level (SPL) for a 16 m pile at location L01 using a theoretical 6600 hammer operating at 6600 kJ (b, 20 m penetration depth, see Section 3.1.1).

Level (SPL)	Flat R_{max}	Flat $R_{95\%}$	LFC R_{max}	LFC $R_{95\%}$	MFC R_{max}	MFC $R_{95\%}$	HFC R_{max}	HFC $R_{95\%}$	PPW R_{max}	PPW $R_{95\%}$
200	0.26	0.26	0.26	0.25	0.03	0.03	-	-	0.09	0.09
190	1.44	1.40	1.40	1.32	0.15	0.14	0.10	0.10	0.49	0.47
180	3.24	3.12	3.23	3.11	1.04	0.93	0.58	0.55	2.43	2.33
170	7.41	6.86	7.38	6.81	3.09	2.95	2.66	2.54	4.45	4.15
160	15.62	14.10	15.59	14.03	6.87	6.25	5.18	4.59	11.13	10.28
150	28.43	25.81	28.40	25.75	15.97	14.54	12.92	11.80	23.09	20.66
140	52.92	46.23	52.90	46.17	33.41	29.31	27.88	24.58	44.42	38.74
130	70.68	55.92	70.68	55.91	67.64	53.11	58.43	48.66	70.68	54.99
120	70.68	56.95	70.68	56.96	70.68	57.22	70.68	57.12	70.68	56.99

A dash (-) indicates that the threshold distance was not reached.

Table F-78. Distance (km) to the single strike sound pressure level (SPL) for a 16 m pile at location L01using a theoretical 6600 hammer operating at 6600 kJ (c, 35 m penetration depth, see Section 3.1.1).

Level (SPL)	Flat R_{max}	Flat $R_{95\%}$	LFC R_{max}	LFC $R_{95\%}$	MFC R_{max}	MFC $R_{95\%}$	HFC R_{max}	HFC $R_{95\%}$	PPW R_{max}	PPW $R_{95\%}$
200	0.27	0.27	0.27	0.26	0.03	0.03	0.02	0.02	0.09	0.09
190	1.56	1.50	1.48	1.42	0.18	0.17	0.13	0.13	0.57	0.55
180	3.27	3.15	3.26	3.14	1.30	1.16	0.78	0.71	2.67	2.54
170	7.76	7.16	7.74	7.08	3.20	3.07	2.89	2.76	4.78	4.31
160	16.00	14.63	15.99	14.58	8.11	7.24	5.93	5.45	12.21	11.04
150	30.32	27.18	30.28	27.11	18.57	16.39	15.16	13.57	25.12	22.46
140	59.22	49.08	59.21	49.03	38.68	33.24	33.39	28.35	50.20	43.49
130	70.68	56.80	70.68	56.79	70.68	54.60	67.71	53.19	70.68	55.91
120	70.68	56.97	70.68	56.97	70.68	57.02	70.68	57.18	70.68	56.93

F.2.2. Location L02

F.2.2.1. Realistic Scenarios

Table F-79. Distance (km) to the single strike sound pressure level (SPL) for a 2.9 m pin pile at location L02 using a Menck MHU1900S hammer operating at 475 kJ.

Level (SPL)	Flat R_{max}	Flat $R_{95\%}$	LFC R_{max}	LFC $R_{95\%}$	MFC R_{max}	MFC $R_{95\%}$	HFC R_{max}	HFC $R_{95\%}$	PPW R_{max}	PPW $R_{95\%}$
200	-	-	-	-	-	-	-	-	-	-
190	0.04	0.04	0.04	0.04	-	-	-	-	0.03	0.03
180	0.25	0.24	0.25	0.24	0.12	0.12	0.10	0.09	0.17	0.16
170	1.42	1.36	1.41	1.35	0.69	0.66	0.65	0.61	1.13	1.06
160	4.48	4.09	4.47	4.08	2.93	2.78	2.89	2.64	3.81	3.47
150	11.29	9.80	11.28	9.80	8.51	7.59	7.63	6.74	10.56	9.00
140	22.19	18.77	22.19	18.75	18.11	15.66	16.86	14.48	20.56	17.57
130	37.99	31.99	37.99	31.97	33.81	28.19	32.09	26.48	36.13	30.66
120	62.03	52.62	62.02	52.61	56.37	47.64	53.01	44.61	60.87	51.56

A dash (-) indicates that the threshold distance was not reached.

Table F-80. Distance (km) to the single strike sound pressure level (SPL) for a 2.9 m pin pile at location L02 using a Menck MHU1900S hammer operating at 950 kJ.

Level (SPL)	Flat R_{max}	Flat $R_{95\%}$	LFC R_{max}	LFC $R_{95\%}$	MFC R_{max}	MFC $R_{95\%}$	HFC R_{max}	HFC $R_{95\%}$	PPW R_{max}	PPW $R_{95\%}$
200	-	-	-	-	-	-	-	-	-	-
190	0.06	0.06	0.06	0.06	0.03	0.03	0.02	0.02	0.05	0.05
180	0.40	0.39	0.40	0.38	0.19	0.18	0.16	0.15	0.31	0.30
170	2.03	1.89	2.03	1.89	1.35	1.16	1.19	1.11	1.72	1.56
160	5.90	5.37	5.89	5.36	4.13	3.80	3.78	3.36	5.23	4.67
150	13.76	11.89	13.76	11.87	11.25	9.62	9.91	8.77	12.73	11.00
140	25.76	22.28	25.76	22.26	22.19	18.79	20.53	17.43	24.59	21.05
130	43.07	37.06	43.07	37.04	38.68	32.69	37.04	30.73	41.88	35.55
120	70.68	55.12	70.68	55.12	64.91	53.55	61.66	51.89	69.84	55.07

A dash (-) indicates that the threshold distance was not reached.

Table F-81. Distance (km) to the single strike sound pressure level (SPL) for a 2.9 m pin pile at location L02 using a Menck MHU1900S hammer operating at 1900 kJ (a, 20 m penetration depth, see Section 3.1.1).

Level (SPL)	Flat R_{max}	Flat $R_{95\%}$	LFC R_{max}	LFC $R_{95\%}$	MFC R_{max}	MFC $R_{95\%}$	HFC R_{max}	HFC $R_{95\%}$	PPW R_{max}	PPW $R_{95\%}$
200	0.02	0.02	0.02	0.02	-	-	-	-	-	-
190	0.16	0.16	0.16	0.15	0.07	0.07	0.06	0.06	0.12	0.11
180	0.91	0.87	0.91	0.87	0.57	0.54	0.37	0.36	0.67	0.64
170	3.42	3.13	3.42	3.12	2.31	2.18	2.24	1.80	2.90	2.69
160	9.08	7.95	9.07	7.94	7.11	5.96	6.37	5.32	7.89	7.12
150	18.14	15.87	18.14	15.85	15.35	13.19	14.56	12.22	17.11	14.84
140	32.93	28.17	32.93	28.15	29.22	24.58	27.85	23.00	32.10	26.94
130	55.32	46.97	55.32	46.94	49.02	41.41	46.17	38.96	53.00	45.07
120	70.68	54.46	70.68	54.46	70.68	54.62	70.68	54.78	70.68	54.47

A dash (-) indicates that the threshold distance was not reached.

Table F-82. Distance (km) to the single strike sound pressure level (SPL) for a 2.9 m pin pile at location L02 using a Menck MHU1900S hammer operating at 1900 kJ (b, 51 m penetration depth, see Section 3.1.1).

Level (SPL)	Flat R_{max}	Flat $R_{95\%}$	LFC R_{max}	LFC $R_{95\%}$	MFC R_{max}	MFC $R_{95\%}$	HFC R_{max}	HFC $R_{95\%}$	PPW R_{max}	PPW $R_{95\%}$
200	-	-	-	-	-	-	-	-	-	-
190	0.02	0.02	0.02	0.02	-	-	-	-	-	-
180	0.14	0.14	0.14	0.14	0.06	0.06	0.05	0.05	0.10	0.10
170	0.83	0.79	0.82	0.78	0.40	0.38	0.32	0.31	0.63	0.60
160	3.03	2.79	3.03	2.78	2.26	1.87	1.79	1.68	2.83	2.35
150	6.91	6.17	6.91	6.15	5.19	4.48	4.30	3.93	6.43	5.46
140	15.27	13.23	15.13	13.22	12.69	10.79	11.29	9.90	14.17	12.25
130	28.26	24.32	27.98	24.30	24.95	20.77	22.95	19.28	26.93	23.08
120	47.10	40.25	47.09	40.23	41.91	35.50	39.68	33.44	45.16	38.67

A dash (-) indicates that the threshold distance was not reached.

Table F-83. Distance (km) to the single strike sound pressure level (SPL) for an 11 m pile at location L02 using a Menck MHU4400 hammer operating at 1100 kJ.

Level (SPL)	Flat R_{max}	Flat $R_{95\%}$	LFC R_{max}	LFC $R_{95\%}$	MFC R_{max}	MFC $R_{95\%}$	HFC R_{max}	HFC $R_{95\%}$	PPW R_{max}	PPW $R_{95\%}$
200	0.04	0.04	0.03	0.03	-	-	-	-	-	-
190	0.23	0.23	0.23	0.22	0.02	0.02	-	-	0.06	0.06
180	1.30	1.23	1.29	1.22	0.14	0.14	0.08	0.08	0.43	0.42
170	3.65	3.44	3.62	3.41	0.75	0.72	0.50	0.44	2.00	1.89
160	7.57	6.98	7.52	6.94	2.99	2.81	2.29	2.11	5.16	4.73
150	13.76	12.36	13.66	12.31	7.25	6.65	5.81	5.34	10.59	9.70
140	22.43	19.91	22.41	19.87	15.11	13.32	13.19	11.59	18.97	16.89
130	34.36	30.20	33.85	30.18	27.16	23.35	24.98	21.20	31.70	27.39
120	52.94	45.88	52.92	45.84	44.07	37.88	41.11	35.19	49.56	42.63

A dash (-) indicates that the threshold distance was not reached.

Table F-84. Distance (km) to the single strike sound pressure level (SPL) for an 11 m pile at location L02 using a Menck MHU4400 hammer operating at 2200 kJ.

Level (SPL)	Flat R_{max}	Flat $R_{95\%}$	LFC R_{max}	LFC $R_{95\%}$	MFC R_{max}	MFC $R_{95\%}$	HFC R_{max}	HFC $R_{95\%}$	PPW R_{max}	PPW $R_{95\%}$
200	0.04	0.04	0.04	0.04	-	-	-	-	-	-
190	0.24	0.24	0.23	0.23	0.03	0.03	-	-	0.09	0.09
180	1.40	1.27	1.36	1.23	0.21	0.20	0.12	0.12	0.53	0.52
170	3.63	3.46	3.61	3.44	1.15	1.08	0.69	0.66	2.35	2.21
160	7.83	7.12	7.81	7.07	3.58	3.38	2.90	2.68	5.45	5.10
150	14.60	13.10	14.58	13.06	8.32	7.62	6.72	6.19	11.82	10.75
140	24.26	21.57	24.25	21.54	16.90	14.85	14.67	12.96	21.34	18.76
130	37.50	32.72	37.46	32.70	29.31	25.55	27.17	23.22	33.79	29.88
120	57.44	50.20	57.23	50.15	47.45	40.96	44.10	37.94	53.93	46.55

A dash (-) indicates that the threshold distance was not reached.

Table F-85. Distance (km) to the single strike sound pressure level (SPL) for an 11 m pile at location L02 using a Menck MHU4400 hammer operating at 4400 kJ.

Level (SPL)	Flat R_{max}	Flat $R_{95\%}$	LFC R_{max}	LFC $R_{95\%}$	MFC R_{max}	MFC $R_{95\%}$	HFC R_{max}	HFC $R_{95\%}$	PPW R_{max}	PPW $R_{95\%}$
200	0.10	0.10	0.09	0.09	-	-	-	-	0.03	0.03
190	0.53	0.51	0.52	0.50	0.06	0.06	0.03	0.03	0.18	0.18
180	2.20	2.05	2.19	2.01	0.36	0.34	0.22	0.22	0.97	0.93
170	4.53	4.25	4.49	4.22	1.85	1.74	1.22	1.17	3.33	3.16
160	9.69	8.76	9.69	8.72	4.46	4.12	3.60	3.46	7.27	6.57
150	17.28	15.36	17.23	15.33	10.54	9.51	8.68	7.78	14.34	12.81
140	27.72	24.68	27.71	24.64	20.10	17.51	17.65	15.47	24.69	21.77
130	42.01	36.86	42.00	36.81	33.82	29.24	31.70	26.81	38.62	33.68
120	64.10	54.12	64.08	54.09	55.34	47.34	51.86	43.73	60.97	52.44

A dash (-) indicates that the threshold distance was not reached.

F.2.2.2. Maximum Scenarios

Table F-86. Distance (km) to the single strike sound pressure level (SPL) for a 4.5 m pile at location L02 using an IHC S2000 hammer operating at 2000 kJ (a, 20 m penetration depth, see Section 3.1.1).

Level (SPL)	Flat R_{max}	Flat $R_{95\%}$	LFC R_{max}	LFC $R_{95\%}$	MFC R_{max}	MFC $R_{95\%}$	HFC R_{max}	HFC $R_{95\%}$	PPW R_{max}	PPW $R_{95\%}$
200	0.05	0.05	0.05	0.05	-	-	-	-	0.03	0.03
190	0.31	0.30	0.30	0.30	0.13	0.12	0.10	0.10	0.18	0.18
180	1.58	1.44	1.58	1.43	0.78	0.67	0.65	0.62	1.19	1.12
170	4.66	4.20	4.65	4.18	2.94	2.79	2.89	2.65	3.79	3.51
160	11.29	9.83	11.28	9.81	8.47	7.35	7.17	6.58	9.97	8.96
150	22.18	18.78	22.18	18.76	17.67	15.42	16.13	14.19	20.51	17.48
140	37.10	31.83	37.10	31.81	32.92	27.76	30.93	25.98	35.53	30.42
130	61.20	52.32	61.19	52.30	55.05	46.70	51.88	43.66	60.04	51.03
120	70.68	54.44	70.68	54.44	70.68	54.43	70.68	54.45	70.68	54.45

A dash (-) indicates that the threshold distance was not reached.

Table F-87. Distance (km) to the single strike sound pressure level (SPL) for a 4.5 m pile at location L02 using an IHC S2000 hammer operating at 2000 kJ (b, 40 m penetration depth, see Section 3.1.1).

Level (SPL)	Flat R_{max}	Flat $R_{95\%}$	LFC R_{max}	LFC $R_{95\%}$	MFC R_{max}	MFC $R_{95\%}$	HFC R_{max}	HFC $R_{95\%}$	PPW R_{max}	PPW $R_{95\%}$
200	0.05	0.05	0.05	0.05	-	-	-	-	0.02	0.02
190	0.27	0.26	0.26	0.26	0.09	0.09	0.06	0.06	0.16	0.15
180	1.49	1.39	1.48	1.38	0.61	0.58	0.39	0.38	0.89	0.85
170	4.01	3.69	3.97	3.68	2.66	2.30	2.28	1.96	3.43	3.18
160	9.90	8.72	9.86	8.69	6.53	5.76	5.68	5.03	8.12	7.33
150	18.92	16.60	18.91	16.58	14.64	12.75	13.19	11.57	16.97	15.04
140	32.54	28.33	32.54	28.31	27.83	23.66	25.78	21.87	30.94	26.60
130	53.48	45.75	53.48	45.72	46.20	39.48	43.76	36.93	50.80	43.51
120	70.68	54.51	70.68	54.51	70.68	54.82	70.68	55.00	70.68	54.59

A dash (-) indicates that the threshold distance was not reached.

Table F-88. Distance (km) to the single strike sound pressure level (SPL) for a 4.5 m pile at location L02 using an IHC S2000 hammer operating at 2000 kJ (c, 60 m penetration depth, see Section 3.1.1).

Level (SPL)	Flat R_{max}	Flat $R_{95\%}$	LFC R_{max}	LFC $R_{95\%}$	MFC R_{max}	MFC $R_{95\%}$	HFC R_{max}	HFC $R_{95\%}$	PPW R_{max}	PPW $R_{95\%}$
200	-	-	-	-	-	-	-	-	-	-
190	0.05	0.05	0.04	0.04	-	-	-	-	0.02	0.02
180	0.24	0.24	0.24	0.23	0.09	0.09	0.06	0.06	0.14	0.14
170	1.22	1.18	1.21	1.16	0.62	0.58	0.56	0.40	0.83	0.79
160	3.22	3.10	3.21	3.10	2.65	2.29	2.29	2.13	2.99	2.80
150	6.54	5.99	6.54	5.98	4.39	3.98	4.00	3.59	5.84	5.10
140	14.59	12.75	14.59	12.73	11.31	9.94	10.53	9.01	13.33	11.59
130	26.65	23.31	26.64	23.29	22.96	19.33	20.92	17.80	25.72	21.90
120	44.10	38.26	44.10	38.24	38.98	33.25	37.07	31.14	42.90	36.48

A dash (-) indicates that the threshold distance was not reached.

Table F-89. Distance (km) to the single strike sound pressure level (SPL) for a 4.5 m pile at location L02 using an IHC S2000 hammer operating at 2000 kJ, with 2 dB shift for post-piling installation (OSP foundation) (a, 20 m penetration depth, see Section 3.1.1).

Level (SPL)	Flat R_{max}	Flat $R_{95\%}$	LFC R_{max}	LFC $R_{95\%}$	MFC R_{max}	MFC $R_{95\%}$	HFC R_{max}	HFC $R_{95\%}$	PPW R_{max}	PPW $R_{95\%}$
200	0.08	0.08	0.08	0.08	0.02	0.02	0.02	0.02	0.05	0.05
190	0.44	0.42	0.43	0.40	0.17	0.16	0.13	0.13	0.28	0.27
180	2.04	1.91	2.03	1.90	1.19	1.11	0.84	0.81	1.47	1.39
170	5.80	5.12	5.78	5.10	3.77	3.41	3.45	3.14	4.72	4.20
160	12.77	11.34	12.76	11.32	9.94	8.83	8.88	7.87	12.02	10.31
150	24.57	21.18	24.57	21.16	20.53	17.46	18.88	16.14	23.00	19.80
140	40.83	35.14	40.81	35.12	37.02	30.66	34.69	28.85	39.00	33.61
130	67.72	54.69	67.71	54.68	60.94	51.67	57.57	48.90	64.91	53.86
120	70.68	54.77	70.68	54.77	70.68	54.40	70.68	54.42	70.68	54.64

Table F-90. Distance (km) to the single strike sound pressure level (SPL) for a 4.5 m pile at location L02 using an IHC S2000 hammer operating at 2000 kJ, with 2 dB shift for post-piling installation (OSP foundation) (b, 40 m penetration depth, see Section 3.1.1).

Level (SPL)	Flat R_{max}	Flat $R_{95\%}$	LFC R_{max}	LFC $R_{95\%}$	MFC R_{max}	MFC $R_{95\%}$	HFC R_{max}	HFC $R_{95\%}$	PPW R_{max}	PPW $R_{95\%}$
200	0.06	0.06	0.06	0.06	0.00	0.00	0.00	0.00	0.03	0.03
190	0.40	0.38	0.39	0.38	0.13	0.13	0.10	0.10	0.23	0.22
180	1.97	1.80	1.95	1.78	0.79	0.74	0.65	0.61	1.23	1.18
170	4.84	4.50	4.83	4.47	3.08	2.83	2.89	2.64	3.71	3.57
160	11.30	10.05	11.29	10.01	7.62	6.89	6.69	6.04	9.94	8.72
150	21.39	18.64	21.39	18.62	16.83	14.57	15.36	13.25	19.33	16.96
140	35.58	30.97	35.57	30.95	31.56	26.33	29.20	24.47	33.84	29.31
130	58.74	50.75	58.73	50.72	51.88	43.83	48.42	40.97	56.41	48.37
120	70.68	54.48	70.68	54.48	70.68	54.49	70.68	54.63	70.68	54.46

Table F-91. Distance (km) to the single strike sound pressure level (SPL) for a 4.5 m pile at location L02 using an IHC S2000 hammer operating at 2000 kJ, with 2 dB shift for post-piling installation (OSP foundation) (c, 60 m penetration depth, see Section 3.1.1).

Level (SPL)	Flat R_{max}	Flat $R_{95\%}$	LFC R_{max}	LFC $R_{95\%}$	MFC R_{max}	MFC $R_{95\%}$	HFC R_{max}	HFC $R_{95\%}$	PPW R_{max}	PPW $R_{95\%}$
200	-	-	-	-	-	-	-	-	-	-
190	0.06	0.06	0.06	0.06	-	-	-	-	0.03	0.03
180	0.33	0.32	0.32	0.31	0.13	0.13	0.10	0.10	0.20	0.20
170	1.62	1.51	1.61	1.49	0.80	0.75	0.65	0.63	1.20	1.14
160	3.50	3.36	3.49	3.35	2.92	2.77	2.87	2.61	3.23	3.09
150	7.84	7.09	7.82	7.07	5.69	4.97	4.80	4.22	6.90	6.11
140	16.54	14.53	16.53	14.51	13.18	11.46	12.02	10.45	15.33	13.31
130	30.06	25.91	30.06	25.90	25.76	21.82	24.19	20.14	28.32	24.45
120	49.42	42.29	49.39	42.26	43.05	36.83	40.35	34.52	47.11	40.41

A dash (-) indicates that the threshold distance was not reached.

Table F-92. Distance (km) to the single strike sound pressure level (SPL) for a 4.5 m pile at location L02 using a Menck MHU3500S hammer operating at 3500 kJ (a, 20 m penetration depth, see Section 3.1.1).

Level (SPL)	Flat R_{max}	Flat $R_{95\%}$	LFC R_{max}	LFC $R_{95\%}$	MFC R_{max}	MFC $R_{95\%}$	HFC R_{max}	HFC $R_{95\%}$	PPW R_{max}	PPW $R_{95\%}$
200	0.03	0.03	0.03	0.03	-	-	-	-	-	-
190	0.22	0.21	0.22	0.21	0.06	0.06	0.05	0.05	0.12	0.12
180	1.21	1.17	1.20	1.16	0.40	0.38	0.32	0.30	0.67	0.65
170	3.59	3.43	3.58	3.41	2.26	1.93	1.79	1.68	2.90	2.69
160	8.11	7.37	8.10	7.35	5.40	4.83	4.70	4.13	6.90	6.14
150	16.54	14.59	16.53	14.57	13.11	11.29	11.98	10.26	15.11	13.20
140	29.30	25.67	29.30	25.64	25.73	21.48	23.70	19.82	27.91	24.15
130	48.53	41.73	48.52	41.70	42.88	36.32	39.92	34.07	46.79	39.87
120	70.68	54.76	70.68	54.76	70.32	55.08	67.97	54.47	70.68	54.86

A dash (-) indicates that the threshold distance was not reached.

Table F-93. Distance (km) to the single strike sound pressure level (SPL) for a 4.5 m pile at location L02 using a Menck MHU3500S hammer operating at 3500 kJ (b, 40 m penetration depth, see Section 3.1.1).

Level (SPL)	Flat R_{max}	Flat $R_{95\%}$	LFC R_{max}	LFC $R_{95\%}$	MFC R_{max}	MFC $R_{95\%}$	HFC R_{max}	HFC $R_{95\%}$	PPW R_{max}	PPW $R_{95\%}$
200	0.03	0.03	0.03	0.03	-	-	-	-	-	-
190	0.22	0.21	0.21	0.21	0.05	0.05	0.03	0.03	0.11	0.11
180	1.19	1.15	1.18	1.13	0.31	0.30	0.23	0.22	0.64	0.61
170	3.47	3.31	3.46	3.30	1.75	1.64	1.41	1.29	2.66	2.49
160	7.29	6.66	7.28	6.63	4.06	3.68	3.60	3.45	5.82	5.18
150	14.72	13.18	14.71	13.16	10.59	9.25	9.03	8.19	13.05	11.45
140	26.07	22.97	26.06	22.95	21.31	18.02	19.10	16.45	24.51	21.06
130	42.05	36.59	42.04	36.56	37.04	31.04	34.15	29.03	39.91	34.51
120	68.92	55.06	68.86	55.05	60.94	51.80	57.56	48.91	65.40	54.13

A dash (-) indicates that the threshold distance was not reached.

Table F-94. Distance (km) to the single strike sound pressure level (SPL) for a 4.5 m pile at location L02 using a Menck MHU3500S hammer operating at 3500 kJ (c, 60 m penetration depth, see Section 3.1.1).

Level (SPL)	Flat R_{max}	Flat $R_{95\%}$	LFC R_{max}	LFC $R_{95\%}$	MFC R_{max}	MFC $R_{95\%}$	HFC R_{max}	HFC $R_{95\%}$	PPW R_{max}	PPW $R_{95\%}$
200	-	-	-	-	-	-	-	-	-	-
190	0.05	0.05	0.05	0.05	-	-	-	-	-	-
180	0.22	0.21	0.20	0.20	0.05	0.05	0.03	0.03	0.09	0.09
170	1.04	0.99	0.97	0.94	0.30	0.29	0.22	0.21	0.55	0.52
160	2.90	2.78	2.89	2.77	1.66	1.41	1.40	1.22	2.33	2.17
150	5.12	4.59	4.95	4.57	3.44	3.27	3.26	3.07	3.79	3.59
140	11.32	10.19	11.31	10.15	7.88	7.14	7.12	6.25	9.97	8.96
130	22.16	18.86	22.15	18.84	17.31	15.00	16.04	13.68	20.06	17.32
120	37.04	31.51	37.03	31.48	32.10	27.01	30.06	25.13	34.71	29.92

A dash (-) indicates that the threshold distance was not reached.

Table F-95. Distance (km) to the single strike sound pressure level (SPL) for a 4.5 m pile at location L02 using a Menck MHU3500S hammer operating at 3500 kJ, with 2 dB shift for post-piling installation (OSP foundation) (a, 20 m penetration depth, see Section 3.1.1).

Level (SPL)	Flat R_{max}	Flat $R_{95\%}$	LFC R_{max}	LFC $R_{95\%}$	MFC R_{max}	MFC $R_{95\%}$	HFC R_{max}	HFC $R_{95\%}$	PPW R_{max}	PPW $R_{95\%}$
200	0.05	0.05	0.05	0.05	-	-	-	-	0.02	0.02
190	0.34	0.33	0.33	0.32	0.10	0.10	0.07	0.07	0.16	0.16
180	1.59	1.51	1.58	1.49	0.64	0.61	0.57	0.54	0.92	0.88
170	4.02	3.72	4.00	3.71	2.88	2.58	2.32	2.19	3.44	3.20
160	9.81	8.61	9.81	8.59	6.55	5.85	5.84	5.16	8.11	7.30
150	18.89	16.42	18.88	16.39	14.86	12.96	13.89	11.82	17.30	15.03
140	32.70	28.36	32.70	28.34	27.98	24.07	27.02	22.33	31.58	26.82
130	54.18	46.36	54.15	46.33	47.37	40.29	44.09	37.76	51.90	44.21
120	70.68	54.48	70.68	54.48	70.68	54.74	70.68	54.92	70.68	54.53

A dash (-) indicates that the threshold distance was not reached.

Table F-96. Distance (km) to the single strike sound pressure level (SPL) for a 4.5 m pile at location L02 using a Menck MHU3500S hammer operating at 3500 kJ, with 2 dB shift for post-piling installation (OSP foundation) (b, 40 m penetration depth, see Section 3.1.1).

Level (SPL)	Flat R_{max}	Flat $R_{95\%}$	LFC R_{max}	LFC $R_{95\%}$	MFC R_{max}	MFC $R_{95\%}$	HFC R_{max}	HFC $R_{95\%}$	PPW R_{max}	PPW $R_{95\%}$
200	0.06	0.06	0.05	0.05	-	-	-	-	0.02	0.02
190	0.30	0.30	0.30	0.29	0.07	0.07	0.05	0.05	0.15	0.15
180	1.58	1.51	1.56	1.49	0.52	0.43	0.32	0.31	0.86	0.82
170	3.69	3.54	3.68	3.53	2.31	2.14	1.80	1.69	3.20	3.04
160	8.57	7.77	8.55	7.74	5.11	4.56	4.14	3.83	6.90	6.20
150	16.59	14.79	16.58	14.77	12.38	10.74	10.94	9.59	14.65	13.05
140	29.16	25.36	29.16	25.34	24.10	20.38	22.15	18.59	26.68	23.43
130	46.81	40.31	46.80	40.28	39.94	34.33	38.00	32.04	44.08	38.11
120	70.68	54.95	70.68	54.96	67.61	54.40	64.83	53.00	70.68	55.09

A dash (-) indicates that the threshold distance was not reached.

Table F-97. Distance (km) to the single strike sound pressure level (SPL) for a 4.5 m pile at location L02 using a Menck MHU3500S hammer operating at 3500 kJ, with 2 dB shift for post-piling installation (OSP foundation) (c, 60 m penetration depth, see Section 3.1.1).

Level (SPL)	Flat R_{max}	Flat $R_{95\%}$	LFC R_{max}	LFC $R_{95\%}$	MFC R_{max}	MFC $R_{95\%}$	HFC R_{max}	HFC $R_{95\%}$	PPW R_{max}	PPW $R_{95\%}$
200	-	-	-	-	-	-	-	-	-	-
190	0.07	0.07	0.06	0.06	-	-	-	-	-	-
180	0.29	0.28	0.27	0.27	0.07	0.06	0.05	0.05	0.12	0.12
170	1.38	1.32	1.33	1.25	0.40	0.38	0.32	0.31	0.68	0.66
160	3.14	3.00	3.12	2.99	2.22	1.93	1.78	1.68	2.84	2.61
150	5.95	5.48	5.94	5.48	3.64	3.48	3.47	3.33	4.77	4.29
140	13.14	11.54	13.14	11.53	9.88	8.50	8.47	7.51	11.39	10.29
130	24.54	21.19	24.54	21.17	19.70	16.99	18.08	15.59	22.96	19.57
120	39.92	34.65	39.92	34.63	35.07	29.87	32.94	27.94	38.14	32.96

A dash (-) indicates that the threshold distance was not reached.

Table F-98. Distance (km) to the single strike sound pressure level (SPL) for a 16 m pile at location L02 using a theoretical 6600 hammer operating at 6600 kJ (a, 10 m penetration depth, see Section 3.1.1).

Level (SPL)	Flat R_{max}	Flat $R_{95\%}$	LFC R_{max}	LFC $R_{95\%}$	MFC R_{max}	MFC $R_{95\%}$	HFC R_{max}	HFC $R_{95\%}$	PPW R_{max}	PPW $R_{95\%}$
200	0.18	0.17	0.17	0.16	-	-	-	-	0.03	0.03
190	0.88	0.86	0.84	0.81	0.06	0.06	0.03	0.03	0.21	0.20
180	2.65	2.51	2.60	2.46	0.41	0.39	0.23	0.23	1.15	1.06
170	4.80	4.45	4.76	4.38	2.03	1.86	1.37	1.22	3.42	3.27
160	9.67	8.71	9.47	8.67	4.43	4.01	3.59	3.44	7.15	6.48
150	16.99	15.24	16.97	15.21	10.12	9.19	8.21	7.55	14.11	12.67
140	27.47	24.42	27.45	24.39	19.31	17.04	16.88	14.84	24.23	21.45
130	41.33	36.34	41.11	36.31	32.54	28.34	30.09	25.67	37.60	33.00
120	62.29	53.51	62.26	53.48	52.46	44.98	48.46	41.37	58.74	51.30

A dash (-) indicates that the threshold distance was not reached.

Table F-99. Distance (km) to the single strike sound pressure level (SPL) for a 16 m pile at location L02using a theoretical 6600 hammer operating at 6600 kJ (b, 20 m penetration depth, see Section 3.1.1).

Level (SPL)	Flat R_{max}	Flat $R_{95\%}$	LFC R_{max}	LFC $R_{95\%}$	MFC R_{max}	MFC $R_{95\%}$	HFC R_{max}	HFC $R_{95\%}$	PPW R_{max}	PPW $R_{95\%}$
200	0.19	0.19	0.19	0.18	-	-	-	-	0.05	0.05
190	1.06	1.00	1.04	0.99	0.09	0.09	0.05	0.05	0.29	0.28
180	3.10	2.95	3.09	2.93	0.53	0.51	0.28	0.27	1.57	1.51
170	5.66	5.21	5.56	5.17	2.37	2.22	1.56	1.47	3.65	3.51
160	10.73	9.84	10.66	9.81	4.84	4.49	3.67	3.54	7.90	7.25
150	18.12	16.25	18.09	16.22	10.66	9.72	8.67	7.93	15.02	13.39
140	28.45	25.29	28.44	25.24	20.08	17.58	17.53	15.34	24.96	22.12
130	42.29	37.23	42.25	37.19	33.04	29.00	30.89	26.24	38.65	33.80
120	63.65	54.08	63.65	54.05	53.50	46.00	49.70	42.12	60.14	52.17

A dash (-) indicates that the threshold distance was not reached.

Table F-100. Distance (km) to the single strike sound pressure level (SPL) for a 16 m pile at location L02 using a theoretical 6600 hammer operating at 6600 kJ (c, 35 m penetration depth, see Section 3.1.1).

Level (SPL)	Flat R_{max}	Flat $R_{95\%}$	LFC R_{max}	LFC $R_{95\%}$	MFC R_{max}	MFC $R_{95\%}$	HFC R_{max}	HFC $R_{95\%}$	PPW R_{max}	PPW $R_{95\%}$
200	0.23	0.23	0.23	0.22	-	-	-	-	0.08	0.08
190	1.27	1.19	1.21	1.16	0.12	0.12	0.06	0.06	0.36	0.35
180	3.33	3.16	3.31	3.14	0.66	0.64	0.37	0.35	1.83	1.73
170	6.05	5.58	6.02	5.55	2.68	2.53	1.92	1.75	3.72	3.58
160	11.32	10.30	11.30	10.27	5.34	4.93	3.98	3.70	8.37	7.69
150	18.94	16.94	18.92	16.91	11.81	10.60	9.88	8.86	15.80	14.16
140	29.87	26.44	29.54	26.41	22.14	19.11	19.09	16.75	26.63	23.54
130	45.09	39.51	45.07	39.47	35.63	31.08	32.97	28.49	41.10	36.12
120	69.70	55.23	69.63	55.23	58.17	50.31	54.10	46.20	64.08	54.09

A dash (-) indicates that the threshold distance was not reached.

F.3. Ranges to PK Thresholds

The following tables present max single-strike PK isopleth ranges (R_{max}). PK metrics are implicitly unweighted. All calculations use an average summer sound speed profile.

F.3.1. Location L01

F.3.1.1. Realistic Scenarios

Table F-101. Distance (km) to the single strike peak pressure level (PK) for a 2.9 m pin pile at location L01 using a Menck MHU1900S hammer.

Level (L_{pk})	Flat R_{max}			
	Hammer energy (kJ)			
	475	950	1900[a]	1900[b]
230	0.00	0.00	0.00	0.00
219	0.00	0.01	0.06	0.01
218	0.01	0.01	0.07	0.01
216	0.01	0.02	0.09	0.02
213	0.02	0.11	0.10	0.03
210	0.11	0.13	0.14	0.04
207	0.13	0.17	0.26	0.07
206	0.14	0.28	0.29	0.08
202	0.30	0.47	0.49	0.11
200	0.45	0.50	0.60	0.15
190	1.20	1.46	1.88	0.76

[a] 20 m penetration depth
[b] 51 m penetration depth

Table F-102. Distance (km) to the single strike peak pressure level (PK) for a 2.9 m pin pile at location L01 using a Menck MHU1900S hammer, with 2 dB shift for post-piling installation (OSP foundation).

Level (L_{pk})	Flat R_{max}			
	Hammer energy (kJ)			
	475	950	1900[a]	1900[b]
230	0.00	0.00	0.00	0.00
219	0.01	0.01	0.08	0.02
218	0.01	0.02	0.09	0.02
216	0.01	0.10	0.10	0.03
213	0.10	0.12	0.13	0.04
210	0.13	0.14	0.20	0.06
207	0.14	0.31	0.42	0.09
206	0.16	0.43	0.46	0.09
202	0.45	0.50	0.60	0.15
200	0.48	0.66	0.80	0.19
190	1.38	1.96	2.00	0.82

[a] 20 m penetration depth
[b] 51 m penetration depth

Table F-103. Distance (km) to the single strike peak pressure level (PK) for an 11 m pile at location L01 using a Menck MHU4400 hammer.

Level (L_{pk})	Flat R_{max}		
	Hammer energy (kJ)		
	1100	2200	4400
230	0.00	0.00	0.01
219	0.02	0.06	0.10
218	0.02	0.07	0.11
216	0.06	0.09	0.14
213	0.09	0.13	0.26
210	0.12	0.16	0.42
207	0.25	0.31	0.58
206	0.28	0.41	0.62
202	0.49	0.62	0.86
200	0.64	0.70	1.26
190	1.74	1.82	3.00

F.3.1.2. Maximum Scenarios

Table F-104. Distance (km) to the single strike peak pressure level (PK) for a 4.5 m pin pile at location L01 using an IHC S2000 hammer.

Level (L_{pk})	Flat R_{max}		
	Hammer energy (kJ)		
	2000[a]	2000[b]	2000[c]
230	0.00	0.00	0.00
219	0.09	0.05	0.02
218	0.10	0.06	0.02
216	0.11	0.07	0.03
213	0.13	0.09	0.04
210	0.17	0.12	0.06
207	0.40	0.23	0.09
206	0.44	0.27	0.10
202	0.64	0.43	0.14
200	0.86	0.50	0.17
190	2.14	1.82	3.00

[a] 20 m penetration depth
[b] 40 m penetration depth
[c] 60 m penetration depth

Table F-105. Distance (km) to the single strike peak pressure level (PK) for a 4.5 m pin pile at location L01 using an IHC S2000 hammer, with 2 dB shift for post-piling installation (OSP foundation).

Level (L_{pk})	Flat R_{max}		
	Hammer energy (kJ)		
	2000[a]	2000[b]	2000[c]
230	0.00	0.00	0.00
219	0.10	0.07	0.02
218	0.11	0.07	0.03
216	0.13	0.09	0.04
213	0.15	0.11	0.06
210	0.32	0.17	0.08
207	0.48	0.33	0.10
206	0.50	0.37	0.11
202	0.86	0.50	0.17
200	1.04	0.72	0.27
190	3.00	2.20	3.00

[a] 20 m penetration depth
[b] 40 m penetration depth
[c] 60 m penetration depth

Table F-106. Distance (km) to the single strike peak pressure level (PK) for a 4.5 m pin pile at location L01 using a Menck MHU3500S hammer.

Level (L_{pk})	Flat R_{max}		
	Hammer energy (kJ)		
	3500[a]	3500[b]	3500[c]
230	0.00	0.00	0.00
219	0.02	0.03	0.01
218	0.02	0.04	0.01
216	0.09	0.05	0.03
213	0.12	0.07	0.04
210	0.14	0.10	0.06
207	0.23	0.15	0.09
206	0.30	0.16	0.10
202	0.52	0.40	0.18
200	0.64	0.47	0.34
190	1.66	3.00	3.00

[a] 20 m penetration depth
[b] 40 m penetration depth
[c] 60 m penetration depth

Table F-107. Distance (km) to the single strike peak pressure level (PK) for a 4.5 m pin pile at location L01 using a Menck MHU3500S hammer, with 2 dB shift for post-piling installation (OSP foundation).

Level (L_{pk})	Flat R_{max}		
	Hammer energy (kJ)		
	3500[a]	3500[b]	3500[c]
230	0.00	0.00	0.00
219	0.07	0.04	0.01
218	0.09	0.05	0.03
216	0.11	0.07	0.04
213	0.13	0.09	0.05
210	0.17	0.12	0.08
207	0.43	0.20	0.10
206	0.47	0.21	0.12
202	0.64	0.47	0.34
200	0.76	0.56	0.42
190	3.00	3.00	3.00

[a] 20 m penetration depth
[b] 40 m penetration depth
[c] 60 m penetration depth

Table F-108. Distance (km) to the single strike peak pressure level (PK) for a 16 m pile at location L01 using a theoretical 6600 kJ hammer.

Level (L_{pk})	Flat R_{max}		
	Hammer energy (kJ)		
	6600[a]	6600[b]	6600[c]
230	0.01	0.01	0.01
219	0.10	0.11	0.12
218	0.12	0.12	0.13
216	0.14	0.15	0.15
213	0.18	0.19	0.25
210	0.32	0.34	0.45
207	0.60	0.52	0.56
206	0.62	0.56	0.62
202	1.00	1.04	0.94
200	1.30	1.28	1.34
190	3.00	3.00	3.00

[a] 10 m penetration depth
[b] 20 m penetration depth
[c] 35 m penetration depth

F.3.2. Location L02

F.3.2.1. Realistic Scenarios

Table F-109. Distance (km) to the single strike peak pressure level (PK) for a 2.9 m pin pile at location L02 using a Menck MHU1900S hammer.

Level (L_{pk})	Flat R_{max}			
	Hammer energy (kJ)			
	475	950	1900[a]	1900[b]
230	0.00	0.00	0.00	0.00
219	0.01	0.01	0.06	0.01
218	0.01	0.02	0.07	0.02
216	0.01	0.07	0.08	0.02
213	0.07	0.09	0.10	0.03
210	0.09	0.10	0.19	0.05
207	0.10	0.20	0.32	0.07
206	0.11	0.21	0.34	0.08
202	0.23	0.34	0.49	0.13
200	0.31	0.52	0.66	0.16
190	0.96	1.26	1.68	0.60

[a] 20 m penetration depth
[b] 51 m penetration depth

Table F-110. Distance (km) to the single strike peak pressure level (PK) for a 2.9 m pin pile at location L02 using a Menck MHU1900S hammer, with 2 dB shift for post-piling installation (OSP foundation).

Level (L_{pk})	Flat R_{max}			
	Hammer energy (kJ)			
	475	950	1900[a]	1900[b]
230	0.00	0.00	0.00	0.00
219	0.01	0.06	0.08	0.02
218	0.01	0.07	0.08	0.02
216	0.05	0.08	0.09	0.03
213	0.08	0.10	0.13	0.04
210	0.10	0.18	0.31	0.07
207	0.18	0.28	0.35	0.09
206	0.20	0.30	0.36	0.10
202	0.31	0.52	0.66	0.16
200	0.42	0.60	0.86	0.25
190	1.16	1.48	1.98	0.64

[a] 20 m penetration depth
[b] 51 m penetration depth

Table F-111. Distance (km) to the single strike peak pressure level (PK) for an 11 m pile at location L02 using a Menck MHU4400 hammer.

Level (L_{pk})	Flat R_{max}		
	Hammer energy (kJ)		
	1100	2200	4400
230	0.00	0.00	0.01
219	0.02	0.05	0.07
218	0.03	0.06	0.07
216	0.05	0.07	0.10
213	0.07	0.09	0.16
210	0.09	0.14	0.32
207	0.18	0.28	0.43
206	0.20	0.32	0.48
202	0.36	0.47	0.74
200	0.49	0.58	0.90
190	1.44	1.62	2.22

F.3.2.2. Maximum Scenarios

Table F-112. Distance (km) to the single strike peak pressure level (PK) for a 4.5 m pin pile at location L02 using an IHC S2000 hammer.

Level (L_{pk})	Flat R_{max}		
	Hammer energy (kJ)		
	2000[a]	2000[b]	2000[c]
230	0.00	0.00	0.00
219	0.08	0.05	0.02
218	0.09	0.06	0.02
216	0.10	0.07	0.03
213	0.18	0.09	0.04
210	0.26	0.14	0.06
207	0.33	0.27	0.10
206	0.38	0.30	0.11
202	0.66	0.41	0.14
200	0.74	0.68	0.21
190	1.82	1.52	0.52

[a] 20 m penetration depth
[b] 40 m penetration depth
[c] 60 m penetration depth

Table F-113. Distance (km) to the single strike peak pressure level (PK) for a 4.5 m pin pile at location L02 using an IHC S2000 hammer, with 2 dB shift for post-piling installation (OSP foundation).

Level (L_{pk})	Flat R_{max}		
	Hammer energy (kJ)		
	2000[a]	2000[b]	2000[c]
230	0.01	0.00	0.00
219	0.09	0.07	0.02
218	0.10	0.07	0.03
216	0.11	0.09	0.04
213	0.21	0.11	0.06
210	0.31	0.23	0.09
207	0.44	0.32	0.12
206	0.54	0.35	0.13
202	0.74	0.68	0.21
200	0.92	0.72	0.26
190	2.30	1.96	0.62

[a] 20 m penetration depth
[b] 40 m penetration depth
[c] 60 m penetration depth

Table F-114. Distance (km) to the single strike peak pressure level (PK) for a 4.5 m pin pile at location L02 using a Menck MHU3500S hammer.

Level (L_{pk})	Flat R_{max}		
	Hammer energy (kJ)		
	3500[a]	3500[b]	3500[c]
230	0.00	0.00	0.00
219	0.06	0.03	0.01
218	0.07	0.04	0.01
216	0.08	0.05	0.02
213	0.10	0.07	0.03
210	0.13	0.11	0.05
207	0.31	0.16	0.08
206	0.33	0.25	0.09
202	0.47	0.38	0.13
200	0.62	0.44	0.15
190	1.64	1.46	0.50

[a] 20 m penetration depth
[b] 40 m penetration depth
[c] 60 m penetration depth

Table F-115. Distance (km) to the single strike peak pressure level (PK) for a 4.5 m pin pile at location L01 using a Menck MHU3500S hammer, with 2 dB shift for post-piling installation (OSP foundation).

Level (L_{pk})	Flat R_{max}		
	Hammer energy (kJ)		
	3500[a]	3500[b]	3500[c]
230	0.01	0.00	0.00
219	0.09	0.07	0.02
218	0.10	0.07	0.03
216	0.11	0.09	0.04
213	0.21	0.11	0.06
210	0.31	0.23	0.09
207	0.44	0.32	0.12
206	0.54	0.35	0.13
202	0.74	0.68	0.21
200	0.92	0.72	0.26
190	2.30	1.96	0.62

[a] 20 m penetration depth
[b] 40 m penetration depth
[c] 60 m penetration depth

Table F-116. Distance (km) to the single strike peak pressure level (PK) for a 16 m pile at location L02 using a theoretical 6600 kJ hammer.

Level (L_{pk})	Flat R_{max}		
	Hammer energy (kJ)		
	6600[a]	6600[b]	6600[c]
230	0.01	0.01	0.01
219	0.07	0.08	0.08
218	0.08	0.09	0.09
216	0.09	0.11	0.11
213	0.18	0.16	0.15
210	0.24	0.31	0.34
207	0.42	0.39	0.43
206	0.44	0.42	0.50
202	0.66	0.80	0.86
200	0.94	1.02	1.14
190	2.10	2.44	2.64

[a] 10 m penetration depth
[b] 20 m penetration depth
[c] 35 m penetration depth

F.4. Ranges to Per-Pile SEL Thresholds

F.4.1.1. Realistic Scenarios

Table F-117. Ranges ($R_{95\%}$; km) to cumulative SEL injury thresholds for three 2.9 m pin piles using a Menck MHU1900S hammer with attenuation at two modeling locations (L01 and L02).

Hearing group	Threshold (dB)	L01				L02			
		Attenuation level (dB)				Attenuation level (dB)			
		0	6	10	15	0	6	10	15
Low-frequency cetaceans	183	18.12	11.17	7.80	4.66	11.48	7.20	4.99	2.81
Mid-frequency cetaceans	185	1.07	0.28	0.12	0.05	0.76	0.22	0.09	0.03
High-frequency cetaceans	155	12.74	8.78	6.63	4.46	9.32	6.35	4.70	3.09
Phocid pinnipeds	185	6.79	3.71	2.27	0.81	4.15	2.22	1.20	0.60
Sea turtles	204	2.66	1.08	0.50	0.18	1.64	0.64	0.34	0.13

Table F-118. Ranges ($R_{95\%}$; km) to cumulative SEL injury thresholds for three 2.9 m pin piles using a Menck MHU1900S hammer with attenuation at two modeling locations (L01 and L02), with 2 dB shift for post-piling installation (OSP foundation).

Hearing group	Threshold (dB)	L01				L02			
		Attenuation level (dB)				Attenuation level (dB)			
		0	6	10	15	0	6	10	15
Low-frequency cetaceans	183	21.22	13.35	9.33	5.80	13.17	8.55	5.99	3.57
Mid-frequency cetaceans	185	1.54	0.46	0.18	0.10	1.13	0.53	0.13	0.06
High-frequency cetaceans	155	14.35	9.96	7.55	5.21	10.42	7.28	5.50	3.63
Phocid pinnipeds	185	8.19	4.56	2.46	1.53	5.10	2.78	1.69	0.76
Sea turtles	204	3.54	1.54	0.80	0.32	2.08	0.88	0.47	0.19

Table F-119. Ranges ($R_{95\%}$; km) to cumulative SEL injury thresholds for one 11 m monopile using a Menck MHU4400 hammer with attenuation at two modeling locations (L01 and L02).

Hearing group	Threshold (dB)	L01				L02			
		Attenuation level (dB)				Attenuation level (dB)			
		0	6	10	15	0	6	10	15
Low-frequency cetaceans	183	15.49	9.81	6.98	4.21	9.33	5.98	4.22	2.55
Mid-frequency cetaceans	185	0.16	0.05	0.03	0.02	0.13	0.06	0.03	0.00
High-frequency cetaceans	155	7.39	4.53	3.05	1.56	5.36	3.33	2.21	1.18
Phocid pinnipeds	185	3.16	1.53	0.56	0.24	2.20	0.81	0.40	0.16
Sea turtles	204	4.03	1.72	0.91	0.38	2.47	1.15	0.62	0.26

F.4.1.2. Maximum Scenarios

Table F-120. Ranges ($R_{95\%}$; km) to cumulative SEL injury thresholds for four 4.5 m pin piles using an IHC S2000 hammer with attenuation at two modeling locations (L01 and L02).

Hearing group	Threshold (dB)	L01				L02			
		Attenuation level (dB)				Attenuation level (dB)			
		0	6	10	15	0	6	10	15
Low-frequency cetaceans	183	27.81	17.25	12.70	8.13	17.01	11.48	8.57	5.54
Mid-frequency cetaceans	185	2.30	0.81	0.38	0.11	1.67	0.62	0.27	0.10
High-frequency cetaceans	155	16.80	11.88	9.23	6.53	12.36	8.98	6.99	4.82
Phocid pinnipeds	185	10.43	6.10	3.90	2.26	6.96	4.01	2.75	1.37
Sea turtles	204	5.60	2.68	1.56	0.70	3.88	1.96	1.09	0.50

Table F-121. Ranges ($R_{95\%}$; km) to cumulative SEL injury thresholds for four 4.5 m pin piles using an IHC S2000 hammer with attenuation at two modeling locations (L01 and L02) with 2 dB shift for post-piling installation (OSP foundation).

Hearing group	Threshold (dB)	L01				L02			
		Attenuation level (dB)				Attenuation level (dB)			
		0	6	10	15	0	6	10	15
Low-frequency cetaceans	183	32.26	20.19	14.87	9.72	19.27	13.17	9.99	6.60
Mid-frequency cetaceans	185	3.03	1.52	0.53	0.17	2.19	1.11	0.59	0.14
High-frequency cetaceans	155	18.69	13.40	10.52	7.49	13.60	10.03	8.00	5.62
Phocid pinnipeds	185	12.20	7.42	4.83	2.43	8.23	4.81	3.30	1.73
Sea turtles	204	7.06	3.60	2.07	0.87	4.78	2.51	1.44	0.68

Table F-122. Ranges ($R_{95\%}$; km) to cumulative SEL injury thresholds for four 4.5 m pin piles using a Menck MHU3500S hammer with attenuation at two modeling locations (L01 and L02).

Hearing group	Threshold (dB)	L01				L02			
		Attenuation level (dB)				Attenuation level (dB)			
		0	6	10	15	0	6	10	15
Low-frequency cetaceans	183	22.18	14.08	10.02	6.34	13.84	9.12	6.53	4.05
Mid-frequency cetaceans	185	1.53	0.44	0.16	0.10	1.12	0.52	0.13	0.06
High-frequency cetaceans	155	14.01	9.74	7.42	5.08	10.23	7.13	5.37	3.58
Phocid pinnipeds	185	8.02	4.52	2.42	1.52	5.07	2.77	1.68	0.76
Sea turtles	204	4.75	2.12	1.14	0.46	3.06	1.46	0.82	0.34

Table F-123. Ranges (R95% in km) to cumulative SEL injury thresholds for four 4.5 m pin piles using a Menck MHUS3500 hammer with attenuation at two modeling locations (L01 and L02) with 2 dB shift for post-piling installation (OSP foundation).

Hearing group	Threshold (dB)	L01				L02			
		Attenuation level (dB)				Attenuation level (dB)			
		0	6	10	15	0	6	10	15
Low-frequency cetaceans	183	25.85	16.34	11.98	7.71	15.73	10.56	7.76	5.02
Mid-frequency cetaceans	185	1.64	0.56	0.26	0.10	1.62	0.59	0.21	0.09
High-frequency cetaceans	155	15.72	11.06	8.51	5.96	11.36	8.15	6.19	4.20
Phocid pinnipeds	185	9.51	5.39	3.21	1.60	6.12	3.40	2.21	1.15
Sea turtles	204	5.74	2.78	1.57	0.72	3.79	1.95	1.10	0.50

Table F-124. Ranges ($R_{95\%}$; km) to cumulative SEL injury thresholds for one 16 m monopile using a 6600 kJ hammer with attenuation at two modeling locations (L01 and L02).

Hearing group	Threshold (dB)	L01				L02			
		Attenuation level (dB)				Attenuation level (dB)			
		0	6	10	15	0	6	10	15
Low-frequency cetaceans	183	21.37	14.15	10.49	6.86	11.71	8.02	5.97	3.96
Mid-frequency cetaceans	185	0.44	0.11	0.05	0.03	0.21	0.08	0.03	0.00
High-frequency cetaceans	155	9.70	6.29	4.52	2.87	6.21	3.90	2.78	1.65
Phocid pinnipeds	185	5.20	2.45	1.56	0.55	2.86	1.52	0.76	0.30
Sea turtles	204	6.52	3.52	2.13	0.93	3.91	2.19	1.37	0.63

F.5. Ranges to Thresholds for Fish

F.5.1.1. Realistic Scenarios

Table F-125. Jacket foundation piles acoustic radial distances ($R_{95\%}$; km) to thresholds for fish — 2.9 m pin piles using a Menck MHU1900S hammer with 0 dB attenuation.

Faunal group	Metric	Threshold	Hammer energy (kJ)							
			L01				L02			
			475	950	1900a	1900b	475	950	1900a	1900b
Small fish	L_E	183	22.14				13.37			
	L_{pk}	206	0.14	0.28	0.29	0.08	0.11	0.21	0.34	0.08
Large fish	L_E	186	17.59				10.95			
	L_{pk}	206	0.14	0.28	0.29	0.08	0.11	0.21	0.34	0.08
All fish	L_p	150	5.22	7.01	9.20	2.86	4.09	5.37	7.95	2.79

L_{pk}= unweighted peak sound pressure (dB re 1 µPa); L_E = unweighted sound exposure level (dB re 1 µPa^2·s); L_p= unweighted sound pressure (dB re 1 µPa). Small fish are defined as having a total mass of less than 2 g.

Table F-126. Jacket foundation piles acoustic radial distances ($R_{95\%}$; km) to thresholds for fish — 2.9 m pin piles using a Menck MHU1900S hammer with 6 dB attenuation.

Faunal group	Metric	Threshold	Hammer energy (kJ)							
			L01				L02			
			475	950	1900a	1900b	475	950	1900a	1900b
Small fish	L_E	183	14.04				8.93			
	L_{pk}	206	0.03	0.11	0.12	0.03	0.07	0.09	0.11	0.04
Large fish	L_E	186	10.84				6.91			
	L_{pk}	206	0.03	0.11	0.12	0.03	0.07	0.09	0.11	0.04
All fish	L_p	150	8.03	10.01	13.10	3.32	6.06	7.69	10.71	3.57

L_{pk}= unweighted peak sound pressure (dB re 1 µPa); L_E = unweighted sound exposure level (dB re 1 µPa^2·s); L_p= unweighted sound pressure (dB re 1 µPa). Small fish are defined as having a total mass of less than 2 g.

Table F-127. Jacket foundation piles acoustic radial distances ($R_{95\%}$; km) to thresholds for fish — 2.9 m pin piles using a Menck MHU1900S hammer with 10 dB attenuation.

Faunal group	Metric	Threshold	Hammer energy (kJ)							
			L01				L02			
			475	950	1900a	1900b	475	950	1900a	1900b
Small fish	L_E	183	9.92				6.33			
	L_{pk}	206	0.01	0.02	0.09	0.02	0.01	0.07	0.08	0.02
Large fish	L_E	186	7.68				4.83			
	L_{pk}	206	0.01	0.02	0.09	0.02	0.01	0.07	0.08	0.02
All fish	L_p	150	5.22	7.01	9.20	2.86	4.09	5.37	7.95	2.79

L_{pk}= unweighted peak sound pressure (dB re 1 µPa); L_E = unweighted sound exposure level (dB re 1 µPa^2·s); L_p= unweighted sound pressure (dB re 1 µPa). Small fish are defined as having a total mass of less than 2 g.

Table F-128. Jacket foundation piles acoustic radial distances ($R_{95\%}$; km) to thresholds for fish — 2.9 m pin piles using a Menck MHU1900S hammer with 15 dB attenuation.

Faunal group	Metric	Threshold	Hammer energy (kJ)							
			L01				L02			
			475	950	1900a	1900b	475	950	1900a	1900b
Small fish	L_E	183	6.28				3.92			
	L_{pk}	206	0.00	0.01	0.01	0.01	0.00	0.01	0.01	0.01
Large fish	L_E	186	4.56				2.80			
	L_{pk}	206	0.00	0.01	0.01	0.01	0.00	0.01	0.01	0.01
All fish	L_p	150	3.51	4.00	5.71	2.05	2.49	3.25	5.13	1.62

L_{pk}= unweighted peak sound pressure (dB re 1 µPa); L_E = unweighted sound exposure level (dB re 1 µPa²·s); L_p= unweighted sound pressure (dB re 1 µPa). Small fish are defined as having a total mass of less than 2 g.

Table F-129. Jacket foundation piles acoustic radial distances ($R_{95\%}$; km) to thresholds for fish — 2.9 m pin piles using a Menck MHU1900S hammer with 0 dB attenuation, with 2 dB shift for post-piling installation (OSP foundation).

Faunal group	Metric	Threshold	Hammer energy (kJ)							
			L01				L02			
			475	950	1900a	1900b	475	950	1900a	1900b
Small fish	L_E	183	25.82				15.24			
	L_{pk}	206	0.16	0.43	0.46	0.09	0.20	0.30	0.36	0.10
Large fish	L_E	186	20.44				12.50			
	L_{pk}	206	0.16	0.43	0.46	0.09	0.20	0.30	0.36	0.10
All fish	L_p	150	15.81	19.24	24.13	7.53	11.29	13.59	17.93	7.33

L_{pk}= unweighted peak sound pressure (dB re 1 µPa); L_E = unweighted sound exposure level (dB re 1 µPa²·s); L_p= unweighted sound pressure (dB re 1 µPa). Small fish are defined as having a total mass of less than 2 g.

Table F-130. Jacket foundation piles acoustic radial distances ($R_{95\%}$; km) to thresholds for fish — 2.9 m pin piles using a Menck MHU1900S hammer with 6 dB attenuation, with 2 dB shift for post-piling installation (OSP foundation).

Faunal group	Metric	Threshold	Hammer energy (kJ)							
			L01				L02			
			475	950	1900a	1900b	475	950	1900a	1900b
Small fish	L_E	183	16.32				10.27			
	L_{pk}	206	0.11	0.13	0.14	0.04	0.09	0.10	0.19	0.05
Large fish	L_E	186	12.97				8.21			
	L_{pk}	206	0.11	0.13	0.14	0.04	0.09	0.10	0.19	0.05
All fish	L_p	150	9.60	12.05	15.27	3.90	7.22	9.05	12.20	4.15

L_{pk}= unweighted peak sound pressure (dB re 1 µPa); L_E = unweighted sound exposure level (dB re 1 µPa²·s); L_p= unweighted sound pressure (dB re 1 µPa). Small fish are defined as having a total mass of less than 2 g.

Table F-131. Jacket foundation piles acoustic radial distances ($R_{95\%}$; km) to thresholds for fish — 2.9 m pin piles using a Menck MHU1900S hammer with 10 dB attenuation, with 2 dB shift for post-piling installation (OSP foundation).

Faunal group	Metric	Threshold	Hammer energy (kJ)							
			L01				L02			
			475	950	1900a	1900b	475	950	1900a	1900b
Small fish	L_E	183	11.91				7.52			
	L_{pk}	206	0.01	0.10	0.10	0.03	0.05	0.08	0.09	0.03
Large fish	L_E	186	9.10				5.81			
	L_{pk}	206	0.01	0.10	0.10	0.03	0.05	0.08	0.09	0.03
All fish	L_p	150	6.64	8.36	10.97	3.12	5.04	6.43	9.24	3.30

L_{pk}= unweighted peak sound pressure (dB re 1 µPa); L_E = unweighted sound exposure level (dB re 1 µPa²·s); L_p= unweighted sound pressure (dB re 1 µPa). Small fish are defined as having a total mass of less than 2 g.

Table F-132. Jacket foundation piles acoustic radial distances ($R_{95\%}$; km) to thresholds for fish — 2.9 m pin piles using a Menck MHU1900S hammer with 15 dB attenuation, with 2 dB shift for post-piling installation (OSP foundation).

Faunal group	Metric	Threshold	Hammer energy (kJ)							
			L01				L02			
			475	950	1900a	1900b	475	950	1900a	1900b
Small fish	L_E	183	7.68				4.83			
	L_{pk}	206	0.00	0.01	0.06	0.01	0.01	0.01	0.06	0.01
Large fish	L_E	186	5.63				3.53			
	L_{pk}	206	0.00	0.01	0.06	0.01	0.01	0.01	0.06	0.01
All fish	L_p	150	3.87	5.03	7.06	2.43	3.04	3.96	6.14	1.97

L_{pk}= unweighted peak sound pressure (dB re 1 µPa); L_E = unweighted sound exposure level (dB re 1 µPa²·s); L_p= unweighted sound pressure (dB re 1 µPa). Small fish are defined as having a total mass of less than 2 g.

Table F-133. 11 m monopile acoustic radial distances ($R_{95\%}$; km) to thresholds for fish — Menck MHU4400 hammer with 0 dB attenuation.

Faunal group	Metric	Threshold	Hammer energy (kJ)					
			L01			L02		
			1100	2200	4400	1100	2200	4400
Small fish	L_E	183	23.004			13.406		
	L_{pk}	206	0.28	0.41	0.62	0.2	0.32	0.48
Large fish	L_E	186	19.074			11.366		
	L_{pk}	206	0.28	0.41	0.62	0.2	0.32	0.48
All fish	L_p	150	8.324	8.963	11.154	6.983	7.115	8.76

L_{pk}= unweighted peak sound pressure (dB re 1 µPa); L_E = unweighted sound exposure level (dB re 1 µPa²·s); L_p= unweighted sound pressure (dB re 1 µPa). Small fish are defined as having a total mass of less than 2 g.

Table F-134. 11 m monopile acoustic radial distances ($R_{95\%}$; km) to thresholds for fish — Menck MHU4400 hammer with 6 dB attenuation.

Faunal group	Metric	Threshold	Hammer energy (kJ)					
			L01			L02		
			1100	2200	4400	1100	2200	4400
Small fish	L_E	183	15.687			9.569		
	L_{pk}	206	0.097	0.136	0.29	0.077	0.096	0.199
Large fish	L_E	186	12.913			7.897		
	L_{pk}	206	0.097	0.136	0.29	0.077	0.096	0.199
All fish	L_p	150	11.25	12.094	14.655	8.943	9.248	11.134

L_{pk}= unweighted peak sound pressure (dB re 1 µPa); L_E = unweighted sound exposure level (dB re 1 µPa^2·s); L_p= unweighted sound pressure (dB re 1 µPa). Small fish are defined as having a total mass of less than 2 g.

Table F-135. 11 m monopile acoustic radial distances ($R_{95\%}$; km) to thresholds for fish — Menck MHU4400 hammer with 10 dB attenuation.

Faunal group	Metric	Threshold	Hammer energy (kJ)					
			L01			L02		
			1100	2200	4400	1100	2200	4400
Small fish	L_E	183	12.013			7.368		
	L_{pk}	206	0.059	0.089	0.139	0.047	0.071	0.095
Large fish	L_E	186	9.652			5.983		
	L_{pk}	206	0.059	0.089	0.139	0.047	0.071	0.095
All fish	L_p	150	8.324	8.963	11.154	6.983	7.115	8.76

L_{pk}= unweighted peak sound pressure (dB re 1 µPa); L_E = unweighted sound exposure level (dB re 1 µPa^2·s); L_p= unweighted sound pressure (dB re 1 µPa). Small fish are defined as having a total mass of less than 2 g.

Table F-136. 11 m monopile acoustic radial distances ($R_{95\%}$; km) to thresholds for fish — Menck MHU4400 hammer with 15 dB attenuation.

Faunal group	Metric	Threshold	Hammer energy (kJ)					
			L01			L02		
			1100	2200	4400	1100	2200	4400
Small fish	L_E	183	8.259			5.133		
	L_{pk}	206	0.009	0.019	0.076	0.01	0.034	0.055
Large fish	L_E	186	6.372			4.076		
	L_{pk}	206	0.009	0.019	0.076	0.01	0.034	0.055
All fish	L_p	150	5.441	5.806	7.577	4.953	4.9	6.279

L_{pk}= unweighted peak sound pressure (dB re 1 µPa); L_E = unweighted sound exposure level (dB re 1 µPa^2·s); L_p= unweighted sound pressure (dB re 1 µPa). Small fish are defined as having a total mass of less than 2 g.

F.5.1.2. Maximum Scenarios

Table F-137. Jacket foundation piles acoustic radial distances ($R_{95\%}$; km) to thresholds for fish — 4.5 m pin piles using an IHC S2000 hammer with 0 dB attenuation.

Faunal group	Metric	Threshold	Hammer energy (kJ)					
			L01			L02		
			2000a	2000b	2000c	2000a	2000b	2000c
Small fish	L_E	183	21.85			13.95		
	L_{pk}	206	0.44	0.27	0.10	0.38	0.30	0.11
Large fish	L_E	186	17.49			11.48		
	L_{pk}	206	0.44	0.27	0.10	0.38	0.30	0.11
All fish	L_p	150	22.13	19.33	7.96	18.78	16.60	5.99

L_{pk}= unweighted peak sound pressure (dB re 1 µPa); L_E = unweighted sound exposure level (dB re 1 µPa^2·s); L_p= unweighted sound pressure (dB re 1 µPa). Small fish are defined as having a total mass of less than 2 g.

Table F-138. Jacket foundation piles acoustic radial distances ($R_{95\%}$; km) to thresholds for fish — 4.5 m pin piles using an IHC S2000 hammer with 6 dB attenuation.

Faunal group	Metric	Threshold	Hammer energy (kJ)					
			L01			L02		
			2000a	2000b	2000c	2000a	2000b	2000c
Small fish	L_E	183	14.03			9.32		
	L_{pk}	206	0.14	0.10	0.05	0.20	0.10	0.05
Large fish	L_E	186	11.00			7.37		
	L_{pk}	206	0.14	0.10	0.05	0.20	0.10	0.05
All fish	L_p	150	14.23	12.37	4.26	12.92	11.48	3.56

L_{pk}= unweighted peak sound pressure (dB re 1 µPa); L_E = unweighted sound exposure level (dB re 1 µPa^2·s); L_p= unweighted sound pressure (dB re 1 µPa). Small fish are defined as having a total mass of less than 2 g.

Table F-139. Jacket foundation piles acoustic radial distances ($R_{95\%}$; km) to thresholds for fish — 4.5 m pin piles using an IHC S2000 hammer with 10 dB attenuation.

Faunal group	Metric	Threshold	Hammer energy (kJ)					
			L01			L02		
			2000a	2000b	2000c	2000a	2000b	2000c
Small fish	L_E	183	10.12			6.79		
	L_{pk}	206	0.11	0.07	0.03	0.10	0.07	0.03
Large fish	L_E	186	7.78			5.29		
	L_{pk}	206	0.11	0.07	0.03	0.10	0.07	0.03
All fish	L_p	150	10.30	8.69	2.92	9.83	8.72	3.10

L_{pk}= unweighted peak sound pressure (dB re 1 µPa); L_E = unweighted sound exposure level (dB re 1 µPa^2·s); L_p= unweighted sound pressure (dB re 1 µPa). Small fish are defined as having a total mass of less than 2 g.

Table F-140. Jacket foundation piles acoustic radial distances ($R_{95\%}$; km) to thresholds for fish — 4.5 m pin piles using an IHC S2000 hammer with 15 dB attenuation.

Faunal group	Metric	Threshold	Hammer energy (kJ)					
			L01			L02		
			2000a	2000b	2000c	2000a	2000b	2000c
Small fish	L_E	183	6.44			4.39		
	L_{pk}	206	0.02	0.04	0.01	0.07	0.04	0.01
Large fish	L_E	186	4.75			3.23		
	L_{pk}	206	0.02	0.04	0.01	0.07	0.04	0.01
All fish	L_p	150	6.57	5.30	2.45	6.68	5.85	2.22

L_{pk}= unweighted peak sound pressure (dB re 1 µPa); L_E = unweighted sound exposure level (dB re 1 µPa^2·s); L_p= unweighted sound pressure (dB re 1 µPa). Small fish are defined as having a total mass of less than 2 g.

Table F-141. Jacket foundation piles acoustic radial distances ($R_{95\%}$; km) to thresholds for fish — 4.5 m pin piles using an IHC S2000 hammer with 0 dB attenuation, with 2 dB shift for post-piling installation (OSP foundation).

Faunal group	Metric	Threshold	Hammer energy (kJ)					
			L01			L02		
			2000a	2000b	2000c	2000a	2000b	2000c
Small fish	L_E	183	25.38			15.77		
	L_{pk}	206	0.50	0.37	0.11	0.54	0.35	0.13
Large fish	L_E	186	20.28			13.08		
	L_{pk}	206	0.50	0.37	0.11	0.54	0.35	0.13
All fish	L_p	150	25.70	22.37	9.52	21.18	18.64	7.09

L_{pk}= unweighted peak sound pressure (dB re 1 µPa); L_E = unweighted sound exposure level (dB re 1 µPa^2·s); L_p= unweighted sound pressure (dB re 1 µPa). Small fish are defined as having a total mass of less than 2 g.

Table F-142. Jacket foundation piles acoustic radial distances ($R_{95\%}$; km) to thresholds for fish — 4.5 m pin piles using an IHC S2000 hammer with 6 dB attenuation, with 2 dB shift for post-piling installation (OSP foundation).

Faunal group	Metric	Threshold	Hammer energy (kJ)					
			L01			L02		
			2000a	2000b	2000c	2000a	2000b	2000c
Small fish	L_E	183	16.26			10.80		
	L_{pk}	206	0.17	0.12	0.06	0.26	0.14	0.06
Large fish	L_E	186	13.05			8.69		
	L_{pk}	206	0.17	0.12	0.06	0.26	0.14	0.06
All fish	L_p	150	16.49	14.38	5.23	14.73	13.02	4.08

L_{pk}= unweighted peak sound pressure (dB re 1 µPa); L_E = unweighted sound exposure level (dB re 1 µPa^2·s); L_p= unweighted sound pressure (dB re 1 µPa). Small fish are defined as having a total mass of less than 2 g.

Table F-143. Jacket foundation piles acoustic radial distances ($R_{95\%}$; km) to thresholds for fish — 4.5 m pin piles using an IHC S2000 hammer with 10 dB attenuation, with 2 dB shift for post-piling installation (OSP foundation).

Faunal group	Metric	Threshold	Hammer energy (kJ)					
			L01			L02		
			2000a	2000b	2000c	2000a	2000b	2000c
Small fish	L_E	183	12.03			8.02		
	L_{pk}	206	0.13	0.09	0.04	0.11	0.09	0.04
Large fish	L_E	186	9.28			6.26		
	L_{pk}	206	0.13	0.09	0.04	0.11	0.09	0.04
All fish	L_p	150	12.25	10.38	3.45	11.34	10.05	3.36

L_{pk}= unweighted peak sound pressure (dB re 1 µPa); L_E = unweighted sound exposure level (dB re 1 µPa^2·s); L_p= unweighted sound pressure (dB re 1 µPa). Small fish are defined as having a total mass of less than 2 g.

Table F-144. Jacket foundation piles acoustic radial distances ($R_{95\%}$; km) to thresholds for fish — 4.5 m pin piles using an IHC S2000 hammer with 15 dB attenuation, with 2 dB shift for post-piling installation (OSP foundation).

Faunal group	Metric	Threshold	Hammer energy (kJ)					
			L01			L02		
			2000a	2000b	2000c	2000a	2000b	2000c
Small fish	L_E	183	7.78			5.29		
	L_{pk}	206	0.09	0.05	0.02	0.08	0.05	0.02
Large fish	L_E	186	5.77			3.97		
	L_{pk}	206	0.09	0.05	0.02	0.08	0.05	0.02
All fish	L_p	150	7.94	6.61	2.64	7.90	6.89	2.69

L_{pk}= unweighted peak sound pressure (dB re 1 µPa); L_E = unweighted sound exposure level (dB re 1 µPa^2·s); L_p= unweighted sound pressure (dB re 1 µPa). Small fish are defined as having a total mass of less than 2 g.

Table F-145. Jacket foundation piles acoustic radial distances ($R_{95\%}$; km) to thresholds for fish — 4.5 m pin piles using a Menck MHU3500S hammer with 0 dB attenuation.

Faunal group	Metric	Threshold	Hammer energy (kJ)					
			L01			L02		
			3500a	3500b	3500c	3500a	3500b	3500c
Small fish	L_E	183	15.62			9.96		
	L_{pk}	206	0.30	0.16	0.10	0.33	0.25	0.09
Large fish	L_E	186	12.62			8.08		
	L_{pk}	206	0.30	0.16	0.10	0.33	0.25	0.09
All fish	L_p	150	17.95	15.69	11.49	14.59	13.18	4.59

L_{pk}= unweighted peak sound pressure (dB re 1 µPa); L_E = unweighted sound exposure level (dB re 1 µPa^2·s); L_p= unweighted sound pressure (dB re 1 µPa). Small fish are defined as having a total mass of less than 2 g.

Table F-146. Jacket foundation piles acoustic radial distances ($R_{95\%}$; km) to thresholds for fish — 4.5 m pin piles using a Menck MHU3500S hammer with 6 dB attenuation.

Faunal group	Metric	Threshold	Hammer energy (kJ)					
			L01			L02		
			3500a	3500b	3500c	3500a	3500b	3500c
Small fish	L_E	183	9.88			6.40		
	L_{pk}	206	0.12	0.08	0.05	0.11	0.08	0.04
Large fish	L_E	186	7.71			5.00		
	L_{pk}	206	0.12	0.08	0.05	0.11	0.08	0.04
All fish	L_p	150	11.55	9.89	7.09	9.86	9.03	3.23

L_{pk}= unweighted peak sound pressure (dB re 1 µPa); L_E = unweighted sound exposure level (dB re 1 µPa^2·s); L_p= unweighted sound pressure (dB re 1 µPa). Small fish are defined as having a total mass of less than 2 g.

Table F-147. Jacket foundation piles acoustic radial distances ($R_{95\%}$; km) to thresholds for fish — 4.5 m pin piles using a Menck MHU3500S hammer with 10 dB attenuation.

Faunal group	Metric	Threshold	Hammer energy (kJ)					
			L01			L02		
			3500a	3500b	3500c	3500a	3500b	3500c
Small fish	L_E	183	7.10			4.58		
	L_{pk}	206	0.09	0.05	0.03	0.08	0.05	0.02
Large fish	L_E	186	5.18			3.48		
	L_{pk}	206	0.09	0.05	0.03	0.08	0.05	0.02
All fish	L_p	150	8.26	7.08	4.83	7.37	6.66	2.78

L_{pk}= unweighted peak sound pressure (dB re 1 µPa); L_E = unweighted sound exposure level (dB re 1 µPa^2·s); L_p= unweighted sound pressure (dB re 1 µPa). Small fish are defined as having a total mass of less than 2 g.

Table F-148. Jacket foundation piles acoustic radial distances ($R_{95\%}$; km) to thresholds for fish — 4.5 m pin piles using a Menck MHU3500S hammer with 15 dB attenuation.

Faunal group	Metric	Threshold	Hammer energy (kJ)					
			L01			L02		
			3500a	3500b	3500c	3500a	3500b	3500c
Small fish	L_E	183	4.24			2.84		
	L_{pk}	206	0.01	0.01	0.01	0.01	0.02	0.01
Large fish	L_E	186	2.96			2.08		
	L_{pk}	206	0.01	0.01	0.01	0.01	0.02	0.01
All fish	L_p	150	5.07	4.24	3.04	4.94	4.42	1.85

L_{pk}= unweighted peak sound pressure (dB re 1 µPa); L_E = unweighted sound exposure level (dB re 1 µPa^2·s); L_p= unweighted sound pressure (dB re 1 µPa). Small fish are defined as having a total mass of less than 2 g.

Table F-149. Jacket foundation piles acoustic radial distances ($R_{95\%}$; km) to thresholds for fish — 4.5 m pin piles using a Menck MHU3500S hammer with 0 dB attenuation, with 2 dB shift for post-piling installation (OSP foundation).

Faunal group	Metric	Threshold	Hammer energy (kJ)					
			L01			L02		
			3500a	3500b	3500c	3500a	3500b	3500c
Small fish	L_E	183	18.05			11.41		
	L_{pk}	206	0.47	0.21	0.12	0.37	0.32	0.11
Large fish	L_E	186	14.59			9.30		
	L_{pk}	206	0.47	0.21	0.12	0.37	0.32	0.11
All fish	L_p	150	20.62	18.13	13.38	16.42	14.79	5.48

L_{pk}= unweighted peak sound pressure (dB re 1 µPa); L_E = unweighted sound exposure level (dB re 1 µPa²·s); L_p= unweighted sound pressure (dB re 1 µPa). Small fish are defined as having a total mass of less than 2 g.

Table F-150. Jacket foundation piles acoustic radial distances ($R_{95\%}$; km) to thresholds for fish — 4.5 m pin piles using a Menck MHU3500S hammer with 6 dB attenuation, with 2 dB shift for post-piling installation (OSP foundation).

Faunal group	Metric	Threshold	Hammer energy (kJ)					
			L01			L02		
			3500a	3500b	3500c	3500a	3500b	3500c
Small fish	L_E	183	11.63			7.48		
	L_{pk}	206	0.14	0.10	0.06	0.13	0.11	0.05
Large fish	L_E	186	9.10			5.94		
	L_{pk}	206	0.14	0.10	0.06	0.13	0.11	0.05
All fish	L_p	150	13.52	11.66	8.29	11.35	10.28	3.47

L_{pk}= unweighted peak sound pressure (dB re 1 µPa); L_E = unweighted sound exposure level (dB re 1 µPa²·s); L_p= unweighted sound pressure (dB re 1 µPa). Small fish are defined as having a total mass of less than 2 g.

Table F-151. Jacket foundation piles acoustic radial distances ($R_{95\%}$; km) to thresholds for fish — 4.5 m pin piles using a Menck MHU3500S hammer with 10 dB attenuation, with 2 dB shift for post-piling installation (OSP foundation).

Faunal group	Metric	Threshold	Hammer energy (kJ)					
			L01			L02		
			3500a	3500b	3500c	3500a	3500b	3500c
Small fish	L_E	183	8.32			5.48		
	L_{pk}	206	0.11	0.07	0.04	0.10	0.07	0.03
Large fish	L_E	186	6.40			4.19		
	L_{pk}	206	0.11	0.07	0.04	0.10	0.07	0.03
All fish	L_p	150	9.80	8.30	5.85	8.61	7.77	3.00

L_{pk}= unweighted peak sound pressure (dB re 1 µPa); L_E = unweighted sound exposure level (dB re 1 µPa²·s); L_p= unweighted sound pressure (dB re 1 µPa). Small fish are defined as having a total mass of less than 2 g.

Table F-152. Jacket foundation piles acoustic radial distances ($R_{95\%}$; km) to thresholds for fish — 4.5 m pin piles using a Menck MHU3500S hammer with 15 dB attenuation, with 2 dB shift for post-piling installation (OSP foundation).

Faunal group	Metric	Threshold	Hammer energy (kJ)					
			L01			L02		
			3500a	3500b	3500c	3500a	3500b	3500c
Small fish	L_E	183	5.18			3.48		
	L_{pk}	206	0.02	0.03	0.01	0.06	0.03	0.01
Large fish	L_E	186	3.81			2.55		
	L_{pk}	206	0.02	0.03	0.01	0.06	0.03	0.01
All fish	L_p	150	6.34	5.16	3.49	5.83	5.22	2.24

L_{pk}= unweighted peak sound pressure (dB re 1 µPa); L_E = unweighted sound exposure level (dB re 1 µPa^2·s); L_p= unweighted sound pressure (dB re 1 µPa). Small fish are defined as having a total mass of less than 2 g.

Table F-153. 16 m monopile acoustic radial distances ($R_{95\%}$; km) to thresholds for fish — using a theoretical 6600 kJ hammer with 0 dB attenuation.

Faunal group	Metric	Threshold	Hammer energy (kJ)					
			L01			L02		
			1100	2200	4400	1100	2200	4400
Small fish	L_E	183	30.34			16.26		
	L_{pk}	206	0.62	0.56	0.62	0.44	0.42	0.50
Large fish	L_E	186	25.46			14.09		
	L_{pk}	206	0.62	0.56	0.62	0.44	0.42	0.50
All fish	L_p	150	25.01	25.81	27.18	15.24	16.25	16.94

L_{pk}= unweighted peak sound pressure (dB re 1 µPa); L_E = unweighted sound exposure level (dB re 1 µPa^2·s); L_p= unweighted sound pressure (dB re 1 µPa). Small fish are defined as having a total mass of less than 2 g.

Table F-154. 16 m monopile acoustic radial distances ($R_{95\%}$; km) to thresholds for fish — using a theoretical 6600 kJ hammer with 6 dB attenuation

Faunal group	Metric	Threshold	Hammer energy (kJ)					
			L01			L02		
			1100	2200	4400	1100	2200	4400
Small fish	L_E	183	21.32			12.10		
	L_{pk}	206	0.29	0.27	0.29	0.20	0.20	0.26
Large fish	L_E	186	17.73			10.34		
	L_{pk}	206	0.29	0.27	0.29	0.20	0.20	0.26
All fish	L_p	150	17.53	18.10	18.86	11.07	12.17	12.67

L_{pk}= unweighted peak sound pressure (dB re 1 µPa); L_E = unweighted sound exposure level (dB re 1 µPa^2·s); L_p= unweighted sound pressure (dB re 1 µPa). Small fish are defined as having a total mass of less than 2 g.

Table F-155. 16 m monopile acoustic radial distances ($R_{95\%}$; km) to thresholds for fish — using a theoretical 6600 kJ hammer with 10 dB attenuation.

Faunal group	Metric	Threshold	Hammer energy (kJ)					
			L01			L02		
			1100	2200	4400	1100	2200	4400
Small fish	L_E	183	16.65			9.76		
	L_{pk}	206	0.14	0.15	0.15	0.09	0.11	0.11
Large fish	L_E	186	13.80			8.19		
	L_{pk}	206	0.14	0.15	0.15	0.09	0.11	0.11
All fish	L_p	150	13.72	14.10	14.63	8.71	9.84	10.30

L_{pk}= unweighted peak sound pressure (dB re 1 µPa); L_E = unweighted sound exposure level (dB re 1 µPa^2·s); L_p= unweighted sound pressure (dB re 1 µPa). Small fish are defined as having a total mass of less than 2 g.

Table F-156. 16 m monopile acoustic radial distances ($R_{95\%}$; km) to thresholds for fish — using a theoretical 6600 kJ hammer with 15 dB attenuation.

Faunal group	Metric	Threshold	Hammer energy (kJ)					
			L01			L02		
			1100	2200	4400	1100	2200	4400
Small fish	L_E	183	12.09			7.23		
	L_{pk}	206	0.08	0.09	0.10	0.06	0.06	0.07
Large fish	L_E	186	9.80			5.95		
	L_{pk}	206	0.08	0.09	0.10	0.06	0.06	0.07
All fish	L_p	150	9.79	10.06	10.46	6.32	7.30	7.71

L_{pk}= unweighted peak sound pressure (dB re 1 µPa); L_E = unweighted sound exposure level (dB re 1 µPa^2·s); L_p= unweighted sound pressure (dB re 1 µPa). Small fish are defined as having a total mass of less than 2 g.

Appendix G. Animal Movement and Exposure Modeling

To assess the effects of from anthropogenic sound exposure, an estimate of the received sound levels for individuals of each species known to occur within 50 km of the Project Area during the assessed activities is required. Both sound sources and animals move. The sound fields may be complex, and the sound received by an animal is a function of where the animal is at any given time. To a reasonable approximation, the locations of the Lease Area sound sources are known, and acoustic modeling can be used to predict the individual and aggregate 3-D sound fields of the sources. The location and movement of animals within the sound field, however, is unknown. Realistic animal movement within the sound field can be simulated. Repeated random sampling (Monte Carlo method simulating many animals within the operations area) is used to estimate the sound exposure history of the population of simulated animals (animats) during the operation.

Monte Carlo methods provide a heuristic approach for determining the probability distribution function (PDF) of complex situations, such as animals moving in a sound field. The probability of an event's occurrence is determined by the frequency with which it occurs in the simulation. The greater the number of random samples, in this case the more animats, the better the approximation of the PDF. Animats are randomly placed, or seeded, within the simulation boundary at a specified density (animats/km^2). Higher densities provide a finer PDF estimate resolution but require more computational resources. To ensure good representation of the PDF, the animat density is set as high as practical allowing for computation time. The animat density is much higher than the real-world density to ensure good representation of the PDF. The resulting PDF is scaled using the real-world density.

Several models for marine mammal movement have been developed (Ellison et al. 1999, Frankel et al. 2002, Houser 2006). These models use an underlying Markov chain to transition from one state to another based on probabilities determined from measured swimming behavior. The parameters may represent simple states, such as the speed or heading of the animal, or complex states, such as likelihood of participating in foraging, play, rest, or travel. Attractions and aversions to variables like anthropogenic sounds and different depth ranges can be included in the models.

The JASCO Animal Simulation Model Including Noise Exposure (JASMINE) was based on the open-source marine mammal movement and behavior model (3MB; Houser 2006) and used to predict the exposure of animats (virtual marine mammals and sea turtles) to sound arising from sound sources in simulated representative surveys. Within JASMINE simulations, the modeled sound fields are repeated at proposed foundation locations, mimicking the impact pile driving activity throughout the Lease Area. Animats are programmed to behave like the marine animals likely to be present in the survey area. The parameters used for forecasting realistic behaviors (e.g., diving, foraging, aversion, surface times, etc.) are determined and interpreted from marine species studies (e.g., tagging studies) where available, or reasonably extrapolated from related species. An individual animat's modeled sound exposure levels are summed over the total simulation duration, such as 24 hours or the entire simulation, to determine its total received energy, and then compared to the assumed threshold criteria.

JASMINE uses the same animal movement algorithms as the 3MB model (Houser 2006) but has been extended to be directly compatible with MONM and FWRAM acoustic field predictions, for inclusion of source tracks, and importantly for animats to change behavioral states based on time and space dependent modeled variables such as received levels for aversion behavior (Ellison et al. 2016).

G.1. Animal Movement Parameters

JASMINE uses previously measured behavior to forecast behavior in new situations and locations. The parameters used for forecasting realistic behavior are determined (and interpreted) from marine species studies (e.g., tagging studies). Each parameter in the model is described as a probability distribution. When limited or no information is available for a species parameter, a Gaussian or uniform distribution may be chosen for that parameter. For the Gaussian distribution, the user determines the mean and standard deviation of the distribution from which parameter values are drawn. For the uniform distribution, the user determines the maximum and minimum distribution from which parameter values are drawn. When detailed information about the movement and behavior of a species are available, a user-created distribution vector, including cumulative transition probabilities, may be used (referred to here as a vector model; Houser 2006). Different sets of parameters can be defined for different behavior states. The probability of an animat starting out in or transitioning into a given behavior state can in turn be defined in terms of the animat's current behavioral state, depth, and the time of day. In addition, each travel parameter and behavioral state has a termination function that governs how long the parameter value or overall behavioral state persists in simulation.

The parameters used in JASMINE describe animal movement in both the vertical and horizontal planes. The parameters relating to travel in these two planes are briefly described below. JASCO maintains species-specific choices of values for the behavioral parameters used in this study. The parameter values are available for limited distribution upon request.

Travel sub-models

- **Direction**–determines an animat's choice of direction in the horizontal plane. Sub-models are available for determining the heading of animats, allowing for movement to range from strongly biased to undirected. A random walk model can be used for behaviors with no directional preference, such as feeding and playing. In a random walk, all bearings are equally likely at each parameter transition time step. A correlated random walk can be used to smooth the changes in bearing by using the current heading as the mean of the distribution from which to draw the next heading. An additional variant of the correlated random walk is available that includes a directional bias for use in situations where animals have a preferred absolute direction, such as migration. A user-defined vector of directional probabilities can also be input to control animat heading. For more detailed discussion of these parameters, see Houser (2006) and Houser and Cross (1999).
- **Travel rate**–defines an animat's rate of travel in the horizontal plane. When combined with vertical speed and dive depth, the dive profile of the animat is produced.

Dive sub-models

- **Ascent rate**–defines an animat's rate of travel in the vertical plane during the ascent portion of a dive.
- **Descent rate**–defines an animat's rate of travel in the vertical plane during the descent portion of a dive.
- **Depth**–defines an animat's maximum dive depth.
- **Bottom following**–determines whether an animat returns to the surface once reaching the ocean floor, or whether it follows the contours of the bathymetry.
- **Reversals**–determines whether multiple vertical excursions occur once an animat reaches the maximum dive depth. This behavior is used to emulate the foraging behavior of some marine mammal species at depth. Reversal-specific ascent and descent rates may be specified.
- **Surface interval**–determines the duration an animat spends at, or near, the surface before diving again.

G.1.1. Exposure Integration Time

The interval over which acoustic exposure (L_E) should be integrated and maximal exposure (SPL) determined is not well defined. Both Southall et al. (2007) and the NMFS (2018) recommend a 24 h baseline accumulation period, but state that there may be situations where this is not appropriate (e.g., a high-level source and confined population). Resetting the integration after 24 h can lead to overestimating the number of individual animals exposed because individuals can be counted multiple times during an operation. The type of animal movement engine used in this study simulates realistic movement using swimming behavior collected over relatively short periods (hours to days) and does not include large-scale movement such as migratory circulation patterns. Therefore, the simulation time should be limited to a few weeks, the approximate scale of the collected data (e.g., marine mammal tag data) (Houser 2006). For this study, one-week simulations (i.e., 7 days) were modeled.

Ideally, a simulation area is large enough to encompass the entire range of a population so that any animal that might be present in the Project Area during sound-producing activities is included. However, there are limits to the simulation area, and computational overhead increases with area. For practical reasons, the simulation area is limited in this analysis to a rectangular area enclosing a 70-km (43.5-mile) buffer around the Lease Area (see figures in Appendix G.3). In the simulation, every animat that reaches and leaves a border of the simulation area is replaced by another animat entering at an opposite border—e.g., an animat departing at the northern border of the simulation area is replaced by an animat entering the simulation area at the southern border at the same longitude. When this action places the animat in an inappropriate water depth, the animat is randomly placed on the map at a depth suited to its species definition (Appendix G.3). The exposures of all animats (including those leaving the simulation and those entering) are kept for analysis. This approach maintains a consistent animat density and allows for longer integration periods with finite simulation areas.

G.1.2. Aversion

Animals may avoid loud sounds by moving away from the source, and the risk assessment framework (Southall et al. 2014) suggests implementing aversion in the animal movement model and making a comparison between the exposure estimates with and without aversion. Aversion is implemented in JASMINE by defining a new behavioral state that an animat may transition in to when a received level is exceeded.

There are very few data on which aversive behavior can be based. Because of the dearth of information and to be consistent within this report, aversion probability is based on the Wood et al. (2012) step function that was used to estimate potential behavioral disruption. Animats will be assumed to avert by changing their headings by a fixed amount away from the source, with greater deflections associated with higher received levels (Tables G-1 and G-2). Aversion thresholds for marine mammals are based on the Wood et al. (2012) step function. Animats remain in the aversive state for a specified amount of time, depending on the level of exposure that triggered aversion (Tables G-1 and G-2). During this time, travel parameters are recalculated periodically as with normal behaviors. At the end of the aversion interval, the animat model parameters are changed (see Tables G-1 and G-2), depending on the current level of exposure and the animat either begins another aversion interval or transitions to a non-aversive behavior; while if aversion begins immediately, transition to a regular behavior occurs at the end of the next surface interval, consistent with regular behavior transitions.

Table G-1. North Atlantic right whales: Aversion parameters for the animal movement simulation based on Wood et al. (2012) behavioral response criteria.

Probability of aversion	Received sound level (L_p, dB re 1 µPa)	Change in course (°)	Duration of aversion(s)
10%	140	10	30
50%	160	20	60
90%	180	30	300

Table G-2. Harbor porpoises: Aversion parameters for the animal movement simulation based on Wood et al. (2012) behavioral response criteria.

Probability of aversion	Received sound level (L_p, dB re 1 µPa)	Change in course (°)	Duration of aversion(s)
50%	120	20	60
90%	140	30	300

G.1.3. Seeding Density and Scaling

The exposure criteria for impulsive sounds were used to determine the number of animats exceeding exposure thresholds. To generate statistically reliable probability density functions, all simulations were seeded with an animat density of 0.5 animats/km^2 over the entire simulation area. Some species have depth preference restrictions, e.g., sperm whales prefer water greater than 1000 m (Aoki et al. 2007), and the simulation location contained a relatively high portion of shallow water areas. For each species, the local modeling density, that is the density of animats near the construction area, was determined by dividing the simulation seeding density by the proportion of seedable area. To evaluate potential injurious or behavioral harassment, threshold exceedance was determined in 24 h time windows for each species. From the numbers of animats exceeding threshold, the numbers of individual animals for each species predicted to exceed threshold were determined by scaling the animat results by the ratio of local real-world density to local modeling density. As described in Section 2.8, the local density estimates were obtained from the habitat-based models of Roberts et al. (2015, 2016, 2017, 2018, 2020).

G.2. Animal Movement Modeling Results

G.2.1. Marine Mammal Exposure Range Estimates

Tables G-3 to G-9 contain exposure-based ranges for Level A and Level B acoustic thresholds (NOAA 2005, Wood et al. 2012, NMFS 2018). Level B sound pressure levels (SPL) are presented as both unweighted (NOAA 2005) and M-weighted (Wood et al. 2012). Results include realistic and maximum scenario jacket foundations and monopiles with broadband mitigation of 0, 6, 10, and 15 dB during the summer season.

Table G-3. Realistic scenario WTG monopile foundation (11 m diameter, MHU4400S hammer, two piles per day) exposure ranges in km to marine mammal Level A and Level B thresholds with sound attenuation.

Low-frequency cetaceans																
Fin whale[a] (sei whale[a,b])	7.59	3.93	2.09	0.78	0.07	0	0	0	10.41	6.48	4.38	3.10	10.54	6.50	4.37	3.09
Minke whale	4.47	1.81	0.85	0.13	0.03	<0.01	<0.01	0	10.12	6.25	4.34	3.03	10.32	6.31	4.33	3.03
Humpback whale	10.19	4.74	2.95	1.28	0.02	0	0	0	10.59	6.63	4.69	3.05	10.67	6.60	4.60	3.06
North Atlantic right whale[a]	6.87	3.59	2.01	0.67	0.06	0	0	0	10.53	6.51	4.56	3.15	10.59	6.50	4.48	3.14
Mid-frequency cetaceans																
Atlantic white sided dolphin	0.02	0	0	0	0	0	0	0	10.12	6.28	4.35	3.11	4.32	2.84	2.32	1.24
Short-beaked common dolphin	0.02	0	0	0	<0.01	0	0	0	10.20	6.33	4.38	3.08	4.37	2.85	2.37	1.34
Bottlenose dolphin	0	0	0	0	0	0	0	0	10.62	6.63	4.67	3.25	4.64	3.09	2.45	1.49
Risso's dolphin	0.01	<0.01	0	0	0	0	0	0	10.35	6.51	4.46	3.10	4.44	2.88	2.34	1.29
Pilot whale	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sperm whale	0	0	0	0	0	0	0	0	10.46	6.59	4.48	3.12	4.47	2.88	2.32	1.31
High-frequency cetaceans																
Harbor porpoise	2.98	1.23	0.61	0.08	0.70	0.33	0.22	0.09	10.40	6.53	4.43	3.12	55.20	49.34	40.26	28.12
Pinnipeds in water																
Gray seal	1.23	0.46	0.10	0	0.05	0	0	0	10.63	6.66	4.79	3.10	7.67	4.23	3.10	2.57
Harbor seal	1.13	0.24	0.01	0	0.07	0	0	0	10.59	6.62	4.65	3.16	7.43	4.23	3.17	2.50

[a] Listed as Endangered under the ESA.
[b] Fin whale used as a surrogate for sei whale behavioral definition.

Table G-4. Realistic scenario WTG jacket foundation (2.9 m diameter, MHU1900S hammer, four piles per day) exposure ranges ($ER_{95\%}$) in km to marine mammal Level A and Level B thresholds with sound attenuation.

Low-frequency cetaceans																
Fin whale[a] (sei whale[a,b])	6.20	3.00	1.66	0.81	0	0	0	0	8.11	4.38	3.09	2.44	8.20	4.42	3.09	2.44
Minke whale	4.00	1.92	0.89	0.25	0.02	0	0	0	7.69	4.36	3.01	2.37	7.76	4.38	3.02	2.38
Humpback whale	9.76	4.57	2.43	0.82	0	0	0	0	8.83	4.66	3.07	2.52	8.85	4.67	3.07	2.52
North Atlantic right whale[a]	5.88	2.97	1.62	0.66	0.02	0	0	0	8.28	4.34	3.16	2.32	8.35	4.37	3.16	2.32
Mid-frequency cetaceans																
Atlantic white sided dolphin	0.01	0	0	0	0	0	0	0	7.94	4.39	2.99	2.34	5.83	3.15	2.56	1.42
Short-beaked common dolphin	0.02	0.02	0.02	0	0	0	0	0	7.94	4.40	3.06	2.42	5.88	3.14	2.72	1.54
Bottlenose dolphin	0.07	<0.01	<0.01	0	0	0	0	0	9.12	4.86	3.29	2.73	6.69	3.46	2.91	1.64
Risso's dolphin	0.01	0.01	0.01	0	0	0	0	0	7.94	4.39	2.99	2.29	5.80	3.16	2.55	1.47
Pilot whale	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sperm whale	0	0	0	0	0	0	0	0	8.34	4.57	3.05	2.31	5.84	3.20	2.61	1.39
High-frequency cetaceans																
Harbor porpoise	4.76	2.73	1.70	0.77	0.37	0.19	0.09	0.07	8.14	4.52	3.11	2.35	56.09	53.27	49.31	42.46
Pinnipeds in water																
Gray seal	2.32	0.99	0.22	0.04	0.01	0	0	0	8.62	4.70	3.27	2.37	7.60	4.17	3.07	2.11
Harbor seal	2.17	0.73	0.17	0	0.07	0	0	0	8.58	4.62	3.12	2.53	7.53	4.21	2.99	2.02

[a] Listed as Endangered under the ESA.
[b] Fin whale used as a surrogate for sei whale behavioral definition.

Table G-5. Realistic scenario OSP jacket foundation[a] (2.9 m diameter, MHU1900S hammer) exposure ranges, $ER_{95\%}$, in km to marine mammal Level A and Level B thresholds assuming four piles per day with sound attenuation.

Low-frequency cetaceans																
Fin whale[b] (sei whale[b,c])	7.69	3.79	2.22	0.96	0	0	0	0	9.78	5.51	3.58	2.76	9.90	5.55	3.60	2.76
Minke whale	4.90	2.48	1.31	0.36	0.02	0	0	0	9.27	5.32	3.50	2.79	9.36	5.36	3.53	2.79
Humpback whale	12.85	6.30	3.43	1.19	0	0	0	0	10.55	6.03	3.87	2.80	10.58	6.02	3.86	2.81
North Atlantic right whale[b]	7.25	3.65	2.21	0.93	0.02	0	0	0	9.87	5.50	3.64	2.82	9.95	5.51	3.63	2.82
Mid-frequency cetaceans																
Atlantic white sided dolphin	0.01	0	0	0	0	0	0	0	9.56	5.41	3.60	2.70	7.05	3.88	2.85	1.95
Short-beaked common dolphin	0.02	0.02	0.02	0	0	0	0	0	9.42	5.42	3.55	2.77	7.13	3.80	2.89	2.12
Bottlenose dolphin	0.32	0.05	<0.01	0	0	0	0	0	10.55	6.08	3.86	3.00	8.14	4.34	3.13	2.21
Risso's dolphin	0.02	0.01	0.01	0	0	0	0	0	9.52	5.51	3.54	2.57	7.10	3.83	2.75	2.06
Pilot whale	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sperm whale	0.02	0	0	0	0	0	0	0	9.99	5.65	3.55	2.80	7.12	3.82	2.89	1.90
High-frequency cetaceans																
Harbor porpoise	5.71	3.27	2.06	1.10	0.37	0.19	0.09	0.07	9.77	5.63	3.72	2.75	57.47	53.88	51.54	46.96
Pinnipeds in water																
Gray seal	3.63	1.09	0.48	0.04	0.01	0	0	0	10.39	5.84	3.76	2.88	9.05	5.10	3.44	2.58
Harbor seal	3.15	1.22	0.39	0.07	0.07	0	0	0	10.07	5.74	3.93	2.94	9.01	4.87	3.19	2.90

[a] OSP foundations include a 2 dB shift for post piling
[b] Listed as Endangered under the ESA.
[c] Fin whale used as a surrogate for sei whale behavioral definition.

Table G-6. Maximum scenario WTG jacket foundation (4.5 m diameter, IHCS2000 hammer) exposure ranges, $ER_{95\%}$, in km to marine mammal Level A and Level B thresholds assuming four piles per day with sound attenuation.

Low-frequency cetaceans																
Fin whale[a] (sei whale[a,b])	9.51	4.88	2.74	1.25	0.05	0	0	0	9.32	5.45	3.65	2.69	9.45	5.48	3.66	2.70
Minke whale	5.57	2.71	1.45	0.39	0.03	0	0	0	8.91	5.28	3.50	2.71	9.12	5.34	3.50	2.71
Humpback whale	15.70	8.19	4.85	2.00	0	0	0	0	9.78	5.66	3.70	2.86	9.85	5.69	3.70	2.87
North Atlantic right whale[a]	9.16	4.59	2.88	1.26	0.06	0	0	0	9.28	5.43	3.69	2.77	9.41	5.44	3.70	2.78
Mid-frequency cetaceans																
Atlantic white sided dolphin	0.01	0	0	0	0	0	0	0	9.03	5.38	3.61	2.74	6.37	3.46	2.82	1.90
Short-beaked common dolphin	0.02	0.02	0.02	0	0	0	0	0	9.14	5.43	3.52	2.74	6.37	3.38	2.79	1.98
Bottlenose dolphin	0.60	0.07	<0.01	0	0	0	0	0	9.81	5.91	3.85	2.84	7.20	3.85	2.91	2.20
Risso's dolphin	0.01	0.01	0.01	0	0	0	0	0	9.01	5.44	3.63	2.70	6.37	3.52	2.78	1.97
Pilot whale	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sperm whale	0.01	0	0	0	0	0	0	0	9.51	5.59	3.63	2.73	6.55	3.42	2.82	1.85
High-frequency cetaceans																
Harbor porpoise	6.31	3.60	2.37	1.07	0.53	0.26	0.12	0.06	9.28	5.50	3.75	2.74	58.98	56.33	50.58	42.45
Pinnipeds in water																
Gray seal	4.26	1.57	0.74	0.22	0.03	0	0	0	9.68	5.72	3.61	2.77	8.31	4.70	3.31	2.43
Harbor seal	3.96	1.45	0.75	0.14	0.07	0	0	0	9.51	5.57	3.76	2.89	8.26	4.72	3.18	2.60

[a] Listed as Endangered under the ESA.
[b] Fin whale used as a surrogate for sei whale behavioral definition.

Table G-7. Maximum scenario WTG monopile foundation (16 m diameter, 6600 kJ hammer, 7000 strikes, two piles per day) exposure ranges ($ER_{95\%}$) in km to marine mammal Level A and Level B thresholds with sound attenuation.

Low-frequency cetaceans																
Fin whale[a] (sei whale[a,b])	11.15	6.38	4.11	1.80	0.08	0.01	0	0	13.54	8.95	6.55	4.10	13.75	9.04	6.59	4.13
Minke whale	7.04	3.68	1.95	0.77	0.07	<0.01	0	0	13.27	8.82	6.40	3.99	13.45	8.94	6.45	3.99
Humpback whale	15.68	8.51	5.14	2.70	0.10	0	0	0	13.77	9.17	6.70	4.35	13.93	9.18	6.70	4.35
North Atlantic right whale[a]	10.36	5.94	3.89	1.92	0.11	0	0	0	13.52	9.07	6.54	4.17	13.65	9.11	6.62	4.16
Mid-frequency cetaceans																
Atlantic white sided dolphin	0.02	0.02	0	0	0	0	0	0	13.41	8.76	6.38	3.96	6.33	3.27	2.72	2.00
Short-beaked common dolphin	0.02	0.02	0.01	0	<0.01	<0.01	0	0	13.37	8.83	6.40	4.05	6.37	3.30	2.79	2.03
Bottlenose dolphin	0.03	0	0	0	0	0	0	0	13.75	9.20	6.78	4.20	6.95	3.57	2.94	2.23
Risso’s dolphin	0.01	0.01	<0.01	0	<0.01	0	0	0	13.36	8.88	6.66	4.06	6.64	3.31	2.78	2.00
Pilot whale	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sperm whale	0	0	0	0	0	0	0	0	13.76	9.05	6.65	4.19	6.74	3.32	2.78	2.10
High-frequency cetaceans																
Harbor porpoise	4.21	2.11	1.17	0.37	0.82	0.39	0.24	0.11	13.56	9.03	6.60	4.16	56.84	52.49	48.93	36.79
Pinnipeds in water																
Gray seal	2.90	1.10	0.47	0	0.05	0	0	0	13.80	9.05	6.81	4.11	10.40	6.28	4.05	2.99
Harbor seal	2.64	0.76	0.29	0	0.10	<0.01	<0.01	0	13.74	9.07	6.57	4.22	10.46	6.14	4.09	2.91

[a] Listed as Endangered under the ESA.
[b] Fin whale used as a surrogate for sei whale behavioral definition.

Table G-8. Maximum scenario WTG monopile foundation (16 m diameter, 6600 kJ hammer, 6265 strikes, one pile per day) exposure ranges ($ER_{95\%}$) in km to marine mammal Level A and Level B thresholds with sound attenuation.

Low-frequency cetaceans																
Fin whale[a] (sei whale[a,b])	10.27	5.87	3.68	1.73	0.11	<0.01	0	0	13.76	9.03	6.64	4.14	13.85	9.13	6.66	4.15
Minke whale	6.64	3.41	1.90	0.64	0.08	<0.01	0	0	13.43	9.01	6.51	4.06	13.54	9.11	6.53	4.03
Humpback whale	14.20	8.31	4.61	2.08	0.07	0	0	0	14.13	9.17	6.78	4.27	14.19	9.25	6.76	4.28
North Atlantic right whale[a]	9.51	5.27	3.47	1.67	0.07	0	0	0	13.76	9.01	6.62	4.21	13.82	9.07	6.63	4.22
Mid-frequency cetaceans																
Atlantic white sided dolphin	0	0	0	0	0	0	0	0	13.52	8.97	6.47	4.04	6.38	3.29	2.73	1.83
Short-beaked common dolphin	0.02	0.02	0	0	0	0	0	0	13.53	9.00	6.57	4.12	6.62	3.35	2.74	2.02
Bottlenose dolphin	0	0	0	0	0	0	0	0	13.79	9.39	6.79	4.36	6.94	3.47	3.01	2.38
Risso's dolphin	<0.01	<0.01	0	0	0	0	0	0	13.74	9.01	6.60	4.13	6.71	3.35	2.77	1.99
Pilot whale	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sperm whale	0	0	0	0	0	0	0	0	13.98	9.23	6.75	4.25	6.77	3.39	2.81	2.03
High-frequency cetaceans																
Harbor porpoise	4.12	2.20	1.02	0.28	0.83	0.33	0.24	0.09	13.82	9.17	6.58	4.17	57.40	52.86	49.63	37.38
Pinnipeds in water																
Gray seal	2.64	0.71	0.37	0.01	0.12	0	0	0	13.84	9.34	6.81	4.27	10.64	6.38	4.11	2.95
Harbor seal	2.20	0.61	0.19	0.02	0.10	0.02	0	0	13.79	9.26	6.70	4.23	10.55	6.36	4.17	3.01

[a] Listed as Endangered under the ESA.
[b] Fin whale used as a surrogate for sei whale behavioral definition.

Table G-9. Maximum scenario WTG monopile foundation (16 m diameter, 6600 kJ hammer, 6265 strikes, two piles per day) exposure ranges ($ER_{95\%}$) in km to marine mammal Level A and Level B thresholds with sound attenuation.

Low-frequency cetaceans																
Fin whale[a] (sei whale[a,b])	10.83	6.31	3.94	1.74	0.08	0.01	0	0	13.51	9.01	6.54	4.11	13.70	9.09	6.56	4.13
Minke whale	6.97	3.61	1.81	0.77	0.07	<0.01	0	0	13.24	8.81	6.38	4.00	13.44	8.95	6.44	3.99
Humpback whale	15.04	8.16	5.08	2.45	0.10	0	0	0	13.94	9.07	6.70	4.23	13.99	9.14	6.67	4.20
North Atlantic right whale[a]	10.15	5.77	3.63	1.71	0.11	0	0	0	13.57	9.04	6.59	4.16	13.66	9.14	6.62	4.16
Mid-frequency cetaceans																
Atlantic white sided dolphin	0.02	0.02	0	0	0	0	0	0	13.33	8.78	6.39	3.99	6.34	3.28	2.71	1.95
Short-beaked common dolphin	0.02	0.02	0.01	0	<0.01	<0.01	0	0	13.35	8.81	6.41	4.04	6.37	3.29	2.75	2.01
Bottlenose dolphin	0.03	0	0	0	0	0	0	0	13.75	9.21	6.78	4.24	6.86	3.53	2.98	2.19
Risso's dolphin	0.01	0.01	<0.01	0	<0.01	0	0	0	13.39	8.93	6.60	4.07	6.63	3.31	2.79	2.03
Pilot whale	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sperm whale	0	0	0	0	0	0	0	0	13.75	9.10	6.67	4.21	6.73	3.34	2.82	2.12
High-frequency cetaceans																
Harbor porpoise	4.18	2.02	1.15	0.39	0.82	0.35	0.24	0.10	13.56	8.98	6.63	4.17	56.88	52.39	48.99	36.87
Pinnipeds in water																
Gray seal	2.86	1.03	0.47	0	0.05	0	0	0	13.78	9.14	6.75	4.17	10.44	6.20	4.10	2.96
Harbor seal	2.60	0.78	0.25	0	0.10	0	0	0	13.71	9.13	6.63	4.23	10.40	6.15	4.08	2.91

[a] Listed as Endangered under the ESA.
[b] Fin whale used as a surrogate for sei whale behavioral definition.

G.2.2. Marine Mammal Exposure Estimates

This section contains the construction schedules and marine mammal exposure estimates for the two-year realistic jacket and monopile foundation schedules separated by year.

The yearly realistic WTG jacket construction schedule presented in Table G-10 assumes the installation of 87 3-legged jackets with 2.9 m diameter and 3 4-legged OSP jackets with 4.5 m diameter during year one, and 59 3-legged jackets during year two.

The yearly realistic WTG monopile construction schedule presented in Table G-11 assumes the installation of 95 11-m diameter monopiles and 3 4-legged OSP jackets with 4.5 m diameter during year one, and 51 11-m diameter monopiles during year two.

Table G-10. Yearly realistic jacket construction schedules (days of piling per month) used to estimate the total number of marine mammal and sea turtle acoustic exposures.

Construction month	Year One		Year Two	
	WTG Jacket 2.9 m diameter MHU1900S (3 pin piles/day)	OSP Jacket 4.5 m diameter IHCS2000 (4 pin piles/day)	WTG Jacket 2.9 m diameter MHU1900S (3 pin piles/day)	OSP Jacket 4.5 m diameter IHCS2000 (4 pin piles/day)
Jan	0	0	0	0
Feb	0	0	0	0
Mar	0	0	0	0
Apr	0	0	0	0
May	0	0	0	0
Jun	13	3	13	0
Jul	17	0	17	0
Aug	17	0	16	0
Sep	15	0	13	0
Oct	15	0	0	0
Nov	10	0	0	0
Dec	0	0	0	0
Total # of days	**87**	**3**	**59**	**0**

Table G-11. Yearly realistic monopile construction schedules (days of piling per month) used to estimate the total number of marine mammal and sea turtle acoustic exposures.

Construction month	**Year One**		**Year Two**	
	WTG Monopile 11 m diameter MHU4400S (1 pile/day)	OSP Jacket 4.5 m diameter IHCS2000 (4 pin piles/day)	WTG Monopile 11 m diameter MHU4400S (1 pile/day)	OSP Jacket 4.5 m diameter IHCS2000 (4 pin piles/day)
Jan	0	0	0	0
Feb	0	0	0	0
Mar	0	0	0	0
Apr	0	0	0	0
May	11	0	5	0
Jun	23	3	23	0
Jul	23	0	23	0
Aug	24	0	0	0
Sep	14	0	0	0
Oct	0	0	0	0
Nov	0	0	0	0
Dec	0	0	0	0
Total # of days	**95**	**3**	**51**	**0**

The total number of real-world individual marine mammals predicted to receive sound levels above the Levels A and B thresholds (NOAA 2005, Wood et al. 2012, NMFS 2018) resulting from the construction schedules are described in Tables G-12 to G-15. Level B SPL are shown as unweighted (NOAA 2005) and M-weighted (Wood et al. 2012).

Table G-12. Year one realistic WTG jacket foundation schedule: the mean number of modeled marine mammals estimated to experience sound levels above exposure criteria for different sound attenuation levels (Table G-10).

Species	Level A								Level B							
	L_E (NMFS 2018)				L_{pk} (NMFS 2018)				L_p (NOAA 2005)				L_p (Wood et al. 2012)			
	Attenuation (dB)								Attenuation (dB)							
	0	6	10	15	0	6	10	15	0	6	10	15	0	6	10	15
Low-frequency cetaceans																
Fin whale[a]	204.15	81.54	35.98	10.08	0.11	0	0	0	317.35	165.10	106.77	67.42	332.23	186.71	126.16	79.64
Minke whale	67.98	25.30	10.27	2.28	0.07	<0.01	0	0	178.34	96.18	63.02	38.42	158.92	93.89	65.94	42.64
Humpback whale	15.55	5.79	2.78	0.98	0	0	0	0	19.27	7.97	4.70	3.22	22.71	12.61	8.37	4.92
North Atlantic right whale[a]	4.07	1.76	0.83	0.24	<0.01	0	0	0	7.29	3.56	2.26	1.36	7.83	4.33	2.92	1.78
Sei whale[a]	9.28	3.85	1.78	0.55	<0.01	0	0	0	13.99	7.37	4.79	3.06	14.48	8.19	5.55	3.53
Mid-frequency cetaceans																
Atlantic white sided dolphin	1.21	0	0	0	0	0	0	0	3480.80	1817.33	1135.19	666.59	2698.84	1463.77	992.39	571.49
Short-beaked common dolphin	5.66	5.57	2.83	0	0	0	0	0	20973.48	11866.02	7848.20	4823.57	14698.86	8485.94	6071.82	3564.22
Bottlenose dolphin	4.50	1.43	1.29	0.03	0	0	0	0	1247.35	450.67	239.54	134.65	1284.72	638.16	398.24	194.24
Risso's dolphin	0.20	0.10	0.10	<0.01	0	0	0	0	294.54	159.06	106.60	67.80	236.32	130.50	91.17	52.12
Pilot whale[c]	0	0	0	0	0	0	0	0	0	0	0	0	0.31	0	0	0
Sperm whale[a]	<0.01	<0.01	0	0	0	0	0	0	13.01	5.82	3.63	2.39	11.34	5.94	3.97	2.09
High-frequency cetaceans																
Harbor porpoise	518.36	232.42	109.26	39.60	29.99	13.25	4.93	0.87	1044.86	522.43	321.91	201.88	8271.21	6611.03	5390.81	3942.90
Pinnipeds in water																
Gray seal	100.32	24.16	7.01	1.56	0.52	0.40	0.40	0	713.91	316.59	188.39	114.88	798.89	416.26	267.88	151.80
Harbor seal	81.78	19.23	6.42	0.54	0.66	0.04	0	0	690.54	296.76	175.97	104.63	779.75	398.58	258.60	142.93

[a] Listed as Endangered under the ESA.
[b] Long- and short-finned pilot whales are combined.

Table G-13. Year two realistic WTG jacket foundation schedule: the mean number of modeled marine mammals estimated to experience sound levels above exposure criteria for different sound attenuation levels (Table G-10).

Species	Level A								Level B							
	L_E (NMFS 2018)				L_{pk} (NMFS 2018)				L_p (NOAA 2005)				L_p (Wood et al. 2012)			
	Attenuation (dB)								Attenuation (dB)							
	0	6	10	15	0	6	10	15	0	6	10	15	0	6	10	15
Low-frequency cetaceans																
Fin whale[a]	141.77	54.59	22.85	5.68	0.06	0	0	0	226.70	116.61	75.08	46.83	239.73	133.95	90.25	56.58
Minke whale	42.88	14.72	5.32	0.99	0.04	0	0	0	122.39	64.16	41.61	24.60	110.60	64.50	45.10	28.74
Humpback whale	8.93	3.24	1.51	0.51	0	0	0	0	11.69	4.74	2.80	1.93	14.03	7.75	5.13	2.99
North Atlantic right whale[a]	1.17	0.49	0.22	0.06	<0.01	0	0	0	2.19	1.05	0.66	0.39	2.39	1.31	0.88	0.53
Sei whale[a]	6.59	2.54	1.06	0.26	<0.01	0	0	0	10.54	5.42	3.49	2.18	11.15	6.23	4.20	2.63
Mid-frequency cetaceans																
Atlantic white sided dolphin	0.68	0	0	0	0	0	0	0	2142.09	1100.25	678.49	387.80	1692.15	911.24	613.02	347.19
Short-beaked common dolphin	3.30	3.30	1.65	0	0	0	0	0	11838.04	6649.40	4377.30	2652.16	8357.02	4809.58	3430.12	1989.20
Bottlenose dolphin	2.55	0.85	0.85	0	0	0	0	0	804.98	288.16	153.01	85.85	837.71	415.50	258.92	125.55
Risso's dolphin	0.16	0.08	0.08	0	0	0	0	0	233.01	125.28	83.81	52.95	188.01	103.62	72.29	41.05
Pilot whale[b]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sperm whale[a]	0	0	0	0	0	0	0	0	9.77	4.33	2.70	1.77	8.60	4.50	3.00	1.56
High-frequency cetaceans																
Harbor porpoise	342.31	149.16	66.82	23.06	18.82	8.47	3.06	0.47	698.74	344.19	210.56	130.57	5720.29	4560.32	3707.25	2701.40
Pinnipeds in water																
Gray seal	53.43	10.45	2.09	0.60	0.30	0.30	0.30	0	438.51	189.55	113.14	68.66	506.60	262.15	168.09	93.61
Harbor seal	41.99	7.82	2.61	0	0.29	0	0	0	424.29	176.96	105.13	60.53	494.12	250.61	162.36	87.55

[a] Listed as Endangered under the ESA.
[b] Long- and short-finned pilot whales are combined.

Table G-14. Year one realistic WTG monopile foundation schedule: the mean number of modeled marine mammals estimated to experience sound levels above exposure criteria for different sound attenuation levels (Table G-11).

Species	Level A								Level B							
	L_E (NMFS 2018)				L_{pk} (NMFS 2018)				L_p (NOAA 2005)				L_p (Wood et al. 2012)			
	Attenuation (dB)								Attenuation (dB)							
	0	6	10	15	0	6	10	15	0	6	10	15	0	6	10	15
Low-frequency cetaceans																
Fin whale[a]	151.18	64.84	32.13	9.36	0.41	0.09	0	0	301.49	166.11	106.27	72.98	309.79	180.54	122.85	78.95
Minke whale	58.53	22.91	9.69	1.79	0.09	<0.01	0	0	178.49	105.47	72.34	50.59	163.29	99.23	70.19	47.42
Humpback whale	13.58	4.39	2.19	0.77	0.02	0	0	0	21.69	9.28	5.03	3.12	23.32	13.31	8.79	5.19
North Atlantic right whale[a]	5.49	2.29	0.99	0.37	0.02	0	0	0	14.51	7.29	4.67	2.93	15.19	8.53	5.83	3.61
Sei whale[a]	9.80	4.27	2.15	0.65	0.03	<0.01	0	0	18.96	10.48	6.72	4.62	19.40	11.32	7.71	4.97
Mid-frequency cetaceans																
Atlantic white sided dolphin	0.24	0	0	0	0	0	0	0	3178.43	1685.79	1103.23	755.99	1536.91	861.57	585.90	321.87
Short-beaked common dolphin	2.75	0.09	0.09	0	0	0	0	0	13464.69	8039.44	5558.36	4004.20	6292.09	3800.47	2666.06	1537.07
Bottlenose dolphin	0.73	0.17	0.03	0.03	0	0	0	0	1415.36	602.22	332.71	181.49	720.10	351.26	212.38	90.87
Risso's dolphin	0.13	0.12	<0.01	<0.01	0	0	0	0	276.48	156.77	100.34	69.59	132.94	74.68	51.15	29.01
Pilot whale[b]	0	0	0	0	0	0	0	0	0	0	0	0	0.31	0	0	0
Sperm whale[a]	<0.01	<0.01	0	0	0	0	0	0	14.47	6.91	4.05	2.56	7.06	3.78	2.37	1.18
High-frequency cetaceans																
Harbor porpoise	220.90	94.75	41.05	8.64	54.18	21.64	9.73	2.23	1170.07	635.23	392.64	267.55	7944.41	5741.88	4181.65	2667.48
Pinnipeds in water																
Gray seal	67.56	19.91	5.17	0.76	3.08	0	0	0	1551.87	720.46	421.26	235.20	1250.87	663.30	423.70	251.81
Harbor seal	53.73	12.49	2.90	0.54	0.27	0.04	0	0	1440.97	673.11	375.62	229.59	1206.32	617.27	405.02	224.18

[a] Listed as Endangered under the ESA.
[b] Long- and short-finned pilot whales are combined.

Table G-15. Year two realistic WTG monopile foundation schedule: the mean number of modeled marine mammals estimated to experience sound levels above exposure criteria for different sound attenuation levels (Table G-11).

Species	Level A								Level B							
	L_E (NMFS 2018)				L_{pk} (NMFS 2018)				L_p (NOAA 2005)				L_p (Wood et al. 2012)			
	Attenuation (dB)								Attenuation (dB)							
	0	6	10	15	0	6	10	15	0	6	10	15	0	6	10	15
Low-frequency cetaceans																
Fin whale[a]	74.52	30.84	14.72	3.80	0.21	0.05	0	0	159.01	87.10	55.41	37.96	164.87	95.81	65.04	41.58
Minke whale	29.79	10.82	4.10	0.50	0.05	0	0	0	103.59	60.61	41.57	29.14	96.52	58.20	41.05	27.57
Humpback whale	7.34	2.21	1.07	0.36	0.02	0	0	0	12.85	5.43	2.91	1.79	13.93	7.93	5.22	3.06
North Atlantic right whale[a]	2.68	1.10	0.45	0.16	0.01	0	0	0	7.53	3.75	2.40	1.50	7.92	4.44	3.03	1.87
Sei whale[a]	5.36	2.22	1.06	0.27	0.02	<0.01	0	0	11.43	6.26	3.98	2.73	11.85	6.89	4.67	2.99
Mid-frequency cetaceans																
Atlantic white sided dolphin	0	0	0	0	0	0	0	0	1903.86	994.26	647.00	444.00	867.88	483.57	324.36	170.35
Short-beaked common dolphin	1.29	0	0	0	0	0	0	0	6101.21	3623.73	2500.77	1800.87	2745.03	1656.62	1149.22	640.27
Bottlenose dolphin	0	0	0	0	0	0	0	0	685.31	291.41	161.14	87.67	340.31	165.34	99.46	41.55
Risso's dolphin	0.05	0.05	0	0	0	0	0	0	109.49	61.94	39.48	27.32	51.56	28.90	19.71	11.03
Pilot whale[b]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sperm whale[a]	0	0	0	0	0	0	0	0	7.31	3.48	2.03	1.27	3.47	1.86	1.15	0.56
High-frequency cetaceans																
Harbor porpoise	89.66	34.81	12.13	0.26	26.37	10.55	4.75	1.05	570.41	308.01	189.34	128.95	3954.66	2830.80	2035.43	1274.59
Pinnipeds in water																
Gray seal	25.23	6.31	0.63	0	1.89	0	0	0	914.45	421.91	246.59	136.22	726.58	384.38	244.82	144.80
Harbor seal	18.36	2.45	0	0	0	0	0	0	846.22	393.43	218.44	132.16	699.55	356.29	233.86	127.58

[a] Listed as Endangered under the ESA.
[b] Long- and short-finned pilot whales are combined.

G.2.3. Sea Turtle Exposure Range Estimates

Similar to the results presented for marine mammals (Appendix G.2.1), Tables G-16 to G-22 contain the exposure ranges ($ER_{95\%}$) for sea turtles to injury and behavioral criteria thresholds (Table 4) for the yearly realistic monopile and jacket foundations considering broadband mitigation of 0, 6, 10, and 15 dB attenuation.

Table G-16. Realistic scenario WTG monopile foundation (11 m diameter, MHU4400S hammer, two piles per day) exposure ranges ($ER_{95\%}$) in km to sea turtle injury and behavioral thresholds with sound attenuation.

Species	Injury								Behavior			
	L_E				L_{pk}				L_p			
	Attenuation (dB)								Attenuation (dB)			
	0	6	10	15	0	6	10	15	0	6	10	15
Kemp's ridley turtle[a]	1.00	0.30	0	0	0	0	0	0	2.99	2.06	1.23	0.52
Leatherback turtle[a]	1.59	0.29	0.05	0	0	0	0	0	2.84	1.81	1.11	0.53
Loggerhead turtle[a]	0.35	0.02	0	0	0	0	0	0	2.63	1.90	1.13	0.41
Green turtle	1.91	0.69	0.14	0.01	0	0	0	0	3.18	2.36	1.37	0.66

[a] Listed as Endangered under the ESA.

Table G-17. Realistic scenario WTG jacket foundation (2.9 m diameter, MHU1900S hammer, four piles per day) exposure ranges ($ER_{95\%}$) in km to sea turtle injury and behavioral thresholds with sound attenuation.

Species	Injury								Behavior			
	L_E				L_{pk}				L_p			
	Attenuation (dB)								Attenuation (dB)			
	0	6	10	15	0	6	10	15	0	6	10	15
Kemp's ridley turtle[a]	0.32	0	0	0	0	0	0	0	2.29	0.98	0.53	0.25
Leatherback turtle[a]	0.32	0.08	0	0	0	0	0	0	1.82	0.78	0.42	0.15
Loggerhead turtle[a]	0.15	0	0	0	0	0	0	0	1.73	0.77	0.37	0.18
Green turtle	0.58	0.06	0	0	0	0	0	0	2.48	0.93	0.42	0.20

[a] Listed as Endangered under the ESA.

Table G-18. Realistic scenario OSP jacket foundation[a] (2.9 m diameter, MHU1900S hammer) exposure ranges in km to sea turtle injury and behavior thresholds assuming four piles per day with sound attenuation.

Species	Injury								Behavior			
	L_E				L_{pk}				L_p			
	Attenuation (dB)								Attenuation (dB)			
	0	6	10	15	0	6	10	15	0	6	10	15
Kemp's ridley turtle[b]	0.67	0.16	0	0	0	0	0	0	2.79	1.09	0.75	0.31
Leatherback turtle[b]	0.51	0.08	<0.01	0	0	0	0	0	2.39	1.04	0.50	0.20
Loggerhead turtle[b]	0.15	0.03	0	0	0	0	0	0	2.12	1.14	0.59	0.24
Green turtle	0.98	0.21	0.03	0	0	0	0	0	2.80	1.41	0.60	0.21

[a] OSP foundations include +2 dB for post piling sound production.

[b] Listed as Endangered under the ESA.

Table G-19. Maximum scenario WTG jacket foundation (4.5 m diameter, IHCS2000 hammer) exposure ranges in km to sea turtle injury and behavior thresholds assuming four piles per day with sound attenuation.

Species	Injury								Behavior			
	L_E				L_{pk}				L_p			
	Attenuation (dB)								Attenuation (dB)			
	0	6	10	15	0	6	10	15	0	6	10	15
Kemp's ridley turtle[a]	1.13	0.20	0.16	0	0	0	0	0	2.78	1.35	0.82	0.32
Leatherback turtle[a]	1.44	0.08	0.02	0.02	0	0	0	0	2.50	1.27	0.57	0.29
Loggerhead turtle[a]	0.30	0.07	0	0	0	0	0	0	2.29	1.18	0.70	0.33
Green turtle	1.83	0.50	0.08	0	0	0	0	0	2.73	1.61	0.79	0.36

[a] Listed as Endangered under the ESA.

Table G-20. Maximum scenario WTG monopile foundation (16 m diameter, 6600 kJ hammer, 7000 strikes, two piles per day) exposure ranges ($ER_{95\%}$) in km to sea turtle injury and behavioral thresholds with sound attenuation.

Species	Injury								Behavior			
	L_E				L_{pk}				L_p			
	Attenuation (dB)								Attenuation (dB)			
	0	6	10	15	0	6	10	15	0	6	10	15
Kemp's ridley turtle[a]	2.23	0.83	0.30	0.01	0	0	0	0	3.77	2.80	2.19	1.08
Leatherback turtle[a]	2.52	1.19	0.29	0.05	0	0	0	0	3.51	2.54	2.01	0.98
Loggerhead turtle[a]	0.98	0.23	0.02	0	0	0	0	0	3.28	2.55	2.00	1.02
Green turtle	3.88	1.61	0.70	0.13	0	0	0	0	4.21	2.91	2.47	1.37

[a] Listed as Endangered under the ESA.

Table G-21. Maximum scenario WTG monopile foundation (16 m diameter, 6600 kJ hammer, 6265 strikes, one pile per day) exposure ranges ($ER_{95\%}$) in km to sea turtle injury and behavioral thresholds with sound attenuation.

Species	Injury								Behavior			
	L_E				L_{pk}				L_p			
	Attenuation (dB)								Attenuation (dB)			
	0	6	10	15	0	6	10	15	0	6	10	15
Kemp's ridley turtle[a]	2.14	0.88	0.44	0	0	0	0	0	4.01	2.80	2.30	1.18
Leatherback turtle[a]	3.27	1.06	0.52	0	0	0	0	0	3.69	2.57	2.09	1.13
Loggerhead turtle[a]	0.96	0.34	0	0	0	0	0	0	3.15	2.37	1.90	0.96
Green turtle	3.51	1.41	0.61	0.11	0	0	0	0	4.16	2.87	2.42	1.37

[a] Listed as Endangered under the ESA.

Table G-22. Maximum scenario WTG monopile foundation (16 m diameter. 6600 kJ hammer, 6265 strikes, two piles per day) exposure ranges ($ER_{95\%}$) in km to sea turtle injury and behavioral thresholds with sound attenuation.

Species	Injury								Behavior			
	L_E				L_{pk}				L_p			
	Attenuation (dB)								Attenuation (dB)			
	0	6	10	15	0	6	10	15	0	6	10	15
Kemp's ridley turtle[a]	2.15	0.80	0.28	0.01	0	0	0	0	3.89	2.81	2.23	1.08
Leatherback turtle[a]	2.64	0.76	0.29	0.05	0	0	0	0	3.51	2.46	2.02	1.05
Loggerhead turtle[a]	1.06	0.23	0.02	0	0	0	0	0	3.24	2.57	1.99	1.00
Green turtle	3.74	1.48	0.72	0.13	0	0	0	0	4.21	2.91	2.45	1.33

[a] Listed as Endangered under the ESA.

G.2.4. Sea Turtle Exposure Estimates

The total number of sea turtles predicted to receive sound levels above the injury and behavioral response thresholds (Tables G-23 to G-26) are estimated for the yearly realistic construction schedules described in Tables G-10 and G-11. Results include the realistic WTG monopile and jacket foundation considering broadband mitigation of 0, 6, 10, and 15 dB attenuation, and are calculated in the same way as the marine mammals (Appendix G.2.2).

Table G-23. Year one realistic WTG jacket foundation schedule: the mean number of modeled sea turtles[a] estimated to experience sound levels above exposure criteria for different sound attenuation levels (Table G-10)

Species	Injury									Behavior		
	L_E				L_p					L_p		
	Attenuation (dB)									Attenuation (dB)		
	0	6	10	15	0	6	10	15	0	6	10	15
Kemp's ridley turtle[b]	0.02	<0.01	<0.01	0	0	0	0	0	0.31	0.10	0.04	0.01
Leatherback turtle[b]	1.96	0.44	0.03	<0.01	0	0	0	0	26.07	9.40	4.72	1.49
Loggerhead turtle[b]	0.31	0.01	<0.01	0	0	0	0	0	30.54	10.25	3.29	0.60
Green turtle	0.07	<0.01	<0.01	<0.01	0	0	0	0	0.33	0.11	0.06	0.02

[a] OSP foundations include +2 dB for post piling sound production.
[b] Listed as Endangered under the ESA.

Table G-24. Year two realistic WTG jacket foundation schedule: the mean number of modeled sea turtles[a] estimated to experience sound levels above exposure criteria for different sound attenuation levels (Table G-10).

Species	Injury								Behavior			
	L_E				L_p				L_p			
	Attenuation (dB)								Attenuation (dB)			
	0	6	10	15	0	6	10	15	0	6	10	15
Kemp's ridley turtle [b]	0.01	0	0	0	0	0	0	0	0.19	0.06	0.02	<0.01
Leatherback turtle [b]	0.90	0.20	0	0	0	0	0	0	14.83	5.17	2.59	0.80
Loggerhead turtle[b]	0.11	0	0	0	0	0	0	0	13.94	4.57	1.38	0.22
Green turtle	0.03	<0.01	<0.01	0	0	0	0	0	0.20	0.06	0.03	0.01

[a] OSP foundations include +2 dB for post piling sound production.
[b] Listed as Endangered under the ESA.

Table G-25. Year one realistic WTG monopile foundation schedule: the mean number of modeled sea turtles[a] estimated to experience sound levels above exposure criteria for different sound attenuation levels (Table G-11).

Species	Injury								Behavior			
	L_E				L_p				L_p			
	Attenuation (dB)								Attenuation (dB)			
	0	6	10	15	0	6	10	15	0	6	10	15
Kemp's ridley turtle [b]	0.06	<0.01	<0.01	0	0	0	0	0	0.31	0.16	0.07	0.03
Leatherback turtle [b]	3.60	0.54	0.03	<0.01	0	0	0	0	24.31	11.33	5.61	2.46
Loggerhead turtle[b]	0.60	0.01	<0.01	0	0	0	0	0	19.63	9.68	5.48	1.92
Green turtle	0.11	0.03	<0.01	<0.01	0	0	0	0	0.35	0.21	0.10	0.05

[a] OSP foundations include +2 dB for post piling sound production.
[b] Listed as Endangered under the ESA.

Table G-26. Year two realistic WTG monopile foundation schedule: the mean number of modeled sea turtles[a] estimated to experience sound levels above exposure criteria for different sound attenuation levels (Table G-11).

Species	Injury								Behavior			
	L_E				L_p				L_p			
	Attenuation (dB)								Attenuation (dB)			
	0	6	10	15	0	6	10	15	0	6	10	15
Kemp's ridley turtle [b]	0.03	<0.01	0	0	0	0	0	0	0.15	0.08	0.04	0.01
Leatherback turtle [b]	1.58	0.22	0	0	0	0	0	0	11.29	5.25	2.59	1.15
Loggerhead turtle[b]	0.20	0	0	0	0	0	0	0	6.84	3.39	1.92	0.68
Green turtle	0.05	0.01	<0.01	0	0	0	0	0	0.17	0.11	0.05	0.02

[a] OSP foundations include +2 dB for post piling sound production.
[b] Listed as Endangered under the ESA.

G.2.5. Impact Pile Driving Simulation Animat Counts

The following tables show the number of animats exceeding Level A and Level B sound exposure thresholds in a 24-hour period for the installation of jacket and monopile foundations during the summer. Results are included for the summer season with broadband mitigation of 0, 6, 10, and 15 dB attenuation.

Table G-27. Realistic scenario WTG monopile foundation (11 m diameter, MHU4400S hammer, one pile per day): the number of modeled marine mammal animats exposed to sound levels above injury and behavioral thresholds with attenuation.

Species	Injury								Behavior							
	L_E (NMFS 2018)				L_{pk} (NMFS 2018)				L_p (NOAA 2005)				L_p (Wood et al. 2012)			
	Attenuation (dB)								Attenuation (dB)							
	0	6	10	15	0	6	10	15	0	6	10	15	0	6	10	15
Low-frequency cetaceans																
Fin whale[a] (sei whale[a,b])	198.86	82.29	39.29	10.14	0.57	0.14	0	0	424.29	232.43	147.86	101.29	439.93	255.66	173.54	110.94
Minke whale	169.14	61.43	23.29	2.86	0.29	0	0	0	588.14	344.14	236.00	165.43	548.00	330.41	233.04	156.56
Humpback whale	64.86	19.57	9.43	3.14	0.14	0	0	0	113.57	48.00	25.71	15.86	123.13	70.11	46.17	27.06
North Atlantic right whale[a]	114.86	47.00	19.14	7.00	0.43	0	0	0	322.43	160.71	102.86	64.14	339.30	189.96	129.73	80.17
Mid-frequency cetaceans																
Atlantic white sided dolphin	0	0	0	0	0	0	0	0	314.86	164.43	107.00	73.43	143.53	79.97	53.64	28.17
Short-beaked common dolphin	0.14	0	0	0	0	0	0	0	673.71	400.14	276.14	198.86	303.11	182.93	126.90	70.70
Bottlenose dolphin	0	0	0	0	0	0	0	0	158.57	67.43	37.29	20.29	78.74	38.26	23.01	9.61
Risso's dolphin	0.14	0.14	0	0	0	0	0	0	321.71	182.00	116.00	80.29	151.49	84.90	57.91	32.41
Pilot whale	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sperm whale	0	0	0	0	0	0	0	0	351.43	167.14	97.57	61.14	166.86	89.27	55.49	26.90
High-frequency cetaceans																
Harbor porpoise	48.57	18.86	6.57	0.14	14.29	5.71	2.57	0.57	309.00	166.86	102.57	69.86	2142.31	1533.50	1102.63	690.47
Pinnipeds in water																
Gray seal	5.71	1.43	0.14	0	0.43	0	0	0	207.14	95.57	55.86	30.86	164.59	87.07	55.46	32.80
Harbor seal	4.29	0.57	0	0	0	0	0	0	197.57	91.86	51.00	30.86	163.33	83.19	54.60	29.79

[a] Endangered species
[b] Fin whale used as a surrogate for sei whale behavioral definition.

Table G-28. Realistic scenario WTG monopile foundation (11 m diameter, MHU4400S hammer, two piles per day): the number of modeled marine mammal animats exposed to sound levels above injury and behavioral thresholds with attenuation.

Species	Injury								Behavior							
	L_E (NMFS 2018)				L_{pk} (NMFS 2018)				L_p (NOAA 2005)				L_p (Wood et al. 2012)			
	Attenuation (dB)								Attenuation (dB)							
	0	6	10	15	0	6	10	15	0	6	10	15	0	6	10	15
Low-frequency cetaceans																
Fin whale[a] (sei whale[a,b])	374.43	161.00	82.57	23.86	2.00	0	0	0	713.29	412.29	276.43	190.57	658.54	401.44	282.33	189.53
Minke whale	320.71	117.71	39.57	4.29	0.43	0.14	0.14	0	1053.00	632.43	444.86	319.71	896.31	562.94	407.60	283.31
Humpback whale	111.14	40.86	17.86	5.00	0.29	0	0	0	163.86	82.00	50.14	30.00	153.30	91.17	63.07	39.80
North Atlantic right whale[a]	211.57	82.00	39.14	11.29	0.71	0	0	0	498.00	276.29	174.43	110.86	454.97	272.96	188.71	123.00
Mid-frequency cetaceans																
Atlantic white sided dolphin	0.14	0	0	0	0	0	0	0	550.57	320.14	212.29	144.14	238.16	141.14	97.14	53.76
Short-beaked common dolphin	0.29	0	0	0	0.14	0	0	0	1223.14	756.57	542.86	399.43	520.61	332.14	239.97	138.54
Bottlenose dolphin	0	0	0	0	0	0	0	0	230.86	112.29	68.00	38.71	107.71	56.33	35.41	17.10
Risso's dolphin	0.43	0.29	0	0	0	0	0	0	531.29	308.57	203.43	145.71	228.53	138.30	96.99	56.01
Pilot whale	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sperm whale	0	0	0	0	0	0	0	0	571.86	310.71	191.71	125.86	252.01	143.17	96.03	49.61
High-frequency cetaceans																
Harbor porpoise	96.86	40.00	11.71	0.86	27.71	10.86	6.14	2.14	515.43	298.43	194.29	134.71	2705.63	2002.39	1494.47	979.99
Pinnipeds in water																
Gray seal	13.43	2.43	0.29	0	1.00	0	0	0	310.57	163.71	102.57	62.86	225.57	124.63	84.63	51.01
Harbor seal	9.86	1.57	0.14	0	0.43	0	0	0	296.57	155.00	96.14	60.14	224.57	121.74	83.37	49.13

[a] Endangered species
[b] Fin whale used as a surrogate for sei whale behavioral definition.

Table G-29. Realistic scenario WTG jacket foundation (2.9 m diameter, MHU1900S hammer, three piles per day): the number of modeled marine mammal animats exposed to sound levels above injury and behavioral thresholds with attenuation.

Species	Injury								Behavior							
	L_E (NMFS 2018)				L_{pk} (NMFS 2018)				L_p (NOAA 2005)				L_p (Wood et al. 2012)			
	Attenuation (dB)								Attenuation (dB)							
	0	6	10	15	0	6	10	15	0	6	10	15	0	6	10	15
Low-frequency cetaceans																
Fin whale[a] (sei whale[a,b])	359.86	138.57	58.00	14.43	0.14	0	0	0	575.43	296.00	190.57	118.86	608.50	340.01	229.07	143.61
Minke whale	322.43	110.71	40.00	7.43	0.29	0	0	0	920.29	482.43	312.86	185.00	831.69	485.03	339.14	216.09
Humpback whale	89.86	32.57	15.14	5.14	0	0	0	0	117.57	47.71	28.14	19.43	141.09	77.94	51.56	30.09
North Atlantic right whale[a]	214.00	90.57	40.29	10.14	0.14	0	0	0	401.29	192.00	121.71	71.71	437.39	240.09	161.27	97.54
Mid-frequency cetaceans																
Atlantic white sided dolphin	0.14	0	0	0	0	0	0	0	450.57	231.43	142.71	81.57	355.93	191.67	128.94	73.03
Short-beaked common dolphin	0.29	0.29	0.14	0	0	0	0	0	1023.43	574.86	378.43	229.29	722.49	415.80	296.54	171.97
Bottlenose dolphin	0.43	0.14	0.14	0	0	0	0	0	135.29	48.43	25.71	14.43	140.79	69.83	43.51	21.10
Risso's dolphin	0.29	0.14	0.14	0	0	0	0	0	417.43	224.43	150.14	94.86	336.81	185.63	129.50	73.54
Pilot whale	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sperm whale	0	0	0	0	0	0	0	0	395.57	175.29	109.29	71.57	348.11	182.16	121.29	63.26
High-frequency cetaceans																
Harbor porpoise	207.86	90.57	40.57	14.00	11.43	5.14	1.86	0.29	424.29	209.00	127.86	79.29	3473.47	2769.11	2251.11	1640.34
Pinnipeds in water																
Gray seal	25.57	5.00	1.00	0.29	0.14	0.14	0.14	0	209.86	90.71	54.14	32.86	242.44	125.46	80.44	44.80
Harbor seal	20.71	3.86	1.29	0	0.14	0	0	0	209.29	87.29	51.86	29.86	243.73	123.61	80.09	43.19

[a] Endangered species
[b] Fin whale used as a surrogate for sei whale behavioral definition.

Table G-30. Realistic scenario WTG jacket foundation (2.9 m diameter, MHU1900S hammer, four piles per day): the number of modeled marine mammal animats exposed to sound levels above injury and behavioral thresholds with attenuation.

Species	Injury								Behavior							
	L_E (NMFS 2018)				L_{pk} (NMFS 2018)				L_p (NOAA 2005)				L_p (Wood et al. 2012)			
	Attenuation (dB)								Attenuation (dB)							
	0	6	10	15	0	6	10	15	0	6	10	15	0	6	10	15
Low-frequency cetaceans																
Fin whale[a] (sei whale[a,b])	459.14	184.71	77.71	18.29	0	0	0	0	710.14	377.00	243.14	152.86	710.06	404.83	276.50	176.59
Minke whale	436.29	150.29	55.86	10.43	0.57	0	0	0	1195.71	640.00	415.71	247.43	1033.89	614.21	432.23	280.21
Humpback whale	111.29	42.71	20.00	5.86	0	0	0	0	136.86	59.29	35.57	24.14	154.37	86.10	57.93	34.67
North Atlantic right whale[a]	276.00	117.00	55.00	13.71	0.29	0	0	0	484.86	240.29	153.57	93.29	496.40	278.53	190.27	118.36
Mid-frequency cetaceans																
Atlantic white sided dolphin	0.43	0	0	0	0	0	0	0	578.57	306.14	190.57	112.57	435.71	239.93	164.51	95.17
Short-beaked common dolphin	0.29	0.14	0.14	0	0	0	0	0	1316.71	743.14	491.14	303.43	891.41	518.73	375.74	221.00
Bottlenose dolphin	0.71	0.14	0.14	0	0	0	0	0	145.86	53.57	29.29	17.29	147.93	73.81	46.03	23.10
Risso's dolphin	0.29	0.14	0.14	0	0	0	0	0	515.86	285.29	193.57	121.43	397.77	223.64	157.27	89.76
Pilot whale	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sperm whale	0	0	0	0	0	0	0	0	468.43	222.29	138.86	91.14	395.97	208.61	141.86	76.06
High-frequency cetaceans																
Harbor porpoise	268.43	121.43	57.71	19.00	15.14	6.43	2.43	0.43	529.71	269.71	168.29	104.29	3902.54	3095.37	2528.10	1868.39
Pinnipeds in water																
Gray seal	35.14	9.57	1.86	0.57	0.14	0	0	0	241.57	109.43	66.43	40.86	266.29	139.71	90.67	51.00
Harbor seal	31.14	5.71	1.57	0	0.29	0	0	0	241.71	109.29	64.43	39.43	267.96	139.10	91.47	50.39

[a] Endangered species
[b] Fin whale used as a surrogate for sei whale behavioral definition.

Table G-31. Realistic scenario OSP jacket foundation[a] (2.9 m diameter, MHU1900S hammer, four piles per day): the number of modeled marine mammal animats exposed to sound levels above injury and behavioral thresholds with attenuation.

Species	Injury								Behavior							
	L_E (NMFS 2018)				L_{pk} (NMFS 2018)				L_p (NOAA 2005)				L_p (Wood et al. 2012)			
	Attenuation (dB)								Attenuation (dB)							
	0	6	10	15	0	6	10	15	0	6	10	15	0	6	10	15
Low-frequency cetaceans																
Fin whale[b] (sei whale[b,c])	588.43	258.14	124.57	34.14	0	0	0	0	864.71	474.57	298.14	187.86	843.64	488.94	332.54	212.20
Minke whale	594.71	216.00	95.43	22.57	0.57	0	0	0	1414.00	816.86	500.71	313.29	1204.10	737.97	508.87	337.49
Humpback whale	152.57	60.71	29.14	9.86	0	0	0	0	171.14	83.00	43.71	29.86	182.97	106.54	69.66	43.37
North Atlantic right whale[b]	350.29	160.43	84.71	25.14	0.29	0	0	0	593.71	308.71	192.71	119.71	591.13	337.53	230.67	145.56
Mid-frequency cetaceans																
Atlantic white sided dolphin	0.43	0	0	0	0	0	0	0	704.14	392.29	243.00	146.00	524.37	292.20	198.66	120.24
Short-beaked common dolphin	0.43	0.14	0.14	0	0	0	0	0	1541.57	925.57	600.00	389.00	1053.74	620.19	443.47	274.97
Bottlenose dolphin	1.43	0.43	0.14	0	0	0	0	0	193.43	75.14	40.29	23.57	185.11	93.47	58.11	30.54
Risso's dolphin	0.43	0.14	0.14	0	0	0	0	0	618.57	356.14	231.71	155.71	475.73	268.34	188.87	113.16
Pilot whale	0	0	0	0	0	0	0	0	0	0	0	0	28.17	0	0	0
Sperm whale	0.14	0	0	0	0	0	0	0	587.43	288.71	169.57	113.57	489.91	255.47	171.51	99.64
High-frequency cetaceans																
Harbor porpoise	335.29	163.86	86.57	32.14	15.14	6.43	2.43	0.43	645.57	350.86	210.71	132.57	4179.93	3357.36	2812.76	2158.87
Pinnipeds in water																
Gray seal	49.86	15.29	4.14	0.71	0.14	0	0	0	305.86	144.71	85.00	51.57	327.31	175.14	113.36	65.37
Harbor seal	47.71	10.43	2.43	0.29	0.29	0	0	0	307.14	141.29	85.14	52.71	329.49	174.50	111.59	66.20

[a] OSP foundations include a 2 dB shift for post piling
[b] Endangered species
[c] Fin whale used as a surrogate for sei whale behavioral definition.

Table G-32. Maximum scenario WTG jacket foundation (4.5 m diameter, IHCS2000 hammer, four piles per day): the number of modeled marine mammal animats exposed to sound levels above injury and behavioral thresholds with attenuation.

Species	Injury								Behavior							
	L_E (NMFS 2018)				L_{pk} (NMFS 2018)				L_p (NOAA 2005)				L_p (Wood et al. 2012)			
	Attenuation (dB)								Attenuation (dB)							
	0	6	10	15	0	6	10	15	0	6	10	15	0	6	10	15
Low-frequency cetaceans																
Fin whale[a] (sei whale[a,c])	811.57	402.00	218.57	79.00	1.29	0	0	0	1001.57	570.14	393.14	285.57	947.11	557.04	395.10	271.30
Minke whale	892.71	393.71	185.86	39.71	0.71	0	0	0	1722.14	1055.29	718.00	519.14	1433.54	903.23	649.39	462.00
Humpback whale	215.00	89.29	47.00	17.57	0	0	0	0	181.43	87.43	50.57	39.00	192.59	112.21	74.87	47.97
North Atlantic right whale[a]	503.71	237.00	132.14	50.57	0.57	0	0	0	673.43	368.29	245.29	173.57	649.91	377.50	264.04	176.56
Mid-frequency cetaceans																
Atlantic white sided dolphin	0.29	0	0	0	0	0	0	0	831.43	484.86	326.14	229.86	556.67	325.06	234.20	145.79
Short-beaked common dolphin	0.29	0.14	0.14	0	0	0	0	0	1842.57	1144.43	804.00	609.00	1142.59	706.90	541.47	348.36
Bottlenose dolphin	2.29	0.43	0.14	0	0	0	0	0	221.00	94.29	51.57	32.86	185.79	95.60	61.46	32.66
Risso's dolphin	0.57	0.29	0.29	0	0	0	0	0	718.29	429.86	301.43	223.43	498.89	294.39	215.79	137.44
Pilot whale	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sperm whale	0.29	0	0	0	0	0	0	0	654.00	336.71	216.43	161.29	484.01	267.26	187.70	110.36
High-frequency cetaceans																
Harbor porpoise	428.71	226.57	135.29	54.00	31.43	12.14	4.57	1.43	754.14	423.57	283.43	208.86	4349.49	3587.37	2988.59	2197.54
Pinnipeds in water																
Gray seal	75.43	24.57	9.14	1.00	0.29	0	0	0	340.43	165.71	98.43	69.00	336.04	179.80	120.63	74.89
Harbor seal	68.43	19.71	5.43	0.71	0.71	0	0	0	344.29	162.57	98.57	69.71	339.40	178.86	121.07	73.20

[a] Endangered species
[c] Fin whale used as a surrogate for sei whale behavioral definition.

Table G-33. Maximum scenario OSP jacket foundation[a] (4.5 m diameter, IHCS2000 hammer, four piles per day): the number of modeled marine mammal animats exposed to sound levels above injury and behavioral thresholds with attenuation.

Species	Injury								Behavior							
	L_E (NMFS 2018)				L_{pk} (NMFS 2018)				L_p (NOAA 2005)				L_p (Wood et al. 2012)			
	Attenuation (dB)								Attenuation (dB)							
	0	6	10	15	0	6	10	15	0	6	10	15	0	6	10	15
Low-frequency cetaceans																
Fin whale[b] (sei whale[b,c])	999.86	515.86	298.43	124.71	1.86	0	0	0	1192.86	696.14	469.57	329.86	1111.13	668.73	467.19	317.34
Minke whale	1116.43	528.43	274.86	78.71	1.57	0.29	0	0	2022.57	1260.14	865.29	597.57	1660.81	1058.60	761.47	531.59
Humpback whale	276.43	118.57	65.43	27.00	0	0	0	0	232.57	112.14	66.57	43.14	229.59	134.03	91.93	57.73
North Atlantic right whale[b]	625.00	303.86	182.71	76.86	0.86	0	0	0	808.14	457.00	295.57	201.43	762.24	453.33	313.71	207.69
Mid-frequency cetaceans																
Atlantic white sided dolphin	0.57	0	0	0	0	0	0	0	999.00	584.00	395.00	268.43	667.00	384.21	276.91	179.51
Short-beaked common dolphin	0.29	0.14	0.14	0	0	0	0	0	2161.43	1352.29	949.86	686.43	1351.94	821.10	617.63	427.94
Bottlenose dolphin	3.71	0.86	0.14	0.14	0	0	0	0	286.86	123.86	67.00	38.86	230.47	119.13	77.14	43.20
Risso's dolphin	0.71	0.29	0.29	0.29	0	0	0	0	856.29	509.43	354.57	255.57	596.83	347.09	251.16	167.07
Pilot whale	0	0	0	0	0	0	0	0	0	0	0	0	32.66	0	0	0
Sperm whale	2.57	0.14	0	0	0	0	0	0	813.43	418.14	267.57	186.86	595.19	323.51	224.81	140.36
High-frequency cetaceans																
Harbor porpoise	506.57	285.29	178.57	80.29	42.57	16.71	7.43	2.29	903.57	521.43	341.71	234.14	4611.10	3844.36	3287.43	2540.67
Pinnipeds in water																
Gray seal	100.71	36.00	15.00	2.71	0.43	0	0	0	434.43	216.43	127.14	79.14	409.10	221.96	145.80	90.57
Harbor seal	92.43	32.00	10.71	2.00	1.00	0.14	0	0	432.43	212.71	125.14	84.29	413.29	221.10	144.63	90.84

a OSP foundations include a 2 dB shift for post piling
[b] Endangered species
[c] Fin whale used as a surrogate for sei whale behavioral definition.

Table G-34. Maximum scenario WTG jacket foundation (4.5 m diameter, MHU3500S hammer, four piles per day): the number of modeled marine mammal animats exposed to sound levels above injury and behavioral thresholds with attenuation.

Species	Injury								Behavior							
	L_E (NMFS 2018)				L_{pk} (NMFS 2018)				L_p (NOAA 2005)				L_p (Wood et al. 2012)			
	Attenuation (dB)								Attenuation (dB)							
	0	6	10	15	0	6	10	15	0	6	10	15	0	6	10	15
Low-frequency cetaceans																
Fin whale[a] (sei whale[a,b])	392.57	165.86	74.57	18.43	0.57	0	0	0	546.57	311.43	235.71	167.71	545.53	320.90	231.56	155.44
Minke whale	377.14	129.43	44.71	7.29	0.29	0	0	0	956.86	549.14	418.14	290.29	819.56	496.03	372.84	258.44
Humpback whale	97.29	35.14	17.57	5.29	0	0	0	0	96.86	44.29	29.14	21.86	119.57	67.26	44.66	27.13
North Atlantic right whale[a]	229.86	97.00	47.00	13.71	0.14	0	0	0	363.57	199.00	147.00	100.57	382.51	220.59	156.64	100.57
Mid-frequency cetaceans																
Atlantic white sided dolphin	0	0	0	0	0	0	0	0	437.43	245.86	185.29	123.29	276.14	165.23	112.69	60.77
Short-beaked common dolphin	0.29	0.14	0	0	0	0	0	0	1047.57	632.14	494.43	359.29	601.57	388.80	279.29	156.56
Bottlenose dolphin	0.43	0	0	0	0	0	0	0	104.71	42.57	26.00	15.29	99.17	49.54	29.63	13.29
Risso's dolphin	0.14	0	0	0	0	0	0	0	397.43	235.86	181.43	133.00	263.40	160.31	111.10	63.24
Pilot whale	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sperm whale	0	0	0	0	0	0	0	0	350.00	173.57	126.57	94.43	254.71	142.96	96.29	49.23
High-frequency cetaceans																
Harbor porpoise	199.57	94.14	44.71	9.86	14.57	4.29	2.14	1.29	399.00	223.43	164.43	117.29	3172.14	2397.17	1912.94	1245.79
Pinnipeds in water																
Gray seal	23.00	5.14	0.86	0.29	0.29	0	0	0	177.14	85.00	58.43	41.29	186.41	98.34	65.71	36.21
Harbor seal	20.43	3.14	0.86	0.14	0.14	0	0	0	175.00	80.86	56.86	37.29	186.54	97.23	65.43	35.10

[a] Endangered species
[b] Fin whale used as a surrogate for sei whale behavioral definition.

Table G-35. Maximum scenario OSP jacket foundation[a] (4.5 m diameter, MHU3500S hammer, four piles per day): the number of modeled marine mammal animats exposed to sound levels above injury and behavioral thresholds with attenuation.

Species	Injury								Behavior							
	L_E (NMFS 2018)				L_{pk} (NMFS 2018)				L_p (NOAA 2005)				L_p (Wood et al. 2012)			
	Attenuation (dB)								Attenuation (dB)							
	0	6	10	15	0	6	10	15	0	6	10	15	0	6	10	15
Low-frequency cetaceans																
Fin whale[b] (sei whale[b,c])	490.00	222.29	113.71	36.57	0.86	0.14	0	0	654.00	374.86	262.57	197.43	653.26	383.66	269.07	184.49
Minke whale	500.00	191.00	77.00	13.14	0.43	0	0	0	1124.00	665.57	463.14	341.00	960.76	587.26	423.71	301.44
Humpback whale	133.29	50.86	25.86	9.29	0	0	0	0	125.86	57.29	34.29	25.00	144.17	81.86	54.56	33.46
North Atlantic right whale[b]	295.71	137.29	67.57	22.86	0.14	0	0	0	449.14	241.43	162.43	122.43	462.81	263.06	181.87	122.66
Mid-frequency cetaceans																
Atlantic white sided dolphin	0	0	0	0	0	0	0	0	520.14	299.71	205.14	149.14	339.64	197.24	137.47	79.14
Short-beaked common dolphin	0.29	0.29	0	0	0	0	0	0	1217.71	752.00	535.29	422.14	719.86	446.80	336.14	201.59
Bottlenose dolphin	1.00	0	0	0	0	0	0	0	148.57	57.86	32.14	20.14	125.51	62.44	39.17	18.73
Risso's dolphin	0.14	0	0	0	0	0	0	0	477.86	278.00	199.14	154.14	319.63	187.87	134.90	81.06
Pilot whale	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sperm whale	0	0	0	0	0	0	0	0	443.86	222.43	140.00	107.57	319.39	172.54	118.81	64.61
High-frequency cetaceans																
Harbor porpoise	244.57	119.86	63.71	18.43	18.29	7.14	2.43	1.57	478.71	272.29	181.57	137.29	3396.46	2681.39	2159.19	1479.17
Pinnipeds in water																
Gray seal	36.00	9.71	2.29	0.43	0.29	0.14	0	0	229.14	106.43	68.00	47.86	230.83	121.16	81.73	47.56
Harbor seal	31.43	6.71	1.86	0.14	0.29	0	0	0	228.71	102.43	64.43	45.57	232.34	118.94	80.30	45.94

a OSP foundations include a 2 dB shift for post piling
[b] Endangered species
[c] Fin whale used as a surrogate for sei whale behavioral definition.

Table G-36. Maximum scenario WTG monopile foundation (16 m diameter, 6600 kJ hammer, 7000 strikes, one pile per day): the number of modeled marine mammal animats exposed to sound levels above injury and behavioral thresholds with attenuation.

Species	Injury								Behavior							
	L_E (NMFS 2018)				L_{pk} (NMFS 2018)				L_p (NOAA 2005)				L_p (Wood et al. 2012)			
	Attenuation (dB)								Attenuation (dB)							
	0	6	10	15	0	6	10	15	0	6	10	15	0	6	10	15
Low-frequency cetaceans																
Fin whale[a] (sei whale[a,b])	375.57	174.86	96.71	39.71	1.71	0.14	0	0	649.14	378.57	258.71	154.00	617.41	383.09	270.01	168.66
Minke whale	331.57	155.14	72.43	18.57	1.43	0.14	0	0	892.29	566.86	405.57	258.86	781.64	514.50	372.86	242.81
Humpback whale	139.57	53.14	23.14	9.57	0.43	0	0	0	180.57	87.71	51.57	26.29	167.80	102.24	70.29	42.07
North Atlantic right whale[a]	232.00	99.29	54.71	19.29	0.57	0	0	0	489.71	270.71	177.00	103.43	472.04	286.69	196.57	121.83
Mid-frequency cetaceans																
Atlantic white sided dolphin	0	0	0	0	0	0	0	0	483.57	277.43	188.57	114.00	218.07	118.87	82.61	49.39
Short-beaked common dolphin	0.14	0.14	0	0	0	0	0	0	1038.71	649.57	465.14	300.57	453.26	267.44	197.21	125.23
Bottlenose dolphin	0	0	0	0	0	0	0	0	240.71	116.57	66.00	31.57	116.50	57.40	34.89	17.70
Risso's dolphin	0.14	0.14	0	0	0	0	0	0	484.57	283.14	197.29	123.00	223.56	124.13	86.07	53.17
Pilot whale	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sperm whale	0	0	0	0	0	0	0	0	557.43	291.86	182.43	97.14	251.59	131.04	87.26	47.64
High-frequency cetaceans																
Harbor porpoise	83.29	34.57	15.29	2.29	19.14	8.29	4.00	1.00	474.86	274.29	184.29	110.00	2440.56	1841.39	1479.89	962.59
Pinnipeds in water																
Gray seal	14.57	4.14	1.29	0.14	0.71	0	0	0	311.43	161.14	98.00	51.86	239.17	128.26	81.63	48.21
Harbor seal	11.86	2.00	0.57	0.14	0.29	0.14	0	0	306.43	155.29	94.43	47.43	237.09	124.37	79.41	45.83

[a] Endangered species
[b] Fin whale used as a surrogate for sei whale behavioral definition.

Table G-37. Maximum scenario WTG monopile foundation (16 m diameter, 6600 kJ hammer, 7000 strikes, two piles per day): the number of modeled marine mammal animats exposed to sound levels above injury and behavioral thresholds with attenuation.

Species	Injury								Behavior							
	L_E (NMFS 2018)				L_{pk} (NMFS 2018)				L_p (NOAA 2005)				L_p (Wood et al. 2012)			
	Attenuation (dB)								Attenuation (dB)							
	0	6	10	15	0	6	10	15	0	6	10	15	0	6	10	15
Low-frequency cetaceans																
Fin whale[a] (sei whale[a,b])	658.14	328.57	190.00	83.57	3.14	0.14	0	0	1017.57	633.86	454.86	291.86	888.04	580.09	425.80	280.31
Minke whale	615.29	288.57	141.57	33.57	1.29	0.14	0	0	1523.00	997.86	727.00	487.57	1238.50	844.09	626.96	426.26
Humpback whale	204.71	91.00	47.57	17.29	0.43	0	0	0	242.00	137.86	86.86	48.71	203.50	131.90	92.30	58.59
North Atlantic right whale[a]	389.00	178.57	92.86	39.29	1.43	0	0	0	715.14	427.57	293.14	172.43	612.40	392.63	281.37	177.94
Mid-frequency cetaceans																
Atlantic white sided dolphin	0.14	0.14	0	0	0	0	0	0	803.71	494.00	349.86	222.43	342.86	200.26	143.99	90.20
Short-beaked common dolphin	0.43	0.43	0.14	0	0.29	0.14	0	0	1758.00	1161.86	867.14	588.57	747.16	464.91	355.19	231.89
Bottlenose dolphin	0.29	0	0	0	0	0	0	0	339.57	174.29	110.57	59.00	154.43	79.94	51.70	28.39
Risso's dolphin	0.43	0.43	0.14	0	0.14	0	0	0	746.71	464.71	331.71	209.57	324.06	190.01	140.30	89.39
Pilot whale	0	0	0	0	0	0	0	0	0	0	0	0	12.69	0	0	0
Sperm whale	0	0	0	0	0	0	0	0	835.14	480.57	324.14	193.29	361.14	199.91	139.87	83.36
High-frequency cetaceans																
Harbor porpoise	158.29	69.43	31.57	4.86	40.00	16.43	8.29	3.57	740.29	456.86	325.57	202.43	3034.99	2335.01	1915.36	1305.59
Pinnipeds in water																
Gray seal	32.86	8.43	2.00	0	1.29	0	0	0	439.29	246.71	167.29	95.00	311.67	175.16	118.13	74.69
Harbor seal	27.71	6.00	1.71	0	1.14	0.14	0.14	0	439.71	239.57	158.29	91.00	312.54	174.60	116.71	73.64

[a] Endangered species
[b] Fin whale used as a surrogate for sei whale behavioral definition.

Table G-38. Maximum scenario WTG monopile foundation (16 m diameter, 6600 kJ hammer, 6265 strikes, one pile per day): the number of modeled marine mammal animats exposed to sound levels above injury and behavioral thresholds with attenuation.

Species	Injury								Behavior							
	L_E (NMFS 2018)				L_{pk} (NMFS 2018)				L_p (NOAA 2005)				L_p (Wood et al. 2012)			
	Attenuation (dB)								Attenuation (dB)							
	0	6	10	15	0	6	10	15	0	6	10	15	0	6	10	15
Low-frequency cetaceans																
Fin whale[a] (sei whale[a,b])	347.29	157.71	88.43	33.86	1.14	0.14	0	0	622.14	357.57	244.57	143.14	598.61	368.11	258.77	160.50
Minke whale	298.43	139.43	65.14	16.86	1.14	0.14	0	0	841.57	528.86	372.71	236.29	744.29	485.44	349.11	226.83
Humpback whale	130.71	47.57	21.00	8.57	0.43	0	0	0	177.86	86.43	50.00	24.29	166.23	101.50	69.11	41.07
North Atlantic right whale[a]	213.86	91.29	49.57	17.57	0.57	0	0	0	475.57	260.14	167.71	96.57	461.39	277.90	189.99	116.96
Mid-frequency cetaceans																
Atlantic white sided dolphin	0	0	0	0	0	0	0	0	463.43	263.00	176.86	106.86	209.74	113.33	77.84	46.24
Short-beaked common dolphin	0.14	0.14	0	0	0	0	0	0	981.14	607.71	429.71	276.00	429.34	250.87	182.99	115.46
Bottlenose dolphin	0	0	0	0	0	0	0	0	239.71	116.00	65.71	31.29	115.71	56.84	34.83	17.70
Risso's dolphin	0.14	0.14	0	0	0	0	0	0	468.29	271.71	188.14	115.86	215.86	118.70	81.71	50.60
Pilot whale	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sperm whale	0	0	0	0	0	0	0	0	545.43	283.29	175.71	92.57	246.49	127.43	84.49	45.56
High-frequency cetaceans																
Harbor porpoise	76.29	30.57	13.71	2.14	17.43	7.86	3.86	0.86	456.43	261.29	175.71	100.86	2399.90	1803.34	1450.04	940.34
Pinnipeds in water																
Gray seal	13.14	3.57	1.29	0.14	0.86	0	0	0	308.43	156.86	94.86	50.71	236.34	126.07	80.31	47.27
Harbor seal	10.29	2.00	0.57	0.14	0.29	0.14	0	0	301.43	151.00	92.71	45.57	233.59	122.50	77.66	44.97

[a] Endangered species
[b] Fin whale used as a surrogate for sei whale behavioral definition.

Table G-39. Maximum scenario WTG monopile foundation (16 m diameter, 6600 kJ hammer, 6265 strikes, two piles per day): the number of modeled marine mammal animats exposed to sound levels above injury and behavioral thresholds with attenuation.

Species	Injury								Behavior							
	L_E (NMFS 2018)				L_{pk} (NMFS 2018)				L_p (NOAA 2005)				L_p (Wood et al. 2012)			
	Attenuation (dB)								Attenuation (dB)							
	0	6	10	15	0	6	10	15	0	6	10	15	0	6	10	15
Low-frequency cetaceans																
Fin whale[a] (sei whale[a,b])	614.29	298.57	171.29	74.14	3.00	0.14	0	0	986.29	608.57	428.86	272.57	863.74	560.91	407.47	266.96
Minke whale	560.86	259.00	124.43	28.43	1.00	0.14	0	0	1438.86	933.43	674.57	448.57	1180.56	799.21	589.71	398.44
Humpback whale	194.86	84.57	43.71	15.57	0.43	0	0	0	240.57	133.86	84.71	46.57	202.11	129.51	90.76	57.14
North Atlantic right whale[a]	362.29	163.57	83.57	34.00	1.14	0	0	0	696.86	412.00	283.00	161.71	599.21	382.27	273.43	171.21
Mid-frequency cetaceans																
Atlantic white sided dolphin	0.14	0.14	0	0	0	0	0	0	772.29	472.57	332.71	207.14	330.19	189.73	135.84	84.73
Short-beaked common dolphin	0.43	0.43	0.14	0	0.29	0.14	0	0	1675.86	1093.57	808.86	541.71	708.21	439.96	331.99	214.67
Bottlenose dolphin	0.29	0	0	0	0	0	0	0	337.57	173.00	109.57	58.29	153.24	79.30	51.34	28.11
Risso's dolphin	0.43	0.43	0.14	0	0.14	0	0	0	726.43	445.00	317.14	196.00	313.37	182.01	133.67	84.53
Pilot whale	0	0	0	0	0	0	0	0	0	0	0	0	11.63	0	0	0
Sperm whale	0	0	0	0	0	0	0	0	817.43	467.86	314.14	185.29	354.36	194.20	135.66	79.93
High-frequency cetaceans																
Harbor porpoise	145.14	61.57	29.71	4.14	36.29	14.86	7.57	3.00	715.29	439.71	309.29	190.43	2991.77	2297.07	1883.31	1279.56
Pinnipeds in water																
Gray seal	29.43	7.29	1.57	0	1.29	0	0	0	432.14	242.29	162.14	93.14	307.94	172.41	116.31	72.77
Harbor seal	24.29	5.57	1.29	0	1.00	0	0	0	430.71	233.71	155.86	87.14	308.43	171.46	114.13	71.20

[a] Endangered species
[b] Fin whale used as a surrogate for sei whale behavioral definition.

Table G-40. Realistic scenario WTG monopile foundation (11 m diameter, MHU4400S hammer, one pile per day): the mean number of sea turtles estimated to experience sound levels above injury and behavioral criteria (Finneran et al. 2017) with attenuation.

Species	Injury								Behavior			
	L_E				L_{pk}				L_p			
	Attenuation (dB)								Attenuation (dB)			
	0	6	10	15	0	6	10	15	0	6	10	15
Kemp's ridley turtle[a]	4.29	0.29	0	0	0	0	0	0	25.71	12.71	6.00	2.29
Leatherback turtle[a]	3.14	0.43	0	0	0	0	0	0	22.43	10.43	5.14	2.29
Loggerhead turtle	1.00	0	0	0	0	0	0	0	34.57	17.14	9.71	3.43
Green turtle	8.57	2.43	0.57	0	0	0	0	0	29.00	17.57	8.57	3.86

Table G-41. Realistic scenario WTG monopile foundation (11 m diameter, MHU4400S hammer, one pile per day): the mean number of sea turtles estimated to experience sound levels above injury and behavioral criteria (Finneran et al. 2017) with attenuation.

Species	Injury								Behavior			
	L_E				L_{pk}				L_p			
	Attenuation (dB)								Attenuation (dB)			
	0	6	10	15	0	6	10	15	0	6	10	15
Kemp's ridley turtle[a]	7.86	1.43	0	0	0	0	0	0	53.14	25.14	12.14	4.71
Leatherback turtle[a]	7.00	0.86	0.29	0	0	0	0	0	50.86	25.86	13.57	4.71
Loggerhead turtle	1.57	0.43	0	0	0	0	0	0	64.29	30.29	15.29	6.43
Green turtle	18.71	3.14	0.86	0.14	0	0	0	0	55.14	31.71	14.71	5.00

[a] Listed as Endangered under the ESA.

Table G-42. Realistic scenario WTG jacket foundation (2.9 m diameter, MHU1900S hammer, three piles per day): the mean number of sea turtles estimated to experience sound levels above injury and behavioral criteria (Finneran et al. 2017) with attenuation.

Species	Injury								Behavior			
	L_E				L_{pk}				L_p			
	Attenuation (dB)								Attenuation (dB)			
	0	6	10	15	0	6	10	15	0	6	10	15
Kemp's ridley turtle[a]	1.57	0	0	0	0	0	0	0	27.57	8.14	3.29	1.00
Leatherback turtle[a]	1.29	0.29	0	0	0	0	0	0	21.29	7.43	3.71	1.14
Loggerhead turtle	0.29	0	0	0	0	0	0	0	36.14	11.86	3.57	0.57
Green turtle	5.00	0.43	0.14	0	0	0	0	0	29.14	9.29	4.86	1.86

[a] Listed as Endangered under the ESA.

Table G-43. Realistic scenario WTG jacket foundation (2.9 m diameter, MHU1900S hammer, four piles per day): the mean number of sea turtles estimated to experience sound levels above injury and behavioral criteria (Finneran et al. 2017) with attenuation.

Species	Injury								Behavior			
	L_E				L_{pk}				L_p			
	Attenuation (dB)								Attenuation (dB)			
	0	6	10	15	0	6	10	15	0	6	10	15
Kemp's ridley turtle[a]	1.71	0	0	0	0	0	0	0	34.14	10.86	3.86	1.14
Leatherback turtle[a]	1.71	0.43	0	0	0	0	0	0	28.14	10.43	4.43	1.71
Loggerhead turtle	0.29	0	0	0	0	0	0	0	48.29	16.29	6.71	1.71
Green turtle	6.71	0.57	0	0	0	0	0	0	37.29	13.86	6.71	2.14

[a] Listed as Endangered under the ESA.

Table G-44. Realistic scenario OSP jacket foundation[a] (2.9 m diameter, MHU1900S hammer, four piles per day): the mean number of sea turtles estimated to experience sound levels above injury and behavioral criteria (Finneran et al. 2017) with attenuation.

Species	Injury								Behavior			
	L_E				L_{pk}				L_p			
	Attenuation (dB)								Attenuation (dB)			
	0	6	10	15	0	6	10	15	0	6	10	15
Kemp's ridley turtle[a]	5.00	0.29	0	0	0	0	0	0	46.71	16.00	7.14	1.71
Leatherback turtle[a]	4.14	0.71	0.14	0	0	0	0	0	39.86	15.00	7.57	2.86
Loggerhead turtle	0.71	0.14	0	0	0	0	0	0	66.43	25.14	10.57	3.00
Green turtle	11.14	1.43	0.14	0	0	0	0	0	47.14	18.14	9.86	2.43

[a] OSP foundations include a 2 dB shift for post piling
[b] Listed as Endangered under the ESA.

Table G-45. Maximum scenario WTG jacket foundation (4.5 m diameter, IHCS2000 hammer, four piles per day): the mean number of sea turtles estimated to experience sound levels above injury and behavioral criteria (Finneran et al. 2017) with attenuation.

Species	Injury								Behavior			
	L_E				L_{pk}				L_p			
	Attenuation (dB)								Attenuation (dB)			
	0	6	10	15	0	6	10	15	0	6	10	15
Kemp's ridley turtle[a]	15.86	1.71	0.14	0	0	0	0	0	61.00	27.57	13.14	4.00
Leatherback turtle[a]	10.57	1.29	0.29	0.14	0	0	0	0	59.00	27.00	12.29	5.43
Loggerhead turtle	3.00	0.86	0	0	0	0	0	0	112.71	51.29	23.71	6.71
Green turtle	27.86	6.57	0.71	0	0	0	0	0	65.00	31.43	15.86	6.00

[a] Listed as Endangered under the ESA.

Table G-46. Maximum scenario OSP jacket foundation[a] (4.5 m diameter, IHCS2000 hammer, four piles per day): the mean number of sea turtles estimated to experience sound levels above injury and behavioral criteria (Finneran et al. 2017) with attenuation.

Species	Injury								Behavior			
	L_E				L_{pk}				L_p			
	Attenuation (dB)								Attenuation (dB)			
	0	6	10	15	0	6	10	15	0	6	10	15
Kemp's ridley turtle[a]	24.14	3.86	0.43	0	0	0	0	0	74.29	37.71	20.14	6.29
Leatherback turtle[a]	16.00	3.71	0.86	0.14	0	0	0	0	71.86	34.43	17.71	6.71
Loggerhead turtle	6.71	1.14	0.29	0	0	0	0	0	138.71	64.43	35.71	11.29
Green turtle	41.57	10.43	3.57	0.14	0	0	0	0	76.14	43.14	22.71	8.71

[a] OSP foundations include a 2 dB shift for post piling
[b] Listed as Endangered under the ESA.

Table G-47. Maximum scenario WTG jacket foundation (4.5 m diameter, MHU3500S hammer, four piles per day): the mean number of sea turtles estimated to experience sound levels above injury and behavioral criteria (Finneran et al. 2017) with attenuation.

Species	Injury								Behavior			
	L_E				L_{pk}				L_p			
	Attenuation (dB)								Attenuation (dB)			
	0	6	10	15	0	6	10	15	0	6	10	15
Kemp's ridley turtle[a]	4.57	0	0	0	0	0	0	0	34.71	14.29	6.57	2.00
Leatherback turtle[a]	2.71	0.29	0	0	0	0	0	0	28.86	11.71	5.57	1.57
Loggerhead turtle	0.43	0	0	0	0	0	0	0	51.00	18.43	6.29	1.29
Green turtle	9.57	1.29	0.14	0	0	0	0	0	34.71	14.57	7.29	2.71

[a] Listed as Endangered under the ESA.

Table G-48. Maximum scenario OSP jacket foundation[a] (4.5 m diameter, MHU3500S hammer, four piles per day): the mean number of sea turtles estimated to experience sound levels above injury and behavioral criteria (Finneran et al. 2017) with attenuation.

Species	Injury								Behavior			
	L_E				L_{pk}				L_p			
	Attenuation (dB)								Attenuation (dB)			
	0	6	10	15	0	6	10	15	0	6	10	15
Kemp's ridley turtle[a]	7.86	0.43	0	0	0	0	0	0	43.00	19.71	10.43	3.14
Leatherback turtle[a]	5.57	0.57	0.29	0	0	0	0	0	38.86	16.14	7.71	2.71
Loggerhead turtle	0.57	0.14	0	0	0	0	0	0	66.14	26.86	10.57	2.29
Green turtle	14.86	3.00	0.43	0.14	0	0	0	0	42.57	20.57	10.29	4.00

[a] OSP foundations include a 2 dB shift for post piling
[b] Listed as Endangered under the ESA.

Table G-49. Maximum scenario WTG monopile foundation (16 m diameter, 6600 kJ hammer, 7000 strikes, one pile per day): the mean number of sea turtles estimated to experience sound levels above injury and behavioral criteria (Finneran et al. 2017) with attenuation.

Species	Injury								Behavior			
	L_E				L_{pk}				L_p			
	Attenuation (dB)								Attenuation (dB)			
	0	6	10	15	0	6	10	15	0	6	10	15
Kemp's ridley turtle[a]	12.29	3.14	0.86	0	0	0	0	0	40.71	25.29	16.14	7.29
Leatherback turtle[a]	8.71	1.71	0.57	0	0	0	0	0	36.14	21.57	13.00	6.43
Loggerhead turtle	3.71	0.71	0.14	0	0	0	0	0	56.71	35.14	21.14	10.00
Green turtle	30.00	8.00	3.29	0.43	0	0	0	0	46.29	28.29	20.57	9.14

[a] Listed as Endangered under the ESA.

Table G-50. Maximum scenario WTG monopile foundation (16 m diameter, 6600 kJ hammer, 7000 strikes, two piles per day): the mean number of sea turtles estimated to experience sound levels above injury and behavioral criteria (Finneran et al. 2017) with attenuation.

Species	Injury								Behavior			
	L_E				L_{pk}				L_p			
	Attenuation (dB)								Attenuation (dB)			
	0	6	10	15	0	6	10	15	0	6	10	15
Kemp's ridley turtle[a]	28.57	6.57	2.29	0.43	0	0	0	0	75.57	52.00	32.86	14.14
Leatherback turtle[a]	21.43	5.14	1.29	0.29	0	0	0	0	75.86	46.71	31.29	14.14
Loggerhead turtle	6.14	1.29	0.43	0	0	0	0	0	111.00	66.86	40.29	17.71
Green turtle	54.57	16.29	5.00	0.86	0	0	0	0	84.00	53.29	38.14	19.14

[a] Listed as Endangered under the ESA.

Table G-51. Maximum scenario WTG monopile foundation (16 m diameter, 6600 kJ hammer, 6265 strikes, one pile per day): the mean number of sea turtles estimated to experience sound levels above injury and behavioral criteria (Finneran et al. 2017) with attenuation.

Species	Injury								Behavior			
	L_E				L_{pk}				L_p			
	Attenuation (dB)								Attenuation (dB)			
	0	6	10	15	0	6	10	15	0	6	10	15
Kemp's ridley turtle[a]	11.00	2.71	0.57	0	0	0	0	0	39.57	23.43	15.86	6.57
Leatherback turtle[a]	8.00	1.57	0.43	0	0	0	0	0	35.00	20.00	12.14	5.71
Loggerhead turtle	3.29	0.57	0	0	0	0	0	0	51.29	31.14	19.14	9.43
Green turtle	27.00	7.14	2.71	0.43	0	0	0	0	45.00	27.57	20.29	8.86

[a] Listed as Endangered under the ESA.

Table G-52. Maximum scenario WTG monopile foundation (16 m diameter, 6600 kJ hammer, 6265 strikes, two piles per day): the mean number of sea turtles estimated to experience sound levels above injury and behavioral criteria (Finneran et al. 2017) with attenuation.

Species	Injury								Behavior			
	L_E				L_{pk}				L_p			
	Attenuation (dB)								Attenuation (dB)			
	0	6	10	15	0	6	10	15	0	6	10	15
Kemp's ridley turtle[a]	25.43	5.43	1.86	0.43	0	0	0	0	73.29	49.29	31.29	13.00
Leatherback turtle[a]	19.43	4.86	1.14	0.29	0	0	0	0	72.29	44.86	29.43	13.29
Loggerhead turtle	5.14	1.14	0.29	0	0	0	0	0	101.43	61.29	36.57	16.29
Green turtle	51.00	13.86	4.29	0.71	0	0	0	0	82.00	50.71	36.14	18.00

[a] Listed as Endangered under the ESA.

G.3. Animat Seeding Area

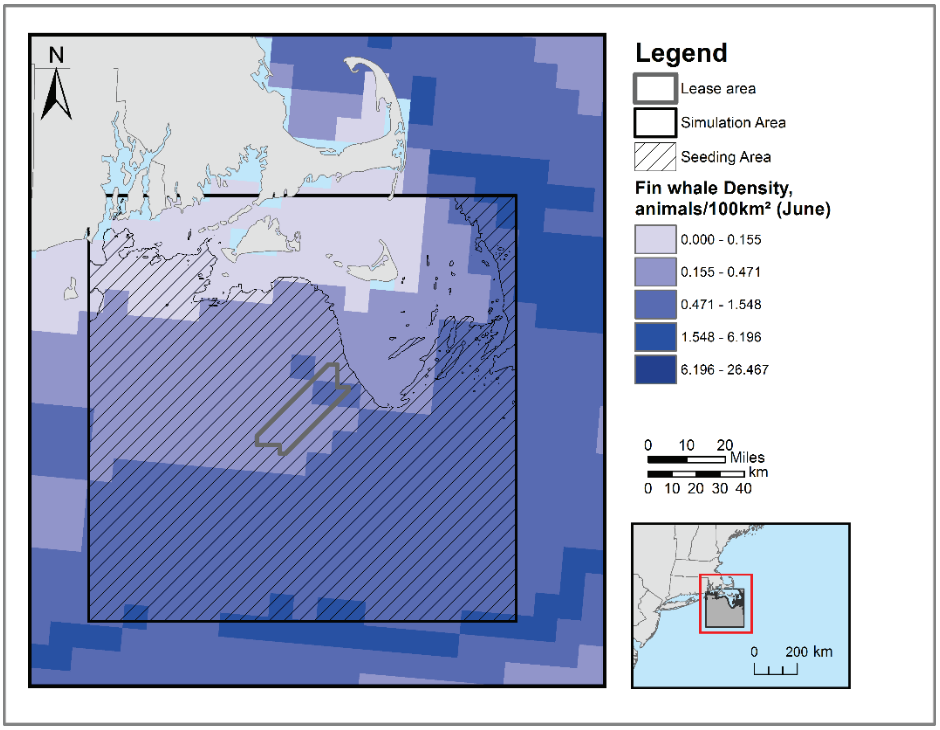

Figure G-1. Map of fin whale animat seeding range with density from Roberts et al. (2016) and (2018) for June, the month with the highest density (also used as a surrogate for sei whale).

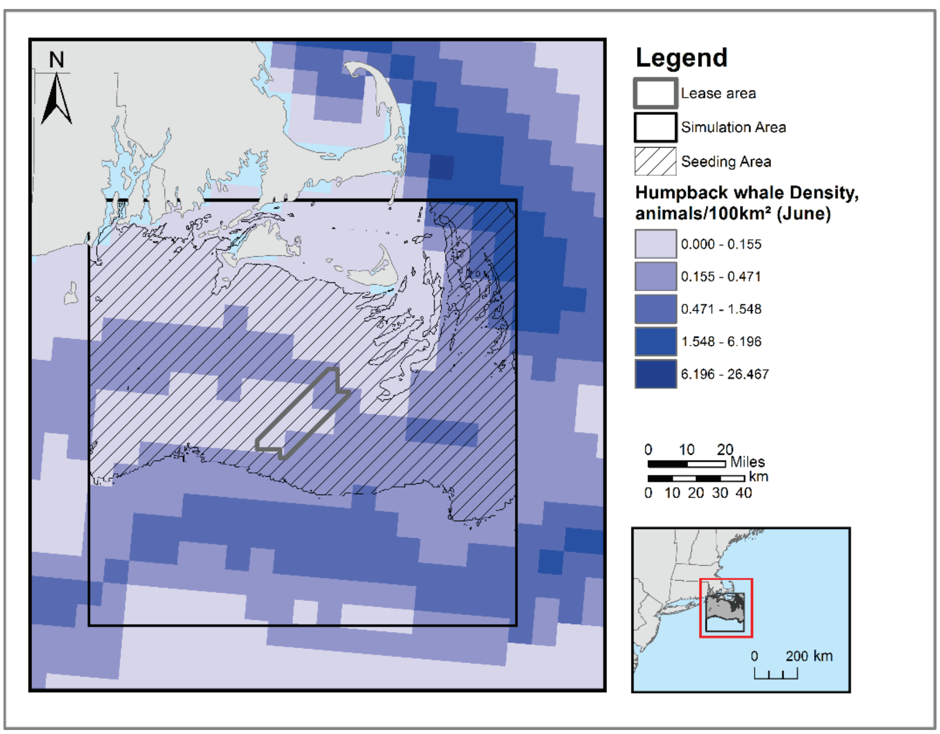

Figure G-2. Map of humpback whale animat seeding range with density from Roberts et al. (2016) and (2018) for June, the month with the highest density.

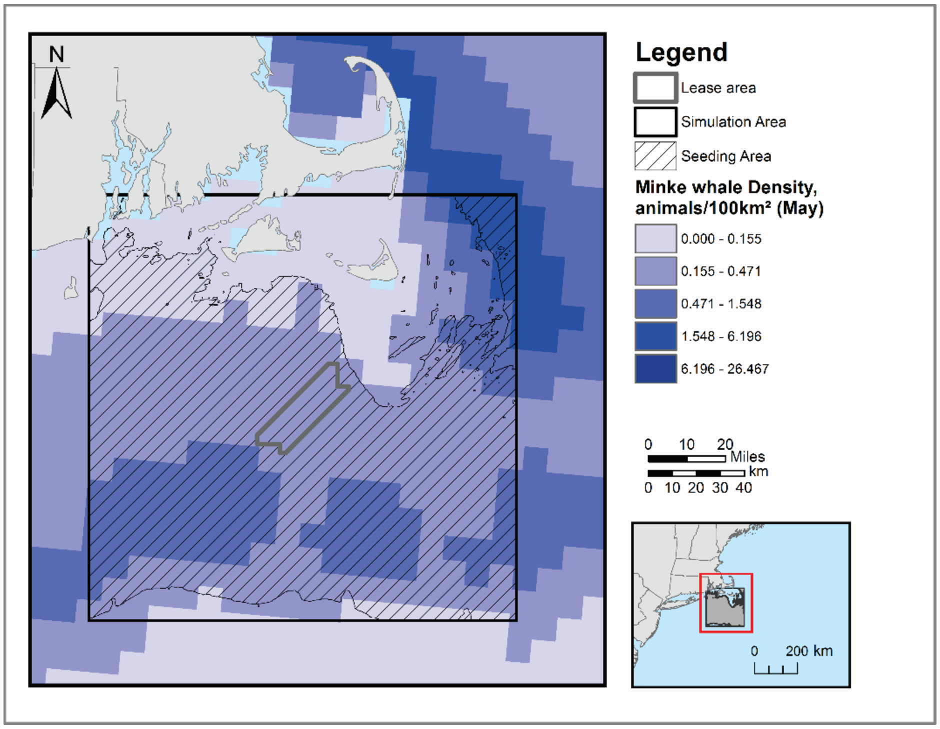

Figure G-3. Map of minke whale animat seeding range with density from Roberts et al. (2016) and (2018) for May, the month with the highest density.

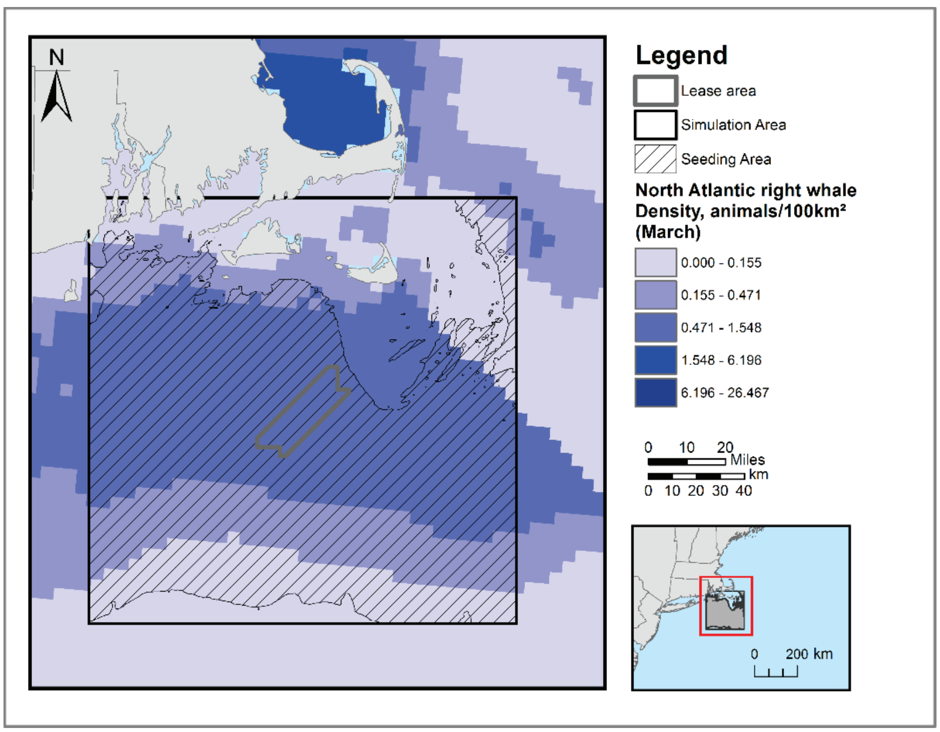

Figure G-4. Map of North Atlantic right whale animat seeding range with density from Roberts et al. (2020) for March, the month with the highest density.

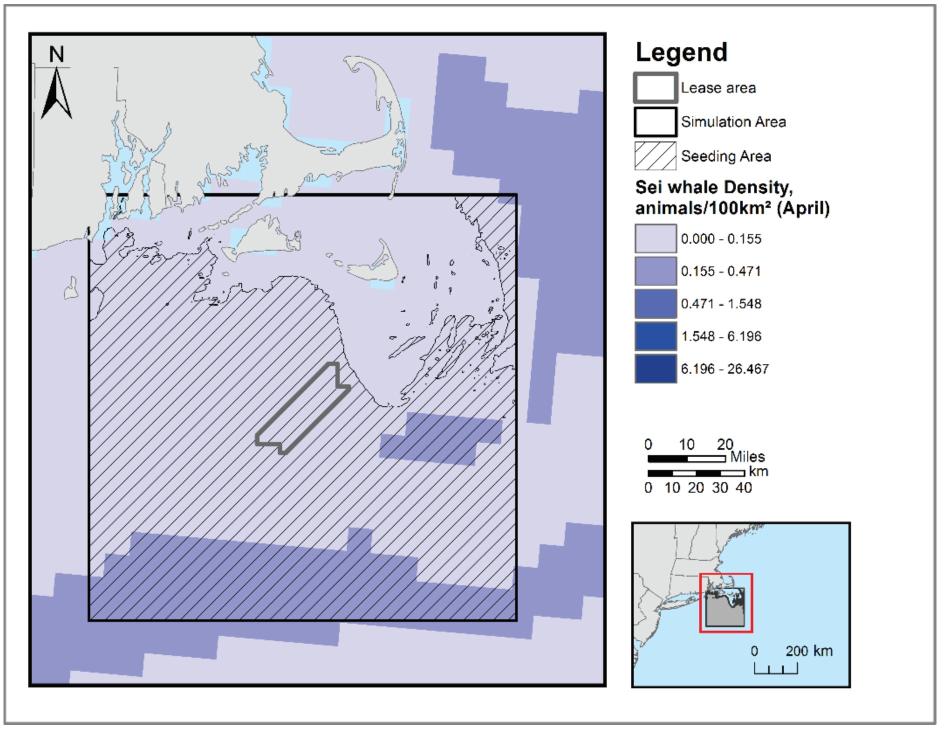

Figure G-5. Map of sei whale animat seeding range with density from Roberts et al. (2016) and (2018) for April, the month with the highest density (seeding area is based on the fin whale species definition, which was used as a surrogate for sei whale).

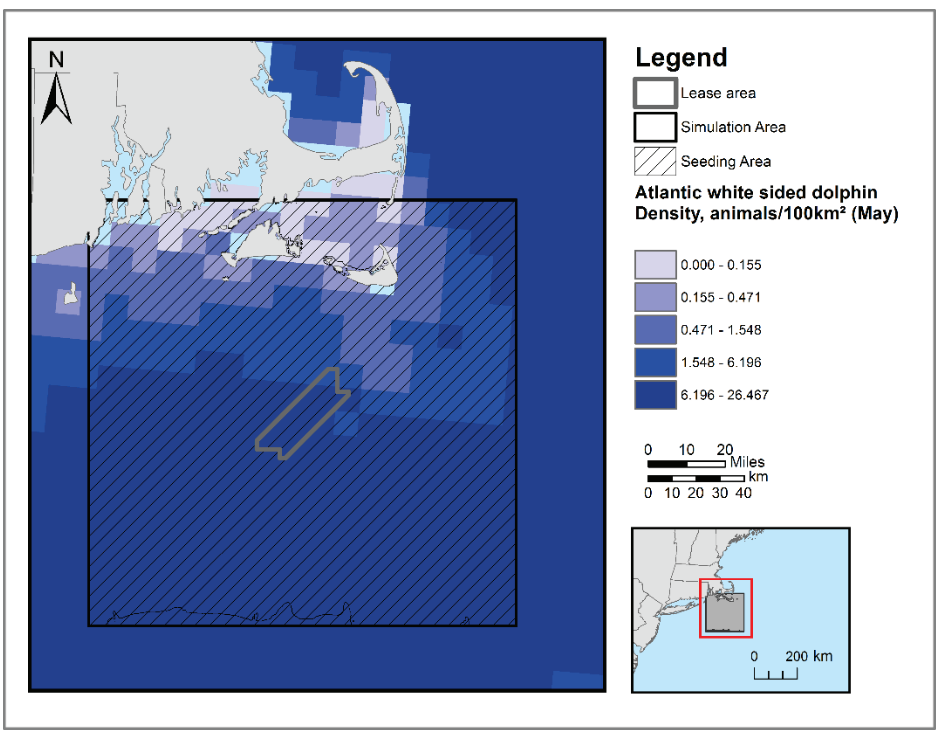

Figure G-6. Map of Atlantic white sided dolphin animat seeding range with density from Roberts et al. (2016) and (2018) for May, the month with the highest density.

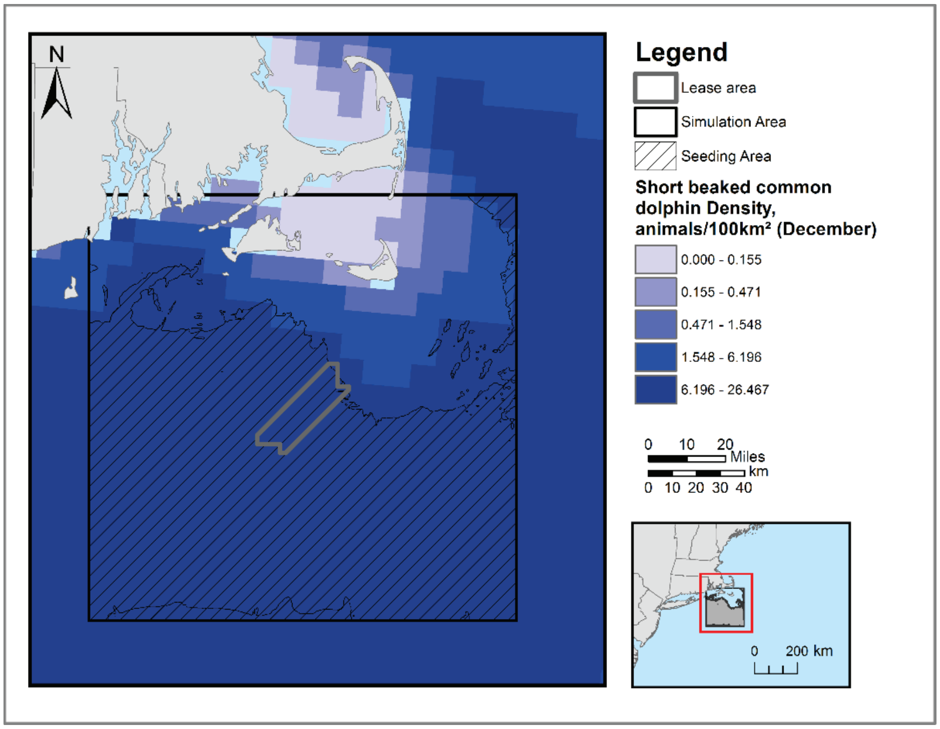

Figure G-7. Map of short-beaked common dolphin animat seeding range with density from Roberts et al. (2016) and (2018) for December, the month with the highest density.

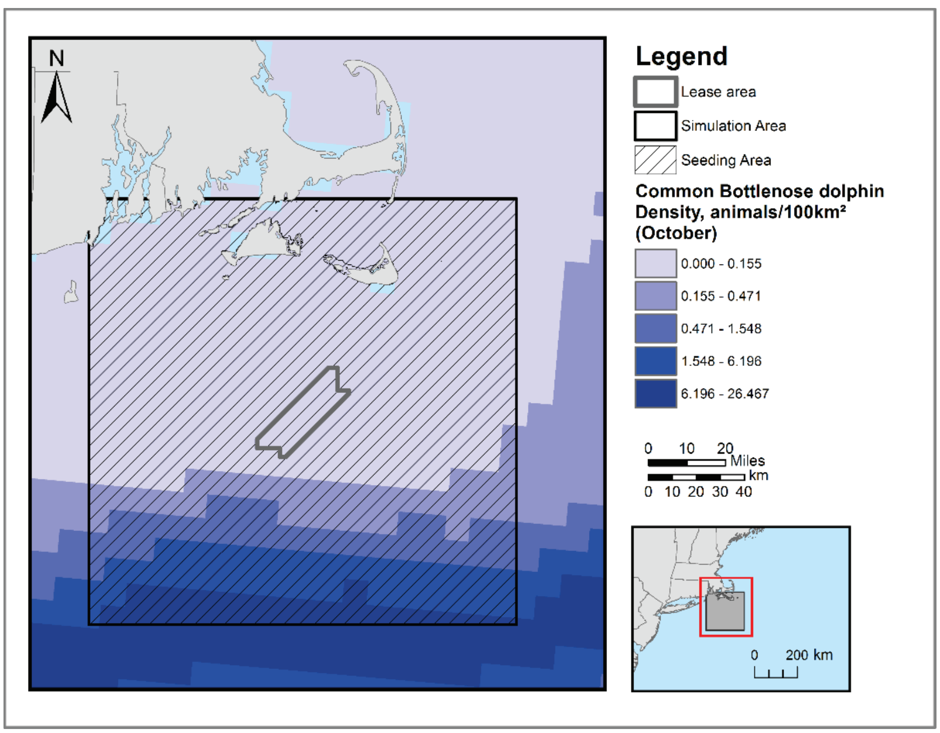

Figure G-8. Map of common bottlenose dolphin animat seeding range with density from Roberts et al. (2016) and (2018) for October, the month with the highest density.

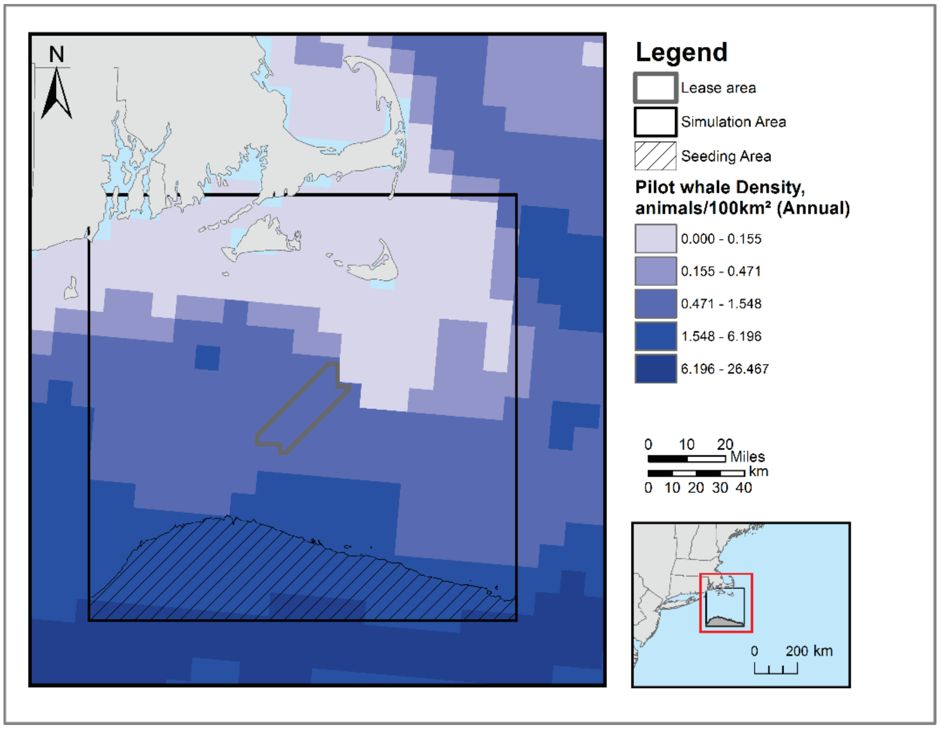

Figure G-9. Map of pilot whale animat seeding range with annual density from Roberts et al. (2016) and (2018).

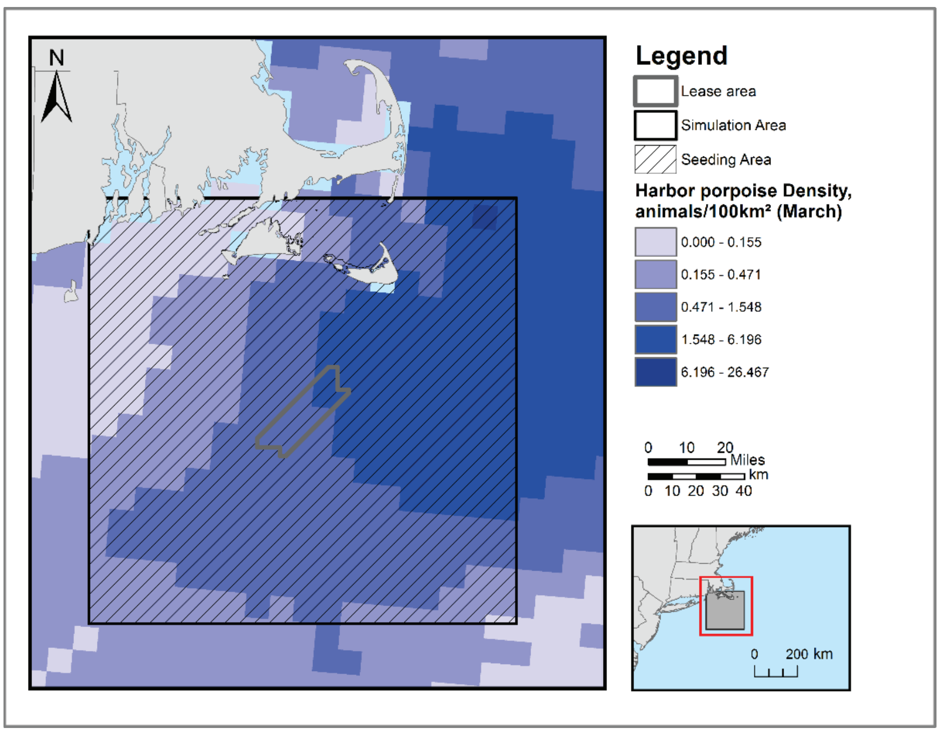

Figure G-10. Map of harbor porpoise animat seeding range with density from Roberts et al. (2016) and (2018) for March, the month with the highest density.

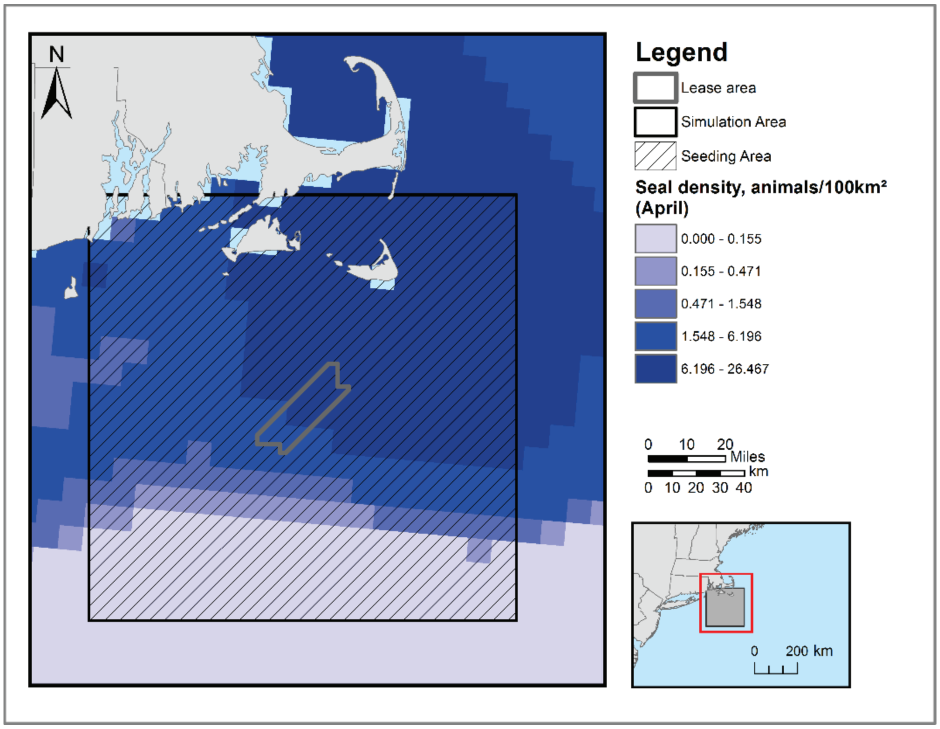

Figure G-11. Map of gray and harbor seal animat seeding range with density from Roberts et al. (2016) and (2018) for April, the month with the highest density.

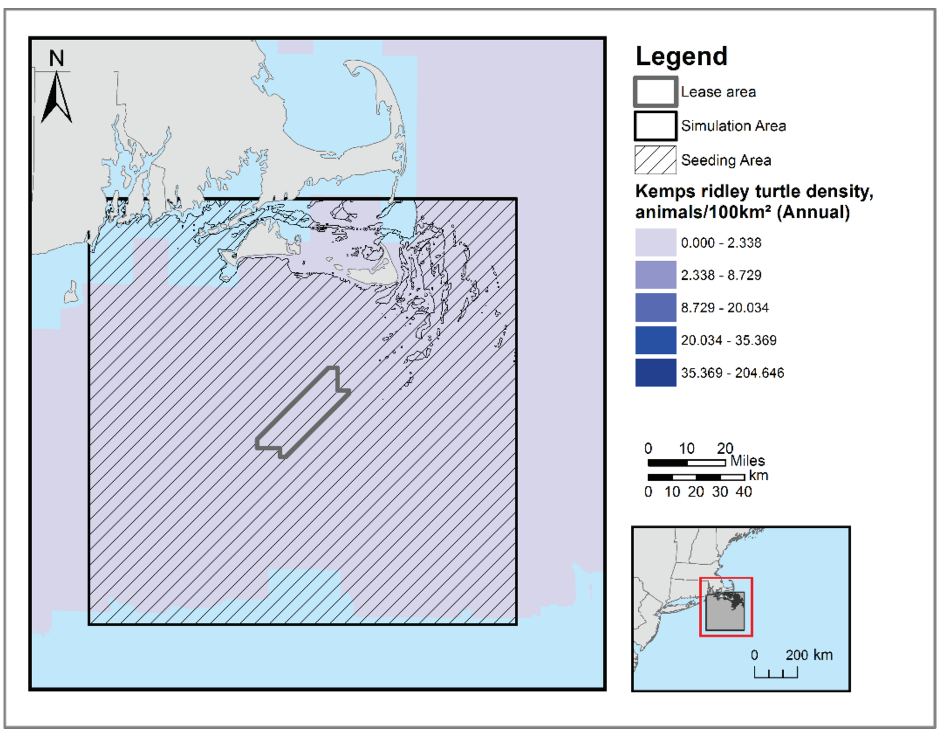

Figure G-12. Map of Kemps ridley turtle animat seeding range with annual density from DoN (2017).

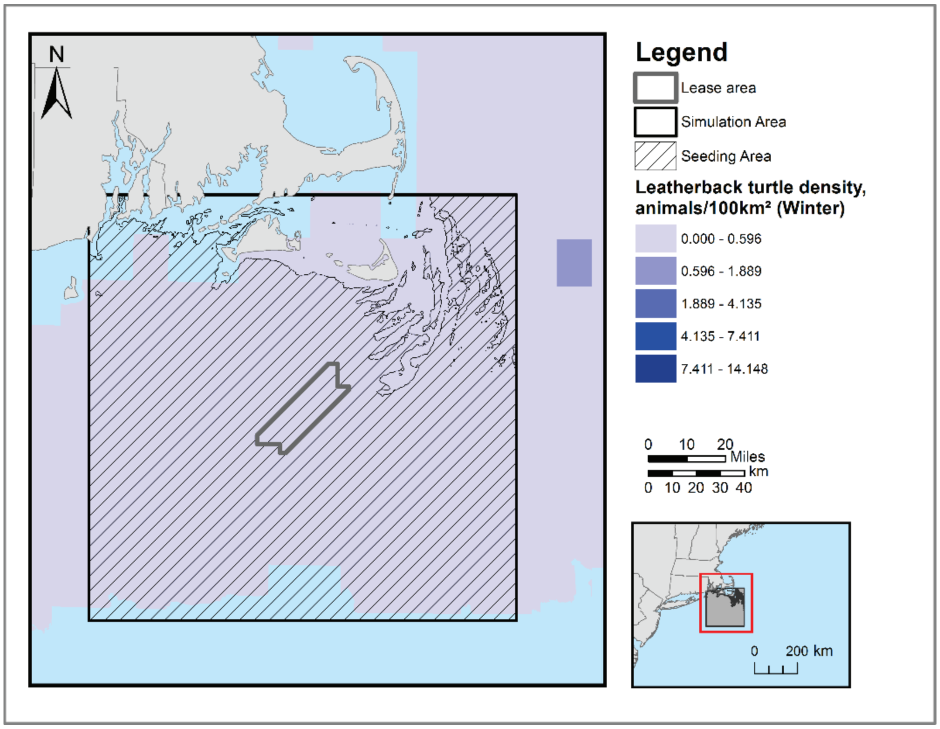

Figure G-13. Map of leatherback turtle animat seeding range with density from DoN (2017) for winter, the season with the highest density. Exposure estimates are calculated using average seasonal density from Kraus et al. (2016) for summer and fall.

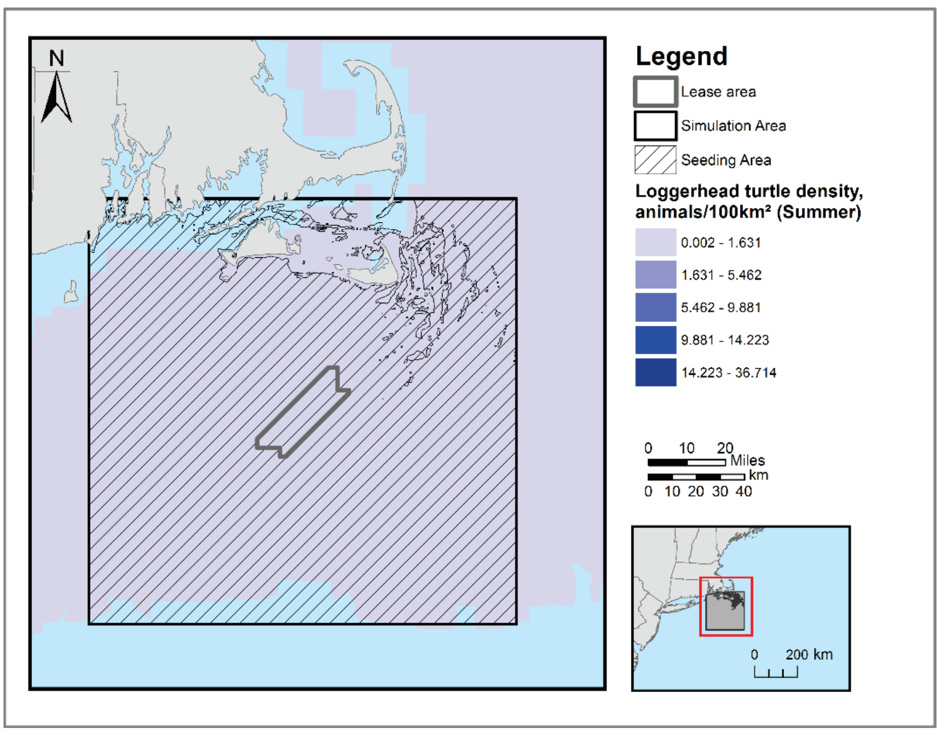

Figure G-14. Map of loggerhead turtle animat seeding range with density from DoN (2017) for summer, the season with the highest density. Exposure estimates are calculated using average seasonal density from Kraus et al. (2016) for summer and fall.