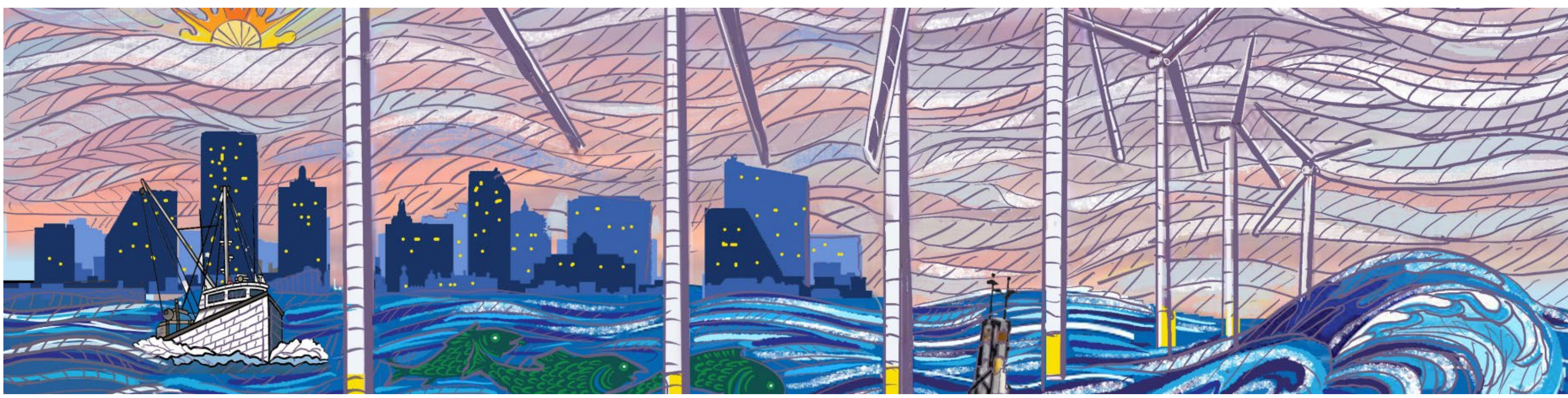

Appendix II-L

Hydroacoustic Modeling Report

Note:

On March 26, 2021, Atlantic Shores Offshore Wind, LLC (Atlantic Shores) submitted a Construction and Operations Plan (COP) to BOEM for the southern portion of Lease OCS-A 0499. On June 30, 2021, the New Jersey Board of Public Utilities (NJ BPU) awarded Atlantic Shores an Offshore Renewable Energy Credit (OREC) allowance to deliver 1,509.6 megawatts (MW) of offshore renewable wind energy into the State of New Jersey. In response to this award, Atlantic Shores updated Volume 1 of the COP to divide the southern portion of Lease OCS-A 0499 into two separate and electrically distinct Projects. Project 1 will deliver renewable energy under this OREC allowance and Project 2 will be developed to support future New Jersey solicitations and power purchase agreements.

As a result of the June 30, 2021 NJ BPU OREC award, Atlantic Shores updated Volume I (Project Information) of the COP in August 2021 to reflect the two Projects. COP Volume II (Affected Environment) and applicable Appendices do not currently include this update and will be updated to reflect Projects 1 and 2 as part Atlantic Shores' December 2021 COP revision.

Technical Report

Underwater Acoustic and Animal Exposure Modeling of Construction Sound for Atlantic Shores Offshore Wind, LLC

Submitted to:

Maria Hartnett
Epsilon Associates, Inc.
mhartnett@epsilonassociates.com

Authors:

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

3 March 2021

P001555-001
Document 02272
Version 1.0

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. Zammit, K.E. Limpert, and C.D. Pyć. 2021. *Technical Report: Underwater Acoustic and Animal Exposure Modeling of Construction Sound for Atlantic Shores Offshore Wind, LLC*. Document 02272, Version 1.0. Technical report by JASCO Applied Sciences for Atlantic Shores Offshore Wind, LLC.

Disclaimer:

Executive Summary

Atlantic Shores Offshore Wind, LLC (Atlantic Shores), a 50/50 joint venture between EDF-RE Offshore Development, LLC (a wholly owned subsidiary of EDF Renewables, Inc. [EDF Renewables]) and Shell New Energies US LLC (Shell), is proposing to develop an offshore wind energy generation project (the Project) within the southern portion of Lease Area OCS-A 0499 (the Lease Area). The Lease Area is located on the Outer Continental Shelf (OCS) within the New Jersey Wind Energy Area, which was identified as suitable for offshore renewable energy development by the Bureau of Ocean Energy Management (BOEM) through a multi-year, public environmental review process.

Atlantic Shores' proposed offshore wind energy generation facility will be located in an approximately 102,055 acres (413 square kilometer [km^2]) Wind Turbine Area (WTA) located in the southern portion of the Lease Area. At its closest point, the WTA is approximately 8.7 miles (mi) (14 km) from the New Jersey shoreline. In addition to the WTA, the Project will include two offshore Export Cable Corridors (ECCs) within federal and New Jersey state waters as well as two onshore interconnection cable routes, two onshore substation sites, and a proposed operations and maintenance (O&M) facility in New Jersey.

Within the WTA, the Project will include up to 200 wind turbine generators (WTGs) and up to 10 offshore substations (OSSs). The Project includes three options for WTG and OSS foundations: piled (monopile or jacket), suction bucket, or gravity foundations. Atlantic Shores is considering three sizes for the OSSs: small, medium, and large. Depending on the final OSS design, there will be up to 10 small OSSs, up to five medium size OSSs, or up to four large OSSs. If jacket foundations are used, a small OSS may require up to four piles (four legs with one pile each), a medium OSS may require up to 12 piles (six legs with up to two piles each), and a large OSS may require up to 24 piles (eight legs with up to three piles each). We evaluated both a maximum design scenario, and a realistic base case scenario. For both the WTG and OSS piled foundation types, the maximum design monopiles will have a diameter of up to 49.2 feet (ft) (15.0 meters [m]), though a more realistic base-case using a diameter of 39.4 ft (12.0 m) is also assessed. The jacket piles will have a diameter of up to 16.4 ft (5.0 m).

The WTGs will be aligned in a uniform grid with east-northeast to west-southwest rows spaced 1 nautical mile (nm) (1.9 km) apart and north to south rows spaced 0.6 nm (1.1 km) apart. The OSS positions will be located between the WTGs along the same east-northeast to west-southwest rows as the proposed WTGs. The WTGs and OSSs will be connected by a system of 66 kV to 150 kV inter-array cables. OSSs within the WTA may be connected to each other by 66 kV to 275 kV inter-link cables. The WTA may also contain one permanent meteorological (met) tower, up to four temporary meteorological and oceanographic (metocean) buoys, scour protection around the base of the foundations, and cable protection. The WTGs, OSSs, and met tower will be permanent structures for the lifetime of the Project whereas the temporary metocean buoys will only be deployed for the duration of construction.

Energy from the OSSs will be delivered to shore via 230 kV to 525 kV high voltage alternating current (HVAC) or high voltage direct current (HVDC) export cables. Up to four export cables will be installed within each of the two ECCs (the Atlantic ECC and the Monmouth ECC), for a total of up to eight export cables. The export cables will traverse federal and state waters to deliver energy from the OSSs to landfall sites in New Jersey. The Atlantic ECC travels from the western tip of the WTA westward to the Atlantic Landfall Site in Atlantic City, NJ and has a total length of approximately 12 mi (19 km). The approximately 61 mi (98 km) long Monmouth ECC travels from the eastern corner of the WTA along the eastern edge of Lease Area OCS-A 0499 to the Monmouth Landfall Site in Sea Girt, NJ. The offshore cables (i.e., the export cables, any inter-link cables, and the inter-array cables) will be buried to a target depth of approximately 5 to 6.6 ft (1.5 to 2 m); cable protection may be necessary in limited areas if sufficient burial depth cannot be achieved. Installation of offshore Project components, including inter-array and export cables, may require the use of dynamically positioned (DP) vessels.

Construction of the Project's onshore and offshore facilities will occur over a period of up to 3 years; offshore construction is expected to last approximately two years. During construction and operation of the Project, Atlantic Shores will use port facilities in New Jersey, New York, the mid-Atlantic, and/or New England. In addition, some components, materials, and vessels could come from U.S. Gulf Coast or international ports. To support Project operations, Atlantic Shores is also proposing to establish an O&M facility in Atlantic City, New Jersey.

The primary sound source associated with the Project is impact (impulsive) pile driving during construction. 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 DP thrusters and vessel propulsion. Secondary sound sources are discussed but not quantitatively modeled as part of this analysis.

WTG and OSS monopile and jacket foundations were modeled at two representative locations in the southern portion of the Lease Area. Forcing functions for impact pile driving were computed for each pile type using GRLWEAP 2010 (GRLWEAP, Pile Dynamics 2010). The resulting forcing functions were used as inputs to JASCO's impact pile driving source models to estimate equivalent acoustic source characteristics. Acoustic sound fields were estimated using JASCO's Marine Operations Noise model (MONM) and Full Wave Range Dependent Acoustic Model (FWRAM). To account for the likely minimum sound reduction resulting from noise abatement systems (NAS) such as bubble curtains, the modeling study included hypothetical broadband attenuation levels of 0, 6, 10, and 15 dB for all impact pile driving.

Results of the acoustic modeling of piling activities are presented as single-strike acoustic ranges to a series of nominal sound pressure levels (SPL), sound exposure levels (SEL), and zero-to-peak pressure levels (PK) in addition to the SEL accumulated over the installation of each foundation type. Acoustic radial distance tables are provided for the modeled hammer energies for each pile diameter with an average summer sound speed profile and reported for different species' hearing group frequency weighting functions. JASCO's Animal Simulation Model Including Noise Exposure (JASMINE) was used to estimate the radial distances (exposure ranges) within which 95% of simulated animals (animats) may be exposed above the relevant regulatory-defined thresholds for injury and behavioral response for marine species that may be in the vicinity of the proposed piling operations. The exposure ranges were estimated for permitting, monitoring and mitigation purposes.

The potential risk from acoustic exposure for marine species was estimated by finding the accumulated sound energy (SEL) and maximum SPL and PK pressure level each animat received over the course of the simulation. Exposure criteria associated with injury and behavioral response are based on relevant regulatory-defined thresholds and best available science for marine mammals, fish and sea turtles (NOAA 2005, Andersson et al. 2007, Wysocki et al. 2007, Stadler and Woodbury 2009, Mueller-Blenkle et al. 2010, Purser and Radford 2011, NMFS 2018), and available relevant scientific understanding of marine mammal and sea turtle behavior. The projected number of animals exposed to sound levels above threshold values was determined by scaling the number of animats exposed above threshold criteria in the model using the local animal densities from the Duke University Habitat-based Cetacean Density Models (2015, Roberts et al. 2016, 2017, 2018, 2020) for marine mammals, and the New York State Energy Research and Development Authority aerial survey reports for sea turtles (NYSERDA; Normandeau Associates and APEM 2018, 2019a, 2019b, 2019, 2020).

The analysis for all pile types predicted the number of individual animals potentially exposed to sound levels above SEL and PK injury threshold criteria using only noise mitigation. The exposures summarized here assume 10 dB of attenuation was achieved using a noise abatement system (NAS) although results at 0, 6, 10, and 15 dB were also assessed to provide context. For critically endangered North Atlantic right whale (NARW), a simulation with conservative assumptions and no mitigation other than NAS resulted in fewer than 1 potential injurious exposure. The foundation type with the longest exposure ranges for marine mammals was the post-piled jacket foundation, with an exposure range of 1.06 km to the SEL injury criteria threshold for NARW. The only species with exposures exceeding PK injury threshold criteria at 10 dB attenuation were harbor porpoise. Exposure modeling results for behavioral thresholds were assessed using both NOAA (2005) and Wood et al. (2012) for marine mammals. The model results predicted that fewer than 10 individual NARWs would be exposed to sound levels that could elicit a behavioral response. Exposure ranges to behavioral thresholds were longest for post-piled jacket foundations, at 12.8 km from the pile for NARW.

Using criteria described by Finneran et al. (2017) less than two sea turtles are predicted to be exposed above the regulatory-defined threshold for injury, with a maximum exposure range of 180 m from the maximum design 15 m monopile. The criteria described by McCauley et al. (2000) and Finneran et al. (2017) that is potentially associated with behavioral response results in less than 46 exposures for Kemp's ridley, leatherback, or green sea turtles. However, the density for loggerhead turtles is predicted to be an order of magnitude higher than any of the other sea turtle species, and this is reflected in the higher behavioral exposures with up to 1,300 exceedances at 10 dB attenuation. For turtles, exposure ranges to behavioral criteria thresholds are longest for the 15 m monopile, at up to 1.4 km from the source. Exposure ranges to behavioral thresholds for jacketed foundations are substantially lower at less than 800 m for all turtle species.

Atlantic Shores is committed to implement monitoring and mitigation measures specified in the BOEM lease documentation for the lease area, including seasonal restrictions on construction activity, piling energy ramp up, Protected Species Observers (PSOs), Passive Acoustic Monitoring (PAM), and species-specific exclusion zones. After mitigation measures are implemented, the residual risk of impacts is expected to be significantly reduced.

Contents

Figures

Tables

Acronyms and Abbreviations

AMAPPS	Atlantic Marine Assessment Program for Protected Species
ANSI	American National Standards Institute
BIA	Biologically Important Area
BOEM	Bureau of Ocean Energy Management
CeTAP	Cetacean and Turtle Assessment Program
COP	Construction and Operations Plan
CPA	closest point of approach
dB	decibels
DP	Dynamic positioning
DPS	Distinct Population Segment
EEZ	Exclusive Economic Zone
ESA	Endangered Species Act
ESP	electrical service platform
FD	Finite difference
FHWG	Fisheries Hydroacoustic Working Group
ft	feet
FWRAM	Full Wave Range Dependent Acoustic Model
GARFO	Greater Atlantic Regional Fisheries Office
GDEM	Global Digital Elevation Model
GEBCO	The General Bathymetric Chart of the Oceans
G&G	Geophysical and Geotechnical
h	hour
ISO	International Organization for Standardisation
HF	high frequency (cetacean hearing group)
HFC	high-frequency cetaceans
Hz	Hertz
IHA	Incidental Harassment Authorization
in	inch
IWC	International Whaling Commission
JASMINE	JASCO Animal Simulation Model Including Noise Exposure
kg	kilogram
kHz	kilohertz
kJ	kilojoule
km	kilometer
L_E	cumulative sound exposure level
LF	low frequency (cetacean hearing group)
LFC	low-frequency cetacean
LLC	Limited Liability Company
L_p	sound pressure level

L_{pk}	peak pressure level
m	meter
MA	Massachusetts
MA WEA	Massachusetts Wind Energy Area
MF	mid-frequency (cetacean hearing group)
MFC	mid-frequency cetaceans
mi	mile
MMPA	Marine Mammal Protection Act
MONM	Marine Operations Noise Model
μPa	micro-Pascal
m/s	meters per second
MW	megawatt
NARW	North Atlantic right whale
NAS	Noise Abatement System
NEFSC	Northeast Fisheries Science Center
NLPSC	Northeast Large Pelagic Survey Collaborative
NOAA	National Oceanic and Atmospheric Administration
NM	nautical mile
NMFS	National Marine Fisheries Service
NYSERDA	New York State Energy Research and Development Authority
OCS	Outer Continental Shelf
OECC	Offshore Export Cable Corridor
OPA	offshore planning area
OSP	Optimum Sustainable Population
OSS	Offshore Substations
PAM	passive acoustic monitoring
PBR	Potential Biological Removal
PDF	probability distribution function
PDSM	Pile Driving Source Model

1. Introduction

1.1. Overview of Assessed Activity

Atlantic Shores Offshore Wind, LLC (Atlantic Shores), a 50/50 joint venture between EDF-RE Offshore Development, LLC (a wholly owned subsidiary of EDF Renewables, Inc. [EDF Renewables]) and Shell New Energies US LLC (Shell), is proposing to develop an offshore wind energy generation project (the Project) within the southern portion of Lease Area OCS-A 0499 (the Lease Area). The Lease Area is located on the Outer Continental Shelf (OCS) within the New Jersey Wind Energy Area, which was identified as suitable for offshore renewable energy development by the Bureau of Ocean Energy Management (BOEM) through a multi-year, public environmental review process.

Atlantic Shores' proposed offshore wind energy generation facility will be located in an approximately 102,055 acres (413 square kilometer [km^2]) Wind Turbine Area (WTA) located in the southern portion of the Lease Area (Figure 1). At its closest point, the WTA is approximately 8.7 miles (mi) (14 km) from the New Jersey shoreline. In addition to the WTA, the Project will include two offshore Export Cable Corridors (ECCs) within federal and New Jersey state waters as well as two onshore interconnection cable routes, two onshore substation sites, and a proposed operations and maintenance (O&M) facility in New Jersey.

Within the WTA, the Project will include up to 200 wind turbine generators (WTGs) and up to 10 offshore substations (OSSs). The Project includes three options for WTG and OSS foundations: piled (monopile or jacket), suction bucket, or gravity foundations. Atlantic Shores is considering three sizes for the OSSs: small, medium, and large. Depending on the final OSS design, there will be up to 10 small OSSs, up to five medium size OSSs, or up to four large OSSs. If jacket foundations are used, a small OSS may require up to four piles (four legs with one pile each), a medium OSS may require up to 12 piles (six legs with up to two piles each), and a large OSS may require up to 24 piles (eight legs with up to three piles each). We evaluated both a maximum design scenario, and a realistic base case scenario. For both the WTG and OSS piled foundation types, the maximum design monopiles will have a diameter of up to 49.2 feet (ft) (15.0 meters [m]), though a more realistic base-case using a diameter of 39.4 ft (12.0 m) is also assessed. The jacket piles will have a diameter of up to 16.4 ft (5.0 m).

The WTGs will be aligned in a uniform grid with east-northeast to west-southwest rows spaced 1 nautical mile (nm) (1.9 km) apart and north to south rows spaced 0.6 nm (1.1 km) apart. The OSS positions will be located between the WTGs along the same east-northeast to west-southwest rows as the proposed WTGs. The WTGs and OSSs will be connected by a system of 66 kV to 150 kV inter-array cables. OSSs within the WTA may be connected to each other by 66 kV to 275 kV inter-link cables. The WTA may also contain one permanent meteorological (met) tower, up to four temporary meteorological and oceanographic (metocean) buoys, scour protection around the base of the foundations, and cable protection. The WTGs, OSSs, and met tower will be permanent structures for the lifetime of the Project whereas the temporary metocean buoys will only be deployed for the duration of construction.

Energy from the OSSs will be delivered to shore via 230 kV to 525 kV high voltage alternating current (HVAC) or high voltage direct current (HVDC) export cables. Up to four export cables will be installed within each of the two ECCs (the Atlantic ECC and the Monmouth ECC), for a total of up to eight export cables. The export cables will traverse federal and state waters to deliver energy from the OSSs to landfall sites in New Jersey. The Atlantic ECC travels from the western tip of the WTA westward to the Atlantic Landfall Site in Atlantic City, NJ and has a total length of approximately 12 mi (19 km). The approximately 61 mi (98 km) long Monmouth ECC travels from the eastern corner of the WTA along the eastern edge of Lease Area OCS-A 0499 to the Monmouth Landfall Site in Sea Girt, NJ. The offshore cables (i.e., the export cables, any inter-link cables, and the inter-array cables) will be buried to a target depth of approximately 5 to 6.6 ft (1.5 to 2 m); cable protection may be necessary in limited areas if sufficient burial depth cannot be achieved. Installation of offshore Project components, including inter-array and export cables, may require the use of dynamically positioned (DP) vessels.

Offshore construction will occur over a period of approximately two years. During construction and operation of the Project, Atlantic Shores will use port facilities in New Jersey, New York, the mid-Atlantic, and/or New England. In addition, some components, materials, and vessels could come from U.S. Gulf

Coast or international ports. To support Project operations, Atlantic Shores is also proposing to establish an O&M facility at a port in Atlantic City, New Jersey.

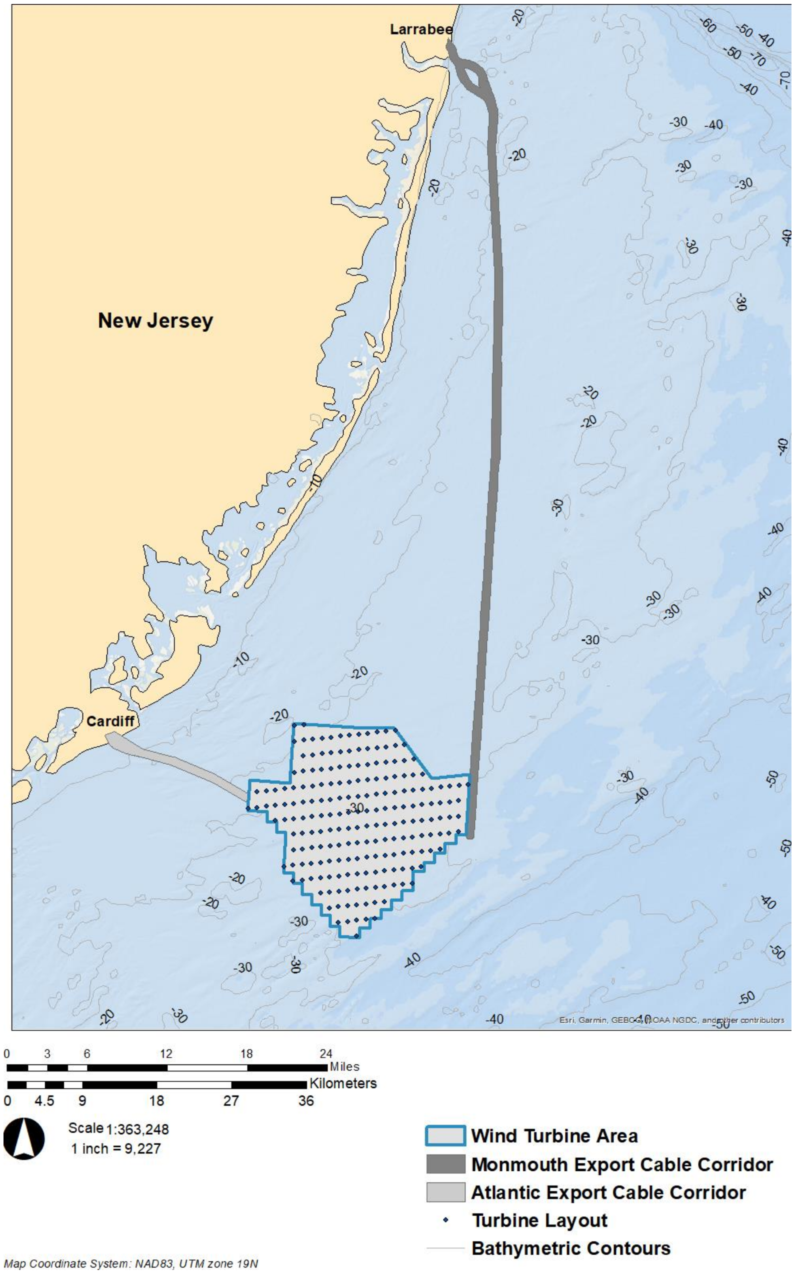

Figure 1. Site of the proposed Project Area.

The primary sound source associated with the Project Area is impact (impulsive) pile driving during foundation installation in the construction phase. Secondary sound sources expected to occur during construction or over the lifecycle of the Project include potential vibratory and suction pile installation, vessel activities associated with cable-laying, dredging and construction, potential installation of gravity-based structures, operations and maintenance, and decommissioning. Vessel noise levels during the operations, maintenance, and decommissioning phases of the Project are expected to be similar to, or less than during construction. The sound level that results from turbine operation is of low intensity

(Madsen et al. 2006), with energy concentrated at low frequencies (below a few kilohertz) (Tougaard et al. 2008).

Acoustic modeling of impact pile driving was conducted for two representative locations in the southern portion of lease area OCS-A 0499. The locations were selected to span the depth range within the Project Area. The results in this report are presented as sound pressure levels (SPL), zero-to-peak sound pressure (PK), and single-strike (i.e., per-impulse) and accumulated sound exposure levels (SEL). Section 2.1 describes the specifications of the impact pile driving source used in the modeling process and all environmental parameters the propagation models require. Sections 2.2 and 2.3 detail the methods used to predict sound source levels and model the sound propagation and potential exposure. Sound attenuation methods are discussed in Section 2.4. Sections 2.5 and 2.6 describe the metrics used to represent underwater acoustic fields and the impact criteria considered. JASCO's Animal Simulation Model Including Noise Exposure (JASMINE) model is described in Section 2.7. Marine fauna included in the acoustic and exposure assessment are summarized in Section 3. Acoustic and exposure modeling results are provided in Section 4 and discussed in Section 5.

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 Project 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. Foundation Types

Project foundation types considered for the WTGs and OSSs include monopiles and jackets. A monopile is a single, hollow cylinder fabricated from steel that is secured in the seabed. Monopile foundations consisting of a single 12 or 15 m diameter pile, were modeled assuming a penetration depth of 60 m (197 ft). The jacket foundation design concept typically consists of a large lattice jacket structure, and a transition piece (TP). The jacket foundation structure is typically supported/secured by three or four pre-installed ("pre-piled") driven piles (one per leg). Alternatively, the jacket is secured to the sea floor via slender piles that are driven through "sleeves" or guides mounted to the base of each leg of the jacket structure. This is described as "post-piling". Jacket foundations were modeled with piles being either pre- or post-piled and driven to a penetration depth of 70 m (230 ft). The pile diameter modeled in the acoustic assessment for both WTG and OSS jacket foundations was 5 m; WTG jacket foundations may include up to four piles and OSS jacket foundations may include up to 24 piles.

1.2.2. Modeling Inputs for Impact Pile Installation

The amount of sound generated during pile driving during foundation 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 more hammer strikes compared to installations in softer sediment. Maximum sound levels from foundation installation usually occur during the last stage of impact pile driving (Betke 2008), where the greatest resistance is encountered. The representative make and model of impact hammers and the hammer energy schedule used in the acoustic modeling effort to assess various scenarios were provided by Atlantic Shores. Key modeling assumptions for the monopiles and a representative hammering schedule are shown in Table 1. Modeled wall thickness along the length of the 12 m pile is 13 cm, whereas the wall thickness for the 15 m pile is 16 cm. Further modeling details for the monopile and jacket foundation scenarios are provided in Appendix B.

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

Modeled maximum scenario	Hammer model	Energy level (kJ)	Strike count	Pile penetration range (m)	Strike rate (strikes/min)
12 m monopile foundation	Menck MHU 4400S	1,400	750	5	30
		1,800	1,250	5	
		2,000	4,650	15	
		3,000	4,200	15	
		4,400	1,500	5	
	Total		**12,350**	**45**	
15 m monopile foundation	Menck MHU 4400S	480	1,438	8	30
		800	1,217	3	
		1,600	1,472	4	
		2,500	2,200	5	
		3,000	4,200	10	
		4,000	2,880	9	
		4,400	1,980	6	
	Total		**15,387**	**45**	
5 m pin piles for jacket foundation	IHC S-2,500	1,200	700	10	30
		1,400	2,200	20	
		1,800	2,100	15	
		2,500	1,750	10	
	Total		**6,750**	**55**	

* Assume self-penetration of 15 m for all piles.

1.2.3. Modeling Locations

Acoustic propagation modeling was conducted for 12 m and 15 m diameter monopiles, and 5 m diameter jacket foundations at two locations: L01 in 36.1 m water depth, and L02 in 28.1 m water depth (Figure 2; Table 2). The water depth at the site locations were extracted from the bathymetry file obtained from the General Bathymetric Chart of the Oceans (GEBCO Compilation Group 2019).

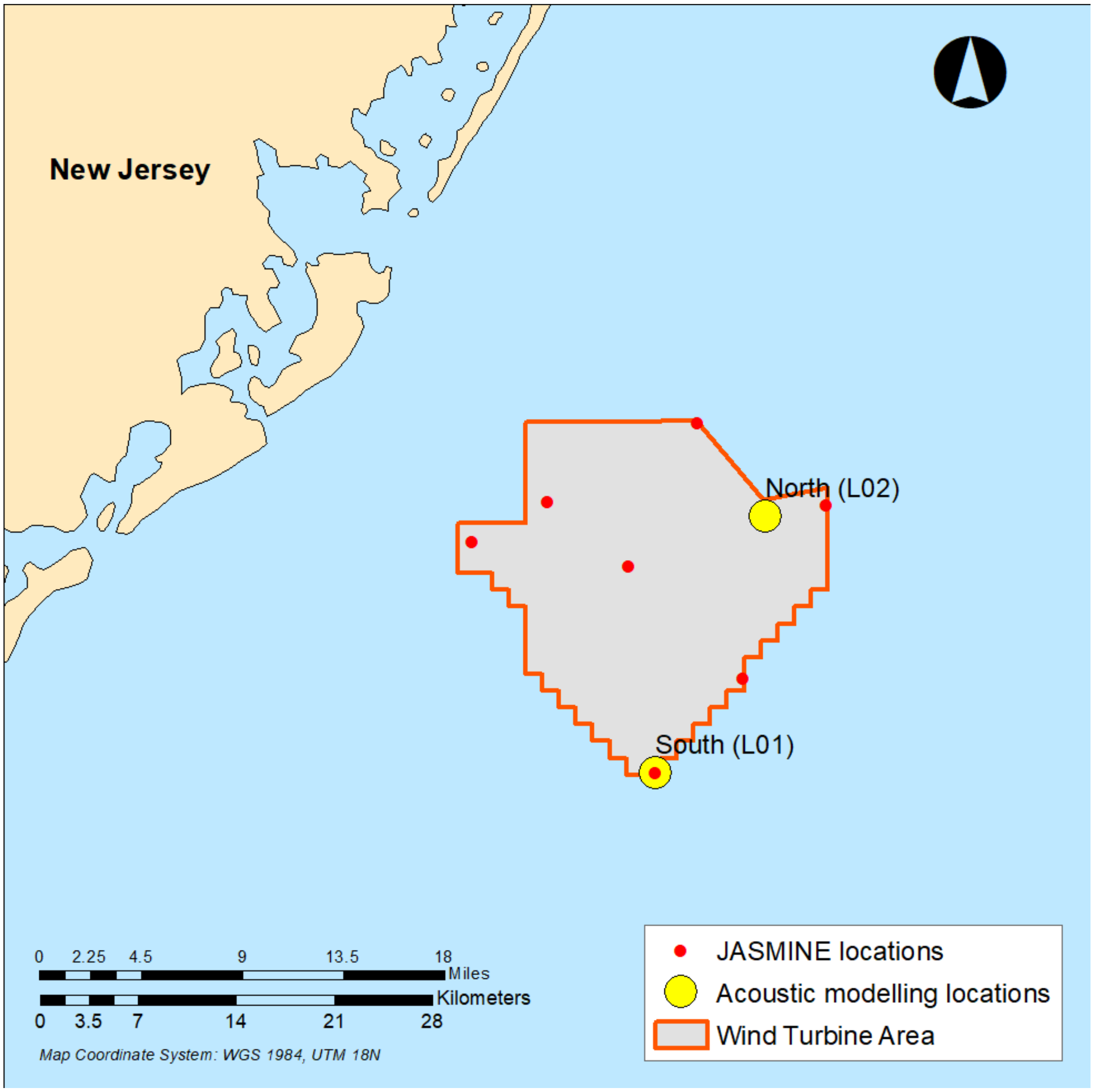

Figure 2. Acoustic propagation and animal movement modeling locations in the Atlantic Shores Project Area.

Table 2. Locations for acoustic modeling of WTG and OSS foundations.

Location name	Location (UTM Zone 18N)		Water depth (m)	Position within Project area	Source type
	Easting	Northing			
L01	578,893.1	4,333,357	36.1	South	Impulsive
L02	586,723.1	4,351,663	28.1	North	

1.2.4. Modeling Scenario and Pile Construction Schedules

Atlantic Shores is proposing to install up to 200 WTG foundations, up to 10 OSS foundations, and one permanent met tower in the WTA over a two-year period. The WTGs and met tower may be supported by either monopile or jacket foundations (201 foundations), and the OSSs will be supported by jacket foundations. The construction schedules describing the expected number of days of piling during each month were provided by Atlantic Shores and created using the number of expected suitable weather days available per month based on historical weather data. Construction 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.

Two construction schedules combining years 1 and 2 of the Project are provided in Table 3. Schedule 1 assumes all WTG foundations and the met tower will be supported by 15 m monopile foundations, and Schedule 2 assumes all WTG foundations and the met tower will be supported by pre-piled jacket foundations. In both Schedules 1 and 2, the OSS jacket foundations were modeled assuming post-piled installation. Modeled scenarios assumed WTG jacket foundations will require 4 pin piles while OSS jacket foundations will require between 4 and 24 pin piles. For all scenarios, the exposure estimates were computed assuming only one monopile or 4 pin piles are installed per day, with no concurrent piling. Construction schedules separated by year are included in Appendix G.2.

Table 3. Construction schedule options combining the two-year duration of the Project. Total days of piling per month were used to estimate the number of marine mammal and sea turtle acoustic exposures for Atlantic Shores.

Construction month	Schedule 1: WTG Monopile		Schedule 2: WTG Jacket	
	WTG Monopile 15 m diameter MHU4400S (1 pile/day)	**OSS Jacket** 5 m diameter IHCS2500 (4 piles/day)	**WTG Jacket** 5 m diameter IHCS2500 (4 piles/day)	**OSS Jacket** 5 m diameter IHCS2500 (4 piles/day)
May	10	0	4	0
Jun	30	0	38	0
Jul	42	12	42	12
Aug	38	12	38	12
Sep	36	0	36	0
Oct	33	0	33	0
Nov	10	0	8	0
Dec	2	0	2	0
Total # of days	**201**	**24**	**201**	**24**

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 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 associated with the Project Area are likely to be similar in 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, operations, and maintenance. 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 Hertz (Hz) is similar to that of a merchant vessel “travelling 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 1–2 kHz frequency band. These acoustic components would not be present during cable lay 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) Level B harassment 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). Based on these studies, sounds from cable laying activities are anticipated to be comparable to potential Project vessel noise impacts from offshore construction activities.

During construction, it is estimated that multiple vessels may operate concurrently in the vicinity of the Project Area. 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 Area 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 noise from vessel traffic associated with construction activities is likely to be the same, or 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 are required for calculating the SPL, SEL, and PK. The source signatures associated with installation of each of the modeled foundation types are 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 a Full Waveform Range-dependent Acoustic Model (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 range for the exceedances determined.

2.1. Acoustic Environment

The Project Area is located on the continental shelf, an environment characterized by predominantly sandy seabed sediments. Water depths in the Project Area vary between 19 to 37 m (62 to 121 ft). From July through September, the average temperature of the upper 10 to 15 m 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 during the winter months (January to March) results in a sound speed profile that is more uniform with depth. 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 3). Sound transmission depends on many environmental parameters, such as the sound speeds in water and substrates. It also depends on the 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. Post-piling has been shown to increase sound levels by 2 dB relative to pre-piling (Bellmann et al. 2020). To account for this, post-piled jacket foundations were modeled with a 2 dB increase in received levels.

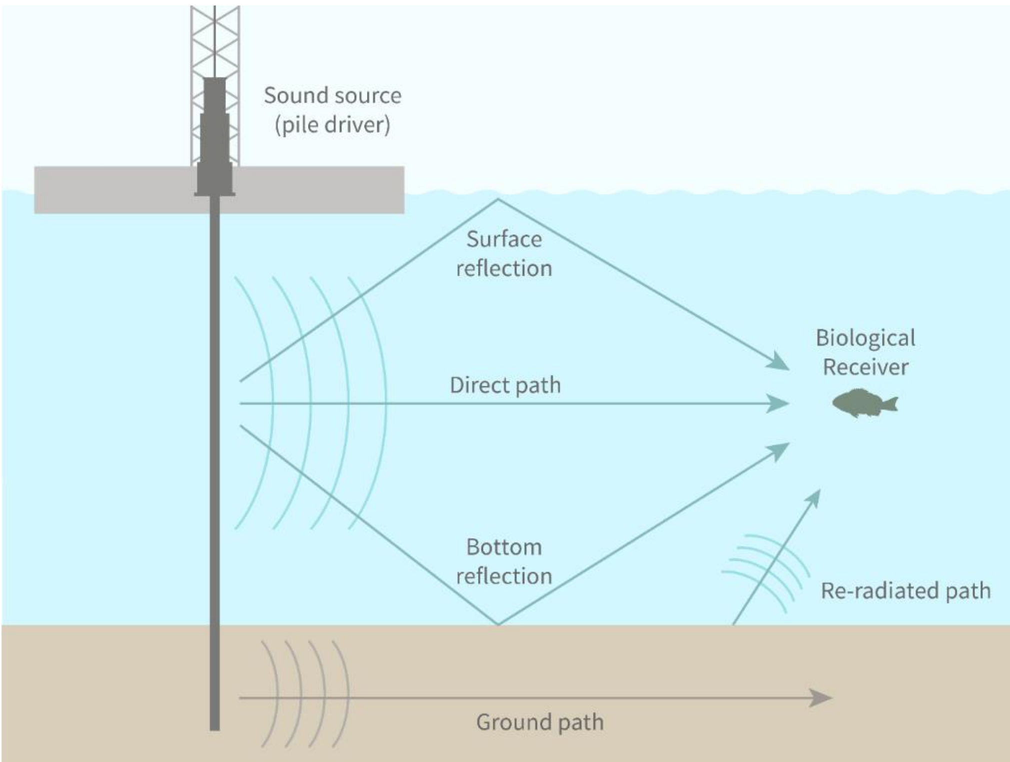

Figure 3. Sound propagation paths associated with pile driving (adapted from Buehler et al. 2015).

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 type, material, size, and length), the pile driving equipment, the number of hammer strikes to install the pile, and the approximate pile penetration depth. See Appendix E.1 for a more detailed description.

Forcing functions were computed for 5 m diameter jacket foundation piles and the 12 and 15 m monopile 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 models (PDSM) used to estimate equivalent acoustic source characteristics detailed in Appendix E.1. Decidecade spectral source levels for each pile type, hammer energy and modeled location, using an average summer sound speed profile are provided in Section 4.1.

2.3. Modeling Sound Propagation

Acoustic propagation modeling used JASCO's Marine Operations Noise Model (MONM) and Full Wave Range Dependent Acoustic Model (FWRAM) that combine the outputs of the source model with the spatial and temporal environmental context (e.g., location, oceanographic conditions, and seabed type) to estimate sound fields. The lower frequency bands were modeled using MONM-RAM, which is based on the parabolic equation method of acoustic propagation modeling. For higher frequencies, additional losses resulting from absorption were added to the propagation loss model. See Appendix E for a more detailed description.

2.4. 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 (NASs) 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 10–15 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 the dominant source of sound in the water for 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 pile 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 in diameter. Other NASs such as the AdBm NMS achieved 6 to 8 dB (M. Bellmann, personal communication, 2019), but HSDs were measured at 10–12 dB attenuation and are independent of depth (Bellmann et al. 2020). Systems may be deployed in series to achieve higher levels of attenuation.

The 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 %. For exposure modeling, several levels of attenuation (0, 6, 10, and 15 dB) were included for comparison purposes.

2.5. Acoustic Thresholds Used to Evaluate Potential Impacts 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 impacts of Project-associated sound sources, it is necessary to first establish the acoustic exposure criteria used by United States (U.S.) 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 a 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 PK (unweighted/flat) sound level metric 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). This assessment uses both the NOAA (2005) and the Wood et al. (2012) criteria to estimate Level B exposures to impulsive piling sounds.

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 4).

Table 4. 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	SEL_{cum}	SEL	L_E

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.

2.5.1. Marine Mammal Hearing Groups

Current data and predictions show that marine mammal species differ in their hearing capabilities, in absolute hearing sensitivity as well as frequency band of hearing (Richardson et al. 1995, Wartzok and Ketten 1999, Southall et al. 2007, Au and Hastings 2008). While hearing measurements are available for a small number of species based on captive animal studies, there are no direct measurements of many odontocetes or any mysticetes. As a result, hearing ranges for many odontocetes are grouped with similar species, and predictions for mysticetes are based on other methods including: anatomical studies and modeling (Houser et al. 2001, Parks et al. 2007, Tubelli et al. 2012, Cranford and Krysl 2015); vocalizations (see reviews in Richardson et al. 1995, Wartzok and Ketten 1999, Au and Hastings 2008); taxonomy; and behavioral responses to sound (Dahlheim and Ljungblad 1990, see review in Reichmuth et al. 2007). In 2007, Southall et al. proposed that marine mammals be divided into hearing groups. This division was updated in 2016 and 2018 by the NMFS using more recent best available science (Table 5).

Southall et al. (2019) published an updated set of Level A sound exposure criteria (i.e., for onset of temporary threshold shift (TTS) and 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 NOAA. The NMFS (2018) hearing groups presented in Table 5 are used in this analysis.

Table 5. Marine mammal hearing groups and their hearing range (Sills et al. 2014, 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.

2.5.2. Marine Mammal Auditory Weighting Functions

The potential for anthropogenic sound to impact 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 5) 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 6, Appendix D).

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).

2.5.3. 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 using 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 6). If a non-impulsive sound has the potential to exceed the peak sound pressure level thresholds associated with impulsive sounds, these thresholds should also be considered.

Table 6. 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 $L_{E,\,24\text{hr}}$ (dB re 1 µPa²s)	Frequency weighted $L_{E,\,24\text{hr}}$ (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 is used for calculating PTS onset. If a non-impulsive sound has the potential of exceeding the peak sound pressure level thresholds associated with impulsive sounds, these thresholds have also been considered.

2.5.4. 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% 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 in this study to estimate Level B exposures to impulsive piling sounds (Table 7).

Table 7. Acoustic thresholds used in this assessment to evaluate potential behavioral impacts 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.

2.6. Acoustic Thresholds Used to Evaluate Potential Impacts 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 acoustics tool (GARFO 2020) for assessing the potential effects to Endangered Species Act (ESA) listed animals 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 8). 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).

A technical report by an American National Standards Institute (ANSI) registered committee (Popper et al. 2014) reviewed available data and suggested metrics and methods for estimating acoustic impacts for fish and sea turtles. Table 10 shows threshold levels suggested by Popper et al. (2014) for PTS for impulsive and continuous sounds. Their report does not define sound levels that may result in behavioral response, but does indicate a high likelihood of response near impact pile driving (tens of meters), moderate response at intermediate ranges (hundreds of meters), and low response far (thousands of meters) from the pile (Popper et al. 2014).

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. Sea turtle auditory weighting functions published by Finneran et al. (2017) are used in conjunction with SEL thresholds for PTS and TTS (Appendix D). The behavioral threshold recommended in the GARFO acoustic tool (GARFO 2020) is an SPL of 175 dB re 1 µPa (McCauley et al. 2000, Finneran et al. 2017) (Table 8).

Table 8. 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	—	—	
Fish without swim bladder[c]	213	216	--	>>186	--
Fish with swim bladder not involved in hearing[c]	207	203	---	>186	--
Fish with swim bladder involved in hearing[c]	207	203	--	186	--
Sea turtles[d,e]	232	204	226	189	175

L_{PK} – peak sound pressure (dB re 1 μPa).
L_E – sound exposure level (dB re 1 μPa^2·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] Popper et al. (2014)
[d] Finneran et al. (2017).
[e] McCauley et al. (2000).

2.7. 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 G.1). 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 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 are summed over a specified duration, i.e., 24 h (Appendix G.1), to determine its total received acoustic energy (SEL) and maximum received PK and SPL. These received levels are then compared to the threshold criteria described in Sections 2.5 and 2.6 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 (see Section 3.2) to obtain the mean number of real-world animals estimated to potentially receive above-threshold sound levels. Appendix G.1 provides fuller description of animal movement modeling and the parameters used in the JASMINE simulations. Due to shifts in animal density and seasonal sound propagation effects, the number of animals predicted to be impacted by the pile driving operations is sensitive to the number of foundations installed during each month.

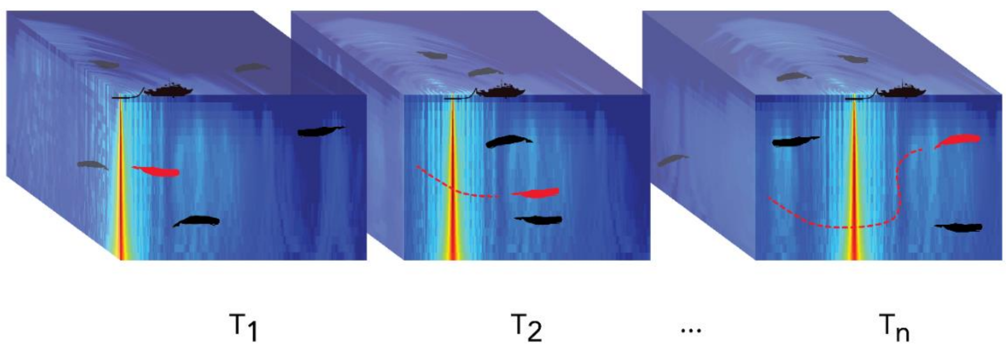

Figure 4. Depiction of animats in an environment with a moving sound field. Example animat (red) shown moving with each time step. The acoustic exposure of each animat is determined by where it is in the sound field, and its exposure history is accumulated as the simulation steps through time.

2.7.1. 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 NARWs and harbor porpoise. Parameters determining aversion at specified sound levels were implemented for the NARW 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 9 and 10). Animats remain in the aversive state for a specified amount of time, depending on the level of exposure that triggered aversion (Tables 9 and 10). 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 9 and 10 and, depending on the current level of exposure, either begins another aversion interval or transitions to a non-aversive behavior. While aversive behavior begins immediately following the exceedance of the relevant sound level threshold, transition back to a regular behavior occurs at the end of the next surface interval, consistent with non-aversive behavior transitions in JASMINE.

Table 9. 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 10. 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

2.8. 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 E.6). 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% of the animats that exceed an acoustic impact threshold is determined (Figure 5). The ER_{max} (maximum Exposure Range) is the farthest CPA of an animat that exceeded threshold and $ER_{95\%}$ (95% Exposure Range) is the horizontal distance that includes 95% 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%.

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 (see Section 4.7).

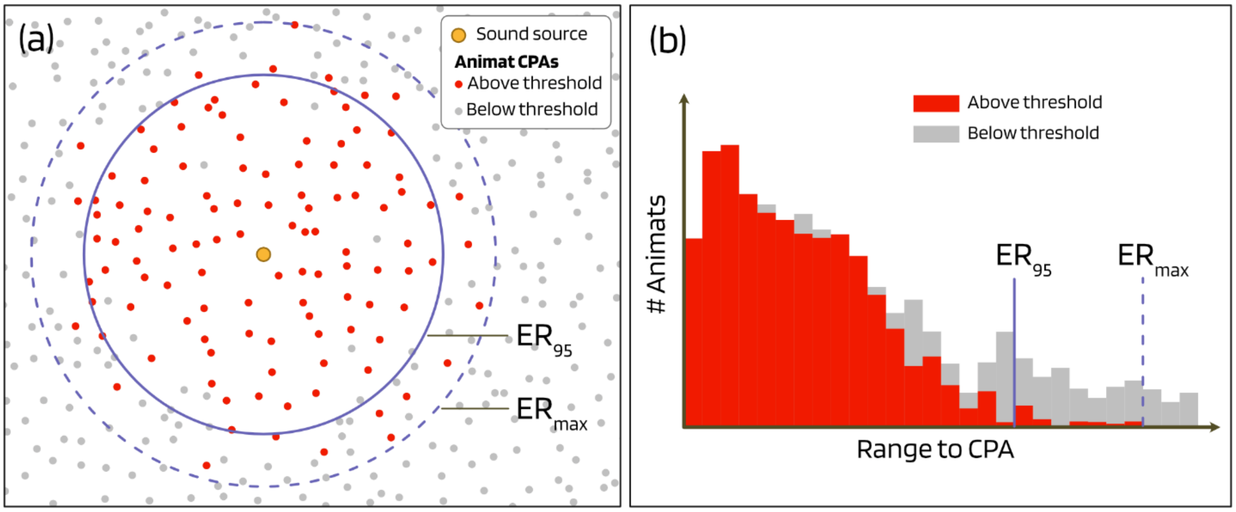

Figure 5. Example distribution of animat closest points of approach (CPAs). Panel (a) shows the horizontal distribution of animats near a sound source. Panel (b) shows the distribution of ranges to animat CPAs. The 95% and maximum Exposure Ranges ($ER_{95\%}$ and ER_{max}) are indicated in both panels.

3. 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 Endangered Species Act (2002). 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” (ESE 2002).

3.1. Marine Mammals that may Occur in the 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 region (CeTAP 1982, USFWS 2014, Roberts et al. 2016, Hayes et al. 2018). All 38 marine mammal species identified in Table 11 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 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.

Mid-Atlantic 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.

There is limited annual research dedicated to marine mammals in mid-Atlantic waters. These waters are within the known migratory route that NARW use as they travel between feeding and calving grounds (Whitt et al. 2013). One study observed obvious skim feeding behavior in New Jersey waters, suggesting feeding may occur in this area, farther south than the main feeding grounds (Whitt et al. 2013). NARW are also thought to be continuous foragers (Stone et al. 2017). Additionally, acoustic detections confirmed occurrence in this area during all seasons, not just during 'typical' migration periods(Whitt et al. 2013, Davis et al. 2017). Other literature suggests that data collected post-2010 shows an increased NARW presence in the mid-Atlantic region (Davis et al. 2017). This area remains relatively understudied, has only been included in broader regional studies, or been compared to detailed research programs in adjacent waters. Therefore, we used a reasonable approximation for behavior probabilities between foraging and migratory states.

We know from this research that NARW are present near the lease area, however, we do not know how much time they spend feeding, or exactly what other functions this habitat area serves for this species. With the lack of specific metrics regarding behavior states, evaluating the potential impacts of pile driving to NARW in nearshore waters of the mid-Atlantic required two simulations. The first simulation had 25% foraging probability and 75% migrating. The second had 50% foraging and 50% migrating. The results of these two simulations were compared to better understand the effect of this parameter on exposure estimates, and to explore the range of potential impacts due to different behavioral patterns. For the remainder of this assessment, the 25% foraging and 75% migrating simulation is assumed when reporting exposure modeling results. Based on recent publications suggesting the area is primarily a migration corridor with occasional opportunistic feeding (Whitt et al. 2013), this configuration is likely more representative of actual NARW behavior within the Project Area.

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 11. Many of the listed marine mammal species do not commonly occur in this region of the Atlantic Ocean. Species 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 in the Project area. Records may exist for adjacent waters.

The likelihood of incidental exposure for each species based on its presence, density, and overlap of proposed activities is described in Section 3.2.

Table 11. Marine mammals that may occur in the Project Area.

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

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

[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.

3.2. 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 12. 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 Atlantic Marine Assessment Program for Protected Species 2010 to 2014 surveys (NEFSC and SEFSC 2011b, 2012, 2014a, 2014b, 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 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 (5 × 5 km for NARW) grid cells partially or fully within the analysis polygon (Figure 6). 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.

There are two stocks of bottlenose dolphins near the Project Area, coastal and offshore, but only one density model from (Roberts et al. 2018). Density for both stocks will be calculated by estimating the total bottlenose dolphin densities in the buffered area and then scaling by their relative abundances:

$$D_{\text{coastal}} = D_{\text{overall}} \times N_{\text{coastal}} / (N_{\text{coastal}} + N_{\text{offshore}}) \quad (1)$$

where D is density and N is abundance.

Animal movement simulation were run for each stock separately with the same behavior definitions. Exposure ranges, therefore, are very similar for the two stocks, differing only because of different random seeds.

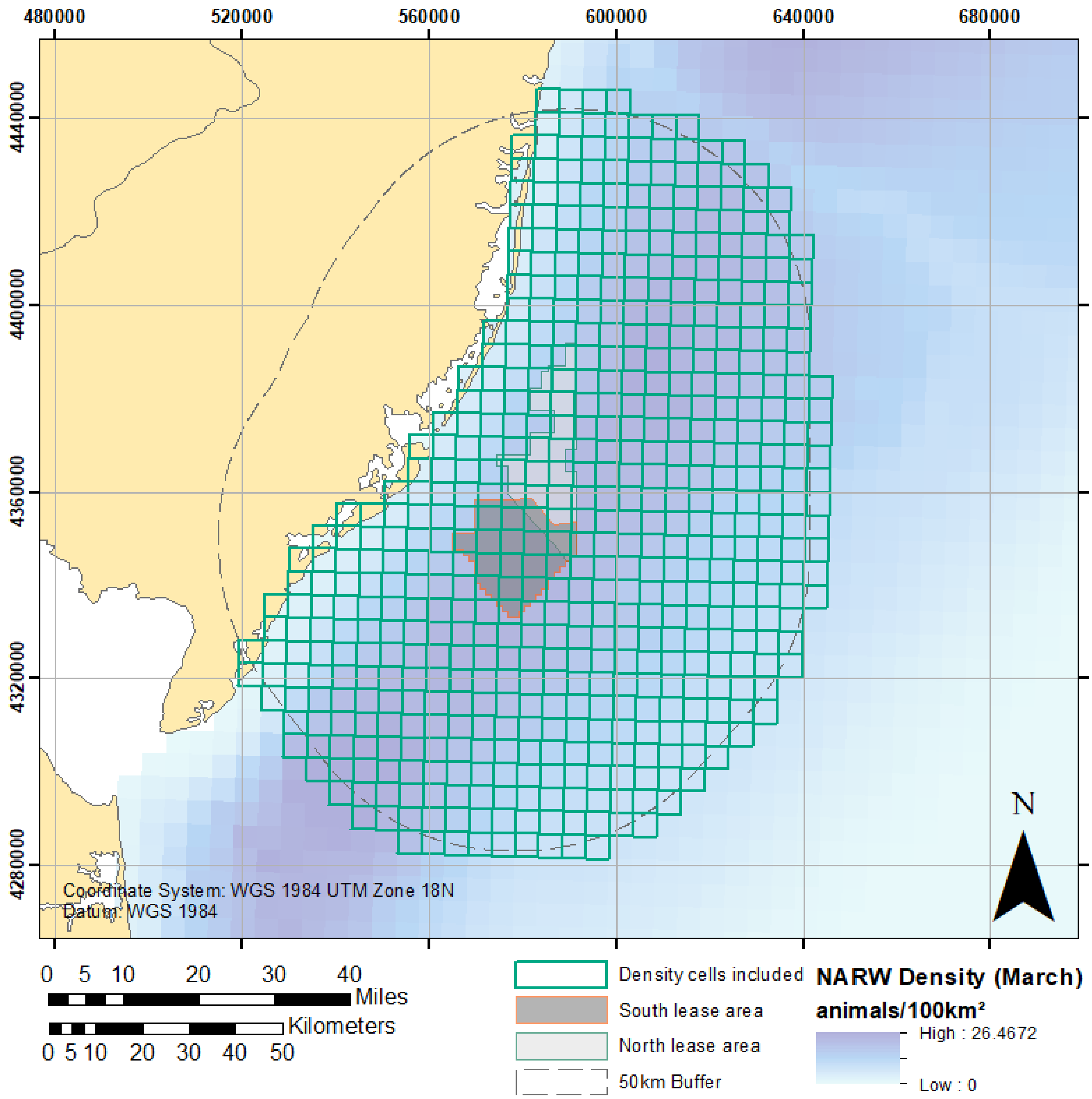

Figure 6. Marine mammal (e.g., NARW) density map showing highlighted grid cells used to calculate mean monthly species estimates within a 50 km buffer around full OCS-A 0499 lease area (Roberts et al. 2015, 2016, 2017, 2018, 2020).

Table 12. Mean monthly marine mammal density estimates for all modeled species within a 50 km buffer around the Atlantic Shores Lease Area.

Species of interest	Monthly densities (animals/100 km^2)[a]												Annual mean
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Fin whale[b]	0.107	0.118	0.128	0.159	0.201	0.251	0.159	0.097	0.189	0.185	0.093	0.105	0.149
Minke whale	0.037	0.045	0.044	0.129	0.166	0.090	0.015	0.009	0.017	0.045	0.019	0.028	0.054
Humpback whale	0.054	0.037	0.041	0.045	0.046	0.037	0.007	0.005	0.020	0.059	0.037	0.062	0.038
North Atlantic right whale[b]	0.337	0.443	0.473	0.403	0.052	0.003	0.001	0.001	0.001	0.003	0.024	0.160	0.158
Sei whale*	0.001	0.001	0.001	0.012	0.012	0.003	0.001	0.001	0.001	0.002	0.002	0.002	0.003
Atlantic white sided dolphin	0.983	0.585	0.647	1.801	2.093	1.460	0.175	0.058	0.172	0.546	0.995	1.166	0.890
Short-beaked common dolphin	11.157	4.717	3.089	3.883	3.084	3.135	3.172	3.065	2.411	4.723	5.928	11.347	4.976
Bottlenose dolphin Northern Coastal	0.267	0.087	0.084	0.242	0.613	1.390	1.656	2.232	1.366	0.777	0.693	0.351	0.813
Bottlenose dolphin	2.532	0.825	0.794	2.292	5.804	13.157	15.681	21.128	12.934	7.359	6.556	3.322	7.699
Risso's dolphin	0.021	0.013	0.007	0.007	0.010	0.014	0.082	0.090	0.031	0.008	0.011	0.028	0.027
Pilot whales[b]	0.166	0.166	0.166	0.166	0.166	0.166	0.166	0.166	0.166	0.166	0.166	0.166	0.166
Sperm whale	0.001	0.001	0.001	0.002	0.004	0.014	0.021	0.020	0.024	0.006	0.003	0.001	0.008
Harbor porpoise	2.677	5.499	7.548	3.739	0.837	0.015	0.030	0.041	0.016	0.095	1.213	2.068	1.982
Seals	4.909	7.488	5.428	3.661	1.336	0.419	0.016	0.006	0.023	0.262	0.396	3.103	2.254

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

3.3. Sea Turtles and Fish Species of Concern that May Occur in the 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. Although uncommon, individual green turtles can be found in the Project Area in the summer and fall when water temperatures are highest.

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 (20–50 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 in the vicinity of the Project 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 of the Atlantic salmon that spawns within eight coastal watersheds within Maine is federally listed as endangered. In 2009, the distinct population segment was expanded to include all areas of the Gulf of Maine between the Androscoggin River and the Dennys River (NOAA Fisheries 2020b). 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 °C, although temperature preference appears to vary by region. For example, off the US East Coast, giant manta rays are commonly found in waters from 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 Offshore Development Area is located at the northern boundary of the species' range (NOAA Fisheries 2020a).

3.4. Sea Turtle Density Estimates

There are limited density estimates for sea turtles in the Project Area. The Project Area is in the Mid-Atlantic North region defined in NEFSC and SEFSC (2011a) for sea turtle distribution. Sea turtles are expected to be present in the Project 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) aerial surveys of the MA WEA and RI/MA WEAs. Kraus et al. (2016) reported that leatherback and loggerhead sea turtles were the most commonly observed turtle species with an additional six Kemp's ridley sea turtles identified over five years.

South of the MA WEA, in the New York Bight, a multi-year series of seasonal aerial surveys were conducted by Normandeau associates for the New York State Energy Research and Development Authority (NYSERDA; Normandeau Associates Inc. and APEM Inc. 2018, Normandeau Associates Inc. and APEM Inc. 2019a, 2019b, Normandeau Associates Inc. and APEM Ltd. 2019, Normandeau Associates Inc. and APEM Inc. 2020)(NYSERDA; Normandeau Associates and APEM 2018, 2019a, 2019b, 2019, 2020). The purpose of the aerial surveys was to gather high resolution data on marine resources within the offshore planning area (OPA) off Long Island, New York. High-resolution digital aerial photographs were collected along specific line transects each season for three consecutive years.

Four turtle species were reported as being present in the area during the NYSERDA surveys: loggerhead turtle, leatherback turtle, Kemp's ridley turtle, and green turtle. To obtain the densities used in the current study, we extracted the maximum seasonal abundance for each species. The abundance was corrected to represent the abundance in the entire OPA then scaled by the full OPA area to obtain a density in units of animals per square kilometer. Two categories listed in the reports included more than one species: one combined loggerhead and Kemp's ridley turtles, and the other included turtles that were observed but not identified to the species level. The counts within the two categories that included more than one species were distributed amongst the relevant species with a weighting that reflected the recorded counts for each species. For example, loggerhead turtles were identified far more frequently than any other species, therefore more of the unidentified counts were assigned to them. The underlying assumption is that a given sample of unidentified turtles would have a distribution of species that was similar to the observed distribution within a given season.

They NYSERDA study (Normandeau Associates and APEM 2018, 2019a, 2019b, 2019, 2020) reported that in the survey area, most of the sea turtles recorded were loggerhead sea turtles, by an order of magnitude. Seasonal sea turtle densities used in animal movement modeling are listed in Table 13 for loggerhead, leatherback, Kemp's ridley, and green sea turtles.

Table 13. Sea turtle density estimates derived from NYSERDA annual reports.

Common name	Density (animals/100 km^2)[a]			
	Spring	Summer	Fall	Winter
Kemp's ridley sea turtle[b]	0.050	0.991	0.190	0.000
Leatherback sea turtle[b]	0.000	0.331	0.789	0.000
Loggerhead sea turtle	0.254	26.799	0.190	0.025
Green turtle	0.000	0.038	0.000	0.000

[a] Densities calculated from NYSERDA aerial survey reports (Normandeau Associates and APEM 2018, 2019a, 2019b, 2019, 2020)
[b] Listed as Endangered under the ESA.

4. Results

Acoustic fields produced by impact pile driving for jacket and monopile foundations (WTG and OSS) were modeled at two sites representing the range of water depths within the Project Area (see Table 2 and Figure 2). This section summarizes the source modeling results (see Section 4.1), the estimated exposure ranges for marine mammals (see Section 4.2) and sea turtles (see Section 4.5), the number of marine mammals (see Section 4.3) and sea turtles (see Section 4.6) predicted to be exposed above regulatory thresholds, and the potential impact to marine mammals by taking into account species' populations (see Section 4.4). Distances to regulatory thresholds for fish are also reported (see Section 4.7).

4.1. Modeled Source Levels

4.1.1. Impact Pile Driving

Forcing functions were computed for each pile diameter (5, 12, and 15 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 7 to8, and modeling parameters and assumptions are listed in Appendix B.1. 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 models 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 for summer sound speed profiles are shown in Figures 10 to 12.

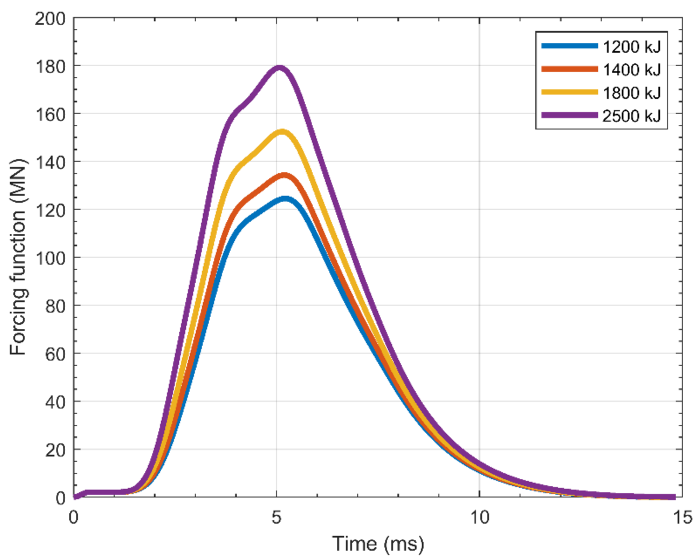

Figure 7. Modeled forcing functions versus time for a 5 m jacket foundation pile as a function of hammer energy.

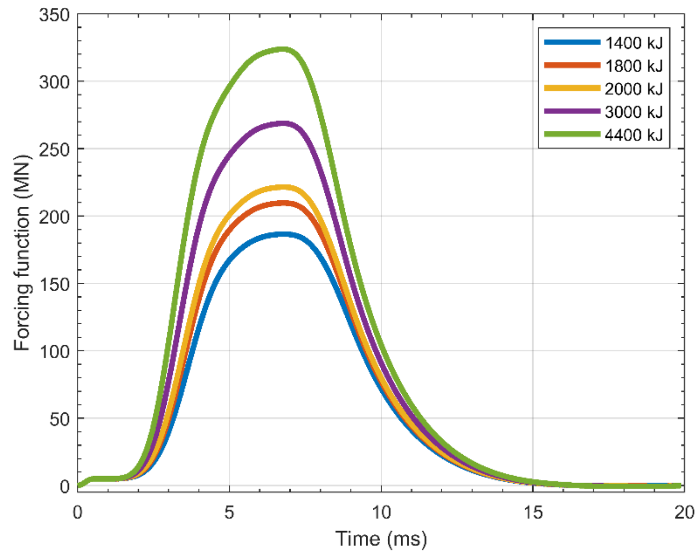

Figure 8. Modeled forcing functions versus time for a 12 m monopile as a function of hammer energy.

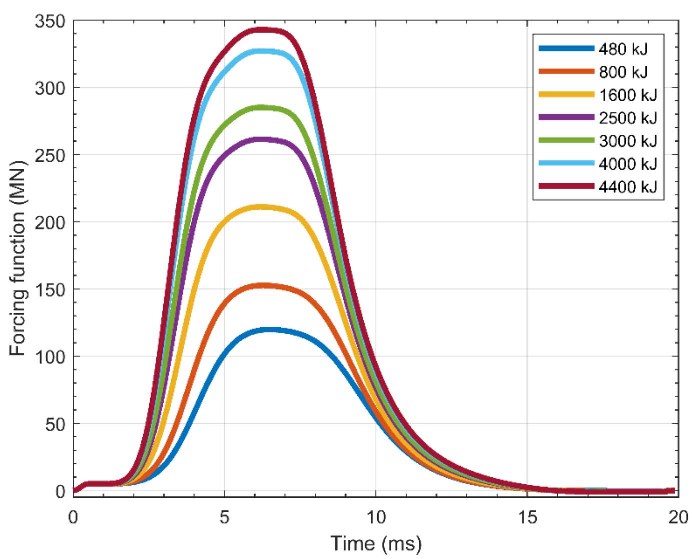

Figure 9. Modeled forcing functions versus time for a 15 m monopile as a function of hammer energy.

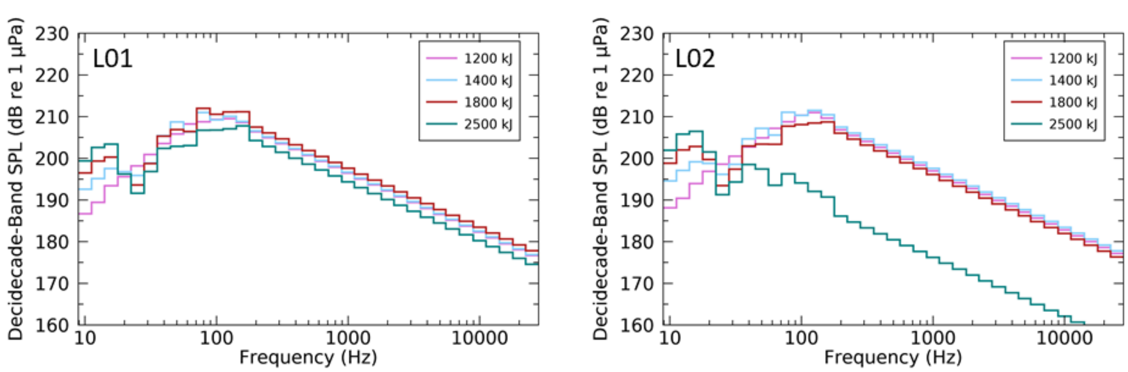

Figure 10. Decidecade band spectral source levels for 5 m jacket foundation pile installation using 2,500 kJ hammer energy at locations L01 and L02 (see Figure 2) with an average summer sound speed profile.

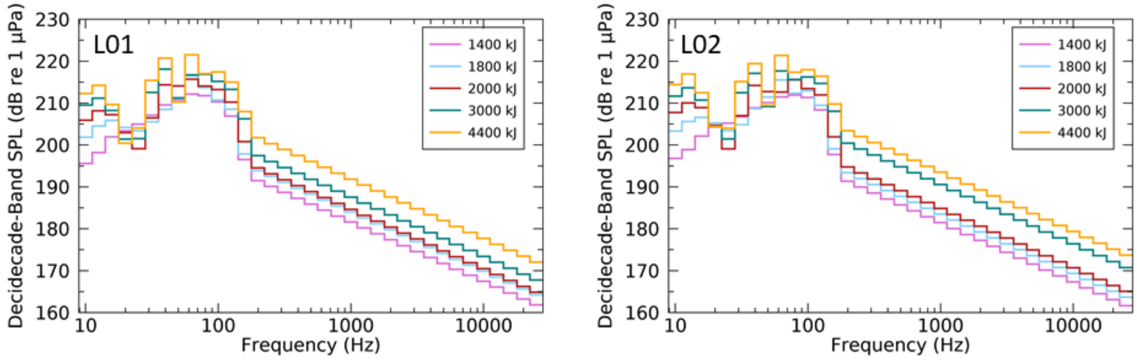

Figure 11. Decidecade band spectral source levels for 12 m monopile installation using 4,400 kJ hammer energy hammer energy at locations L01 and L02 (see Figure 2) with an average summer sound speed profile.

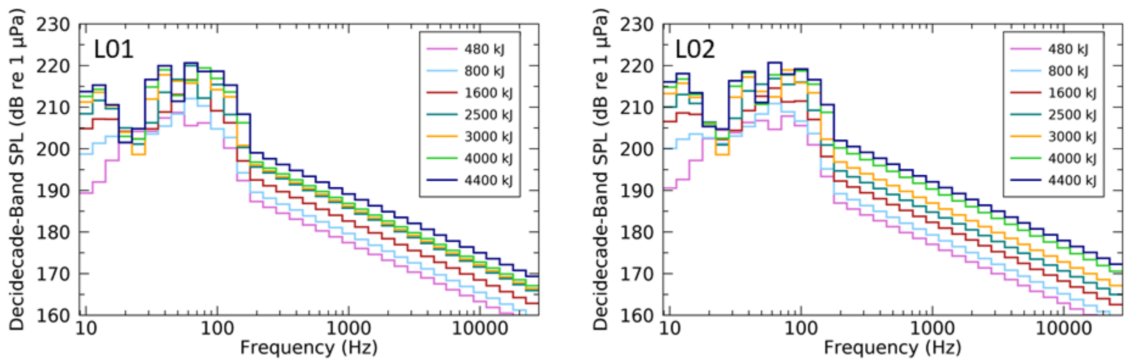

Figure 12. Decidecade band spectral source levels for 15 m monopile installation using 4,400 kJ hammer energy hammer energy at locations L01 and L02 (see Figure 2) with an average summer sound speed profile.

4.2. Marine Mammal Exposure Range Estimates

Three dimensional (3-D) sound fields for the monopile and jacket foundations were calculated using the source characteristics (see Section 4.1.1) at the two representative acoustic modeling locations, L01 and L02 (see Section 1.2.3). 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 (see Section 2.7) 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 behavioral 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 14 to 16 show species-specific exposure ranges, $ER_{95\%}$ (see Section 2.8); the closest points of approach accounting for 95% of exposures above Level A (NMFS 2018) and Level B (Wood et al. 2012, NOAA 2005) acoustic thresholds. Results are shown for monopile and jacket foundations included in the construction schedules (Table 3) 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 14. Monopile foundation (15 m diameter, one pile per day) exposure ranges ($ER_{95\%}$) in km to marine mammal Level A and Level B threshold criteria with sound attenuation.

Species	Level A								Level B							
	L_E (NMFS 2018)				L_{PK} (NMFS 2018)				L_p (NMFS 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])	3.33	2.13	1.81	0.53	0.03	0	0	0	6.41	4.69	3.73	2.88	6.66	4.83	3.77	2.93
Minke whale	2.11	0.95	0.35	0.06	0.01	0	0	0	5.92	4.46	3.48	2.78	6.13	4.58	3.51	2.79
Humpback whale	3.59	2.19	1.25	0.47	0.03	<0.01	0	0	6.35	4.64	3.77	2.89	6.50	4.72	3.82	2.89
North Atlantic right whale[a] (25% foraging)	2.64	1.30	0.72	0.37	0.03	<0.01	<0.01	<0.01	6.33	4.64	3.65	2.85	15.05	12.10	10.42	8.16
Mid-frequency cetaceans																
Atlantic white sided dolphin	0	0	0	0	0	0	0	0	6.25	4.56	3.56	2.79	3.41	2.37	1.74	1.00
Short-beaked common dolphin	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bottlenose dolphin Northern Coastal	0	0	0	0	0	0	0	0	6.74	4.95	3.99	3.03	3.84	2.70	2.00	1.04
Bottlenose dolphin	<0.01	0	0	0	0	0	0	0	6.73	5.05	3.95	3.03	3.84	2.72	2.02	1.13
Risso's dolphin	0	0	0	0	0	0	0	0	6.29	4.74	3.71	2.92	3.52	2.46	1.85	0.93
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	0	0	0	0	0	0	0
High-frequency cetaceans																
Harbor porpoise	1.42	0.50	0.26	0.02	0.60	0.28	0.20	0.05	6.36	4.66	3.74	2.86	20.21	16.53	14.39	11.69
Pinnipeds in water																
Gray seal	0.56	0.17	0.02	0.02	0.05	0	0	0	6.57	4.74	3.77	2.96	5.29	3.57	2.93	2.05
Harbor seal	0.84	0.14	<0.01	0	0.05	<0.01	0	0	6.65	4.72	3.79	2.95	5.37	3.56	2.93	2.04

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

Table 15. Pre-piled jacket foundation (5 m diameter pin piles, four piles per day) exposure ranges ($ER_{95\%}$) in km to marine mammal Level A and Level B threshold criteria with sound attenuation.

Species	Level A								Level B							
	L_E (NMFS 2018)				L_{PK} (NMFS 2018)				L_p (NMFS 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])	3.71	2.17	1.80	0.50	<0.01	<0.01	0	0	5.36	3.55	2.87	2.04	5.45	3.59	2.88	2.04
Minke whale	2.41	1.03	0.40	0.06	0.02	0	0	0	5.01	3.45	2.77	1.88	5.14	3.48	2.78	1.88
Humpback whale	3.71	2.12	1.07	0.42	0.01	0	0	0	5.31	3.66	2.91	1.96	5.43	3.66	2.93	1.97
North Atlantic right whale[a] (25% foraging)	3.13	1.49	0.73	0.19	0.01	0	0	0	5.25	3.49	2.87	1.91	15.27	11.79	9.69	7.20
Mid-frequency cetaceans																
Atlantic white sided dolphin	0.01	0.01	0	0	0	0	0	0	5.27	3.46	2.85	1.88	3.77	2.62	1.74	0.92
Short-beaked common dolphin	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bottlenose dolphin Northern Coastal	0.08	0.01	0	0	0	0	0	0	5.54	3.82	3.05	2.10	3.97	2.77	1.94	1.05
Bottlenose dolphin	0.24	<0.01	0	0	0	0	0	0	5.60	3.95	3.05	2.11	4.02	2.75	1.87	1.01
Risso's dolphin	0.02	<0.01	<0.01	0	<0.01	0	0	0	5.24	3.51	2.89	1.93	3.83	2.64	1.77	0.93
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	0	0	0	0	0	0	0
High-frequency cetaceans																
Harbor porpoise	3.23	1.87	1.11	0.42	0.34	0.17	0.09	0.04	5.24	3.56	2.90	1.95	24.88	20.45	17.92	14.68
Pinnipeds in water																
Gray seal	1.49	0.59	0.15	0	0.04	0	0	0	5.53	3.62	2.94	2.03	4.76	3.11	2.51	1.49
Harbor seal	1.52	0.79	0.16	0.02	0.02	0	0	0	5.41	3.69	3.02	1.97	4.74	3.21	2.55	1.43

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

Table 16. Post-piled jacket foundation[a] (5 m diameter pin piles, four piles per day) exposure ranges ($ER_{95\%}$) in km to marine mammal Level A and Level B threshold criteria with sound attenuation.

Species	Level A								Level B							
	L_E (NMFS 2018)				L_{PK} (NMFS 2018)				L_p (NMFS 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])	4.17	2.56	1.90	0.71	0.04	<0.01	0	0	6.20	4.20	3.16	2.42	6.33	4.30	3.19	2.43
Minke whale	3.02	1.42	0.69	0.15	0.06	0.01	0	0	5.62	3.90	3.05	2.31	5.79	3.95	3.07	2.31
Humpback whale	4.34	2.58	1.56	0.69	0.05	0.01	0	0	6.09	4.13	3.18	2.39	6.21	4.14	3.19	2.39
North Atlantic right whale[b] (25% foraging)	3.53	1.94	1.06	0.47	0.06	0	0	0	5.97	4.11	3.16	2.37	16.56	12.80	10.74	8.05
Mid-frequency cetaceans																
Atlantic white sided dolphin	0.01	0.01	0.01	0	0	0	0	0	5.83	4.02	3.11	2.31	4.35	2.95	2.15	1.23
Short-beaked common dolphin	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bottlenose dolphin Northern Coastal	0.33	0.01	0.01	0	0	0	0	0	6.36	4.32	3.34	2.65	4.64	3.07	2.30	1.22
Bottlenose dolphin	0.30	<0.01	0	0	0	0	0	0	6.40	4.31	3.26	2.63	4.62	3.08	2.32	1.24
Risso's dolphin	0.02	0.02	<0.01	0	<0.01	0	0	0	5.90	4.12	3.14	2.31	4.41	2.97	2.14	1.23
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	0	0	0	0	0	0	0
High-frequency cetaceans																
Harbor porpoise	3.86	2.29	1.48	0.62	0.43	0.23	0.13	0.04	5.92	4.14	3.13	2.40	26.65	21.84	19.13	16.01
Pinnipeds in water																
Gray seal	1.90	0.86	0.24	0.04	0.04	0	0	0	6.06	4.27	3.19	2.44	5.62	3.58	2.88	1.88
Harbor seal	2.09	0.88	0.32	0.10	0.02	<0.01	0	0	6.05	4.29	3.23	2.49	5.51	3.58	2.87	1.84

[a] Post-piled jacket 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.

4.3. 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.1.3) by the ratio of the real-world density (see Section 3.2) to the modeling density (see Appendix G.2.5). Project-level exposure estimates are found by summing the number of individuals above threshold in each construction month.

The construction schedules described in Table 3 are used to calculate the total number of real-world individual marine mammals predicted to receive sound levels above the Level A and Level B thresholds (NMFS 2018, Wood et al. 2012, NOAA 2005) in the Lease Area over the two year duration of pile driving for the Project. Tables 17 and 18 show the mean number of individual animals expected to exceed threshold assuming broadband attenuation of 0, 6, 10, and 15 dB using a summer season sound speed profile for all months. The mean number represents a probability of exposure. For example, a mean exposure of 0.10 indicates that there is a 10% chance of exposing one animal above threshold if the Project is conducted. Mean exposures greater than 1 indicate that more than one animal is predicted to exceed threshold should the Project be conducted.

Table 17. Construction schedule 1: the mean number of modeled marine mammals estimated to experience sound levels above exposure criteria for different sound attenuation levels. The schedule includes the installation of both WTG and OSS foundations (Table 3).

Species	Level A								Level B							
	L_E (NMFS 2018)				L_{pk} (NMFS 2018)				L_p (NMFS 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]	50.09	30.68	18.94	8.31	0.46	<0.01	0	0	94.12	68.30	55.02	43.22	82.81	56.27	43.54	31.81
Minke whale	47.29	18.93	6.80	1.36	0.08	<0.01	0	0	133.90	101.19	82.49	64.67	99.06	72.28	57.45	43.89
Humpback whale	9.42	5.25	2.79	0.99	0.06	0.01	0	0	19.36	13.64	10.51	7.75	15.26	10.68	8.19	5.96
North Atlantic right whale[a] (25% foraging)	2.45	0.98	0.46	0.10	0.01	<0.01	<0.01	<0.01	7.48	5.39	4.16	3.19	14.06	11.02	9.16	7.29
Sei whale[a]	0.55	0.34	0.21	0.09	<0.01	<0.01	0	0	1.05	0.76	0.61	0.48	0.92	0.62	0.48	0.35
Mid-frequency cetaceans																
Atlantic white sided dolphin	0.11	0.05	0.05	0	0	0	0	0	1,015.63	745.58	598.09	459.38	446.35	305.82	228.95	144.57
Short-beaked common dolphin	0	0	0	0	0	0	0	0	0	0	0	0	58.65	15.83	3.86	0
Bottlenose dolphin Northern Coastal	1.03	0.21	0.10	0	0	0	0	0	586.89	345.53	248.52	161.05	253.05	149.29	100.58	55.65
Bottlenose dolphin	15.35	0.97	0	0	0	0	0	0	5,384.84	3,318.94	2,230.21	1,393.00	2,256.62	1,356.53	917.29	505.26
Risso's dolphin	0.02	<0.01	<0.01	0	<0.01	0	0	0	65.04	47.57	38.36	29.28	28.94	19.90	15.04	9.64
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	0	0	0	<0.01	0	0	0
High-frequency cetaceans																
Harbor porpoise	37.41	11.92	2.95	0.75	21.39	9.32	4.68	1.08	203.51	148.88	120.60	91.74	531.18	399.88	326.06	247.76
Pinnipeds in water																
Gray seal	9.83	2.79	0.62	0.16	0.30	0	0	0	138.77	92.42	67.56	50.37	87.95	55.79	42.24	28.60
Harbor seal	12.64	2.80	0.71	0.04	0.68	0.14	0	0	144.41	95.33	71.60	53.44	90.93	58.42	44.27	30.09

[a] Listed as Endangered under the ESA.

Table 18. Construction schedule 2: the mean number of modeled marine mammals estimated to experience sound levels above exposure criteria for different sound attenuation levels. The schedule includes the installation of both WTG and OSS foundations (Table 3).

Species	**Level A**								**Level B**							
	L_E (NMFS 2018)				**L_{pk} (NMFS 2018)**				**L_p (NMFS 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]	83.25	47.09	27.87	12.10	0.15	0.07	0	0	125.08	89.74	75.01	51.88	110.38	73.06	55.96	38.43
Minke whale	73.04	29.13	10.59	1.88	0.06	<0.01	0	0	166.02	119.20	97.12	64.52	118.83	83.22	67.53	47.71
Humpback whale	17.60	8.73	4.44	1.55	0.02	<0.01	0	0	28.61	18.98	14.78	9.36	22.46	14.92	11.63	7.86
North Atlantic right whale[a] (25% foraging)	4.35	1.77	0.86	0.19	<0.01	0	0	0	9.27	6.02	4.74	2.78	21.00	15.77	13.05	9.80
Sei whale[a]	0.81	0.45	0.27	0.12	<0.01	<0.01	0	0	1.21	0.87	0.73	0.50	1.07	0.71	0.54	0.37
Mid-frequency cetaceans																
Atlantic white sided dolphin	0.62	0.31	<0.01	0	0	0	0	0	1,205.94	827.01	685.98	445.83	668.35	466.17	335.96	207.99
Short-beaked common dolphin	0	0	0	0	0	0	0	0	0	0	0	0	125.71	54.13	3.82	0
Bottlenose dolphin Northern coastal	5.40	1.90	0.13	0	0	0	0	0	763.29	419.45	290.09	151.27	457.97	277.51	180.76	102.10
Bottlenose dolphin	33.13	8.97	0	0	0	0	0	0	7,237.52	4,055.11	2,717.47	1,389.67	4,254.28	2,513.30	1,656.79	933.82
Risso's dolphin	0.08	0.04	0.03	0	0.06	0	0	0	104.17	72.98	60.52	42.07	60.39	42.19	31.23	20.04
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	0	0	0	<0.01	0	0	0
High-frequency cetaceans																
Harbor porpoise	146.92	81.35	45.34	11.42	15.06	4.69	1.19	0.42	252.81	175.02	142.39	95.36	892.97	701.18	586.56	460.53
Pinnipeds in water																
Gray seal	27.06	7.70	1.43	<0.01	0.12	0	0	0	148.49	91.49	73.50	46.77	108.15	68.58	53.07	31.93
Harbor seal	28.91	8.11	2.32	0.23	0.23	<0.01	0	0	153.61	96.79	74.00	46.23	110.74	70.96	53.98	33.48

[a] Listed as Endangered under the ESA.

4.3.1. Effect of Aversion

The mean exposure estimates reported in Tables 17 and 18 do not consider animals avoiding loud sounds (aversion) or implementation of mitigation measures other than sound attenuation using NAS. 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 NARW in this study. For comparative purposes only, the results are shown with and without aversion (Tables 19 and 20).

Table 19. Construction schedule 1: mean exposure estimates with and without aversion for NARW and harbor porpoise. The schedule includes the installation of both WTG and OSS foundations (Table 3).

Species	10 dB attenuation – no aversion				10 dB attenuation – with aversion			
	Injury		Behavior		Injury		Behavior	
	L_E	L_{pk}	L_p	L_p	L_E	L_{pk}	L_p	L_p
North Atlantic right whale[a] (25% foraging)	0.46	<0.01	4.16	9.16	0.11	0	3.52	8.95
Harbor porpoise	2.95	4.68	120.60	326.06	<0.01	0	6.59	243.33

[a] Listed as Endangered under the ESA.

Table 20. Construction schedule 2: mean exposure estimates with and without aversion for NARW and harbor porpoise. The schedule includes the installation of both WTG and OSS foundations (Table 3).

Species	10 dB attenuation – no aversion				10 dB attenuation – with aversion			
	Injury		Behavior		Injury		Behavior	
	L_E	L_{pk}	L_p	L_p	L_E	L_{pk}	L_p	L_p
North Atlantic right whale[a] (25% foraging)	0.86	0	4.74	13.05	0.26	0	3.71	12.40
Harbor porpoise	45.34	1.19	142.39	586.56	0.08	0	7.74	383.29

[a] Listed as Endangered under the ESA.

4.4. 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 population or stock sizes. The exposure results shown in Section 4.3, estimated using the schedules combining years 1 and 2 and described in Table 3, are presented as a percentage of species abundance at each attenuation level in Tables 21 and 22. Abundance numbers used to calculate the percentage of population estimated to receive threshold levels of sound are shown in Table 11.

Table 21. Construction schedule 1: 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 OSS foundations (Table 3).

Species	Level A								Level B							
	L_E (NMFS 2018)				**L_{pk} (NMFS 2018)**				**L_p (NMFS 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]	0.68	0.41	0.26	0.11	<0.01	<0.01	0	0	1.27	0.92	0.74	0.58	1.12	0.76	0.59	0.43
Minke whale	0.20	0.08	0.03	<0.01	<0.01	<0.01	0	0	0.55	0.42	0.34	0.27	0.41	0.30	0.24	0.18
Humpback whale	0.67	0.38	0.20	0.07	<0.01	<0.01	0	0	1.39	0.98	0.75	0.56	1.09	0.76	0.59	0.43
North Atlantic right whale[a] (25% foraging)	0.57	0.23	0.11	0.02	<0.01	<0.01	<0.01	<0.01	1.75	1.26	0.97	0.74	3.29	2.57	2.14	1.70
Sei whale[a]	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0	0	0.02	0.01	<0.01	<0.01	0.01	<0.01	<0.01	<0.01
Mid-frequency cetaceans																
Atlantic white sided dolphin	<0.01	<0.01	<0.01	0	0	0	0	0	1.09	0.80	0.64	0.49	0.48	0.33	0.25	0.16
Short-beaked common dolphin	0	0	0	0	0	0	0	0	0	0	0	0	0.03	<0.01	<0.01	0
Bottlenose dolphin Northern coastal	0.02	<0.01	<0.01	0	0	0	0	0	8.84	5.20	3.74	2.43	3.81	2.25	1.52	0.84
Bottlenose dolphin	0.02	<0.01	0	0	0	0	0	0	8.57	5.28	3.55	2.22	3.59	2.16	1.46	0.80
Risso's dolphin	<0.01	<0.01	<0.01	0	<0.01	0	0	0	0.18	0.13	0.11	0.08	0.08	0.06	0.04	0.03
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	0	0	0	0	<0.01	0	0	0
High-frequency cetaceans																
Harbor porpoise	0.04	0.01	<0.01	<0.01	0.02	<0.01	<0.01	<0.01	0.21	0.16	0.13	0.10	0.56	0.42	0.34	0.26
Pinnipeds in water																
Gray seal	0.04	0.01	<0.01	<0.01	<0.01	0	0	0	0.51	0.34	0.25	0.19	0.32	0.21	0.16	0.11
Harbor seal	0.02	<0.01	<0.01	<0.01	<0.01	<0.01	0	0	0.19	0.13	0.09	0.07	0.12	0.08	0.06	0.04

[a] Listed as endangered under the ESA.

Table 22. Construction schedule 2: 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 OSS foundations (Table 3).

Species	Injury								Behavior							
	L_E (NMFS 2018)				L_{pk} (NMFS 2018)				L_p (NMFS 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]	1.12	0.63	0.38	0.16	<0.01	<0.01	0	0	1.69	1.21	1.01	0.70	1.49	0.98	0.75	0.52
Minke whale	0.30	0.12	0.04	<0.01	<0.01	<0.01	0	0	0.69	0.49	0.40	0.27	0.49	0.34	0.28	0.20
Humpback whale	1.26	0.63	0.32	0.11	<0.01	<0.01	0	0	2.05	1.36	1.06	0.67	1.61	1.07	0.83	0.56
North Atlantic right whale[a] (25% foraging)	1.02	0.41	0.20	0.04	<0.01	0	0	0	2.17	1.41	1.11	0.65	4.91	3.68	3.05	2.29
Sei whale[a]	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0	0	0.02	0.01	0.01	<0.01	0.02	0.01	<0.01	<0.01
Mid-frequency cetaceans																
Atlantic white sided dolphin	<0.01	<0.01	<0.01	0	0	0	0	0	1.29	0.89	0.74	0.48	0.72	0.50	0.36	0.22
Short-beaked common dolphin	0	0	0	0	0	0	0	0	0	0	0	0	0.07	0.03	<0.01	0
Bottlenose dolphin Northern coastal	0.08	0.03	<0.01	0	0	0	0	0	11.50	6.32	4.37	2.28	6.90	4.18	2.72	1.54
Bottlenose dolphin	0.05	0.01	0	0	0	0	0	0	11.52	6.45	4.32	2.21	6.77	4.00	2.64	1.49
Risso's dolphin	<0.01	<0.01	<0.01	0	<0.01	0	0	0	0.29	0.21	0.17	0.12	0.17	0.12	0.09	0.06
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	0	0	0	0	<0.01	0	0	0
High-frequency cetaceans																
Harbor porpoise	0.15	0.09	0.05	0.01	0.02	<0.01	<0.01	<0.01	0.26	0.18	0.15	0.10	0.93	0.73	0.61	0.48
Pinnipeds in water																
Gray seal	0.10	0.03	<0.01	<0.01	<0.01	0	0	0	0.55	0.34	0.27	0.17	0.40	0.25	0.20	0.12
Harbor seal	0.04	0.01	<0.01	<0.01	<0.01	<0.01	0	0	0.20	0.13	0.10	0.06	0.15	0.09	0.07	0.04

[a] Listed as endangered under the ESA.

4.5. Sea Turtle Exposure Range Estimates

Similar to the results presented for marine mammals (see Section 4.2), 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 23 to 25 show exposure ranges for pile types included in the construction schedules in Table 3. Exposure ranges for pile types assessed in acoustic modeling but not included in the construction schedules can be found in Appendix G.2.3.

Table 23. Monopile foundation (15 m diameter, 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]	1.03	0.35	0.02	<0.01	0	0	0	0	2.89	1.88	1.31	0.64
Leatherback turtle[a]	1.22	0.28	0.02	0.02	0	0	0	0	2.57	1.76	1.21	0.53
Loggerhead turtle	0.57	0.07	0	0	0	0	0	0	2.54	1.54	1.15	0.62
Green turtle	1.47	0.52	0.18	<0.01	<0.01	0	0	0	2.97	1.87	1.40	0.72

[a] Listed as Endangered under the ESA.

Table 24. Pre-piled jacket foundation (5 m diameter pin piles, 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]	0.60	0.07	0.02	0	0	0	0	0	1.89	0.86	0.50	0.21
Leatherback turtle[a]	0.46	0.03	0.02	<0.01	0	0	0	0	1.78	0.79	0.40	0.16
Loggerhead turtle	0.12	<0.01	0	0	0	0	0	0	1.63	0.76	0.41	0.12
Green turtle	0.76	0.07	0.02	0.02	0	0	0	0	1.99	0.84	0.59	0.12

[a] Listed as Endangered under the ESA.

Table 25. Post-piled jacket foundation[a] (5 m diameter pin piles, 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]	0.86	0.16	0.03	0.02	0	0	0	0	2.32	1.23	0.72	0.27
Leatherback turtle[b]	0.73	0.07	0.01	0.02	0	0	0	0	2.16	1.06	0.64	0.24
Loggerhead turtle	0.22	0.02	0	0	0	0	0	0	1.95	0.98	0.58	0.28
Green turtle	1.31	0.28	0.04	0.02	0	0	0	0	2.43	1.33	0.72	0.28

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

4.6. Sea Turtle Exposure Estimates

As was done for marine mammals (see Section 4.3), the number of individual sea turtles predicted to receive above threshold sound levels were determined using animal movement modeling. The construction schedules described in Table 3 are used to calculate the total number of real-world individual turtles predicted to receive sound levels above injury and behavior thresholds (Finneran et al. 2017) in the Lease Area. Tables 26 and 27 include results assuming broadband attenuation of 0, 6, 10, and 15 dB during the summer season, calculated in the same way as the marine mammal exposures (see Section 4.3).

Table 26. Construction schedule 1: 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 OSS foundations (Table 3).

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]	36.35	9.18	1.90	1.20	0	0	0	0	127.47	71.47	45.48	20.13
Leatherback turtle[a]	13.54	2.85	1.00	0.50	0	0	0	0	76.89	42.75	25.56	9.80
Loggerhead turtle	155.30	20.61	0	0	0	0	0	0	5,175.57	2,455.03	1,277.05	471.80
Green turtle	1.39	0.46	0.10	0.03	0.01	0	0	0	3.86	2.12	1.26	0.61

[a] Listed as Endangered under the ESA.

Table 27. Construction schedule 2: 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 OSS foundations (Table 3).

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]	33.88	5.12	1.98	0.14	0	0	0	0	151.66	71.44	35.29	13.97
Leatherback turtle[a]	12.04	2.18	0.54	0.27	0	0	0	0	90.46	38.27	19.28	8.26
Loggerhead turtle	136.56	12.75	0	0	0	0	0	0	6,437.85	2,438.49	1,195.58	407.75
Green turtle	1.25	0.22	0.05	0.03	0	0	0	0	4.19	1.70	0.96	0.30

[a] Listed as Endangered under the ESA.

4.7. 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, Popper et al. 2014) were calculated directly from the sound fields (see Section 2.6). 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: 5 m, and monopile: 12 m and 15 m) are shown in Tables 28 to 30.

Table 28. Acoustic radial distances ($R_{95\%}$ in km) to thresholds for fish for 12 m monopiles using a 4,400 kJ hammer energy with 0 dB attenuation.

Faunal group	Metric	Threshold (dB)	Hammer energy (kJ)									
			L01					L02				
			1,400	1,800	2,000	3,000	4,400	1,400	1,800	2,000	3,000	4,400
Small fish[a]	L_E	183	10.51					9.55				
	L_{pk}	206	0.19	0.21	0.32	0.38	0.44	0.22	0.25	0.27	0.35	0.47
Large fish[a]	L_E	187	8.90					8.10				
	L_{pk}	206	0.19	0.21	0.32	0.38	0.44	0.22	0.25	0.27	0.35	0.47
All fish[b]	L_p	150	8.16	8.78	9.25	10.20	10.99	7.45	7.89	8.39	9.41	10.08
Fish without swim bladder[c]	L_E	216	1.19					1.14				
	L_{pk}	213	0.08	0.09	0.10	0.12	0.20	0.07	0.07	0.08	0.13	0.17
Fish with swim bladder[c]	L_E	203	3.95					3.55				
	L_{pk}	207	0.17	0.20	0.22	0.36	0.41	0.15	0.22	0.25	0.3	0.37
All fish[c]	L_E	186	9.29					8.47				

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.

[a] FHWG (2008), Stadler and Woodbury (2009)

[b] Andersson et al. (2007), Wysocki et al. (2007), Mueller-Blenkle et al. (2010), Purser and Radford (2011)

[c] Popper et al. (2014)

Table 29. Acoustic radial distances ($R_{95\%}$ in km) to thresholds for fish for 15 m monopiles using a 4,400 kJ hammer energy with 0 dB attenuation.

Faunal group	Metric	Threshold (dB)	Hammer energy (kJ)													
			L01							L02						
			480	800	1,600	2,500	3,000	4,000	4,400	480	800	1,600	2,500	3,000	4,000	4,400
Small fish[a]	L_E	183	11.05							9.98						
	L_{pk}	206	0.09	0.11	0.19	0.33	0.35	0.40	0.43	0.08	0.09	0.23	0.28	0.34	0.46	0.50
Large fish[a]	L_E	187	9.46							8.57						
	L_{pk}	206	0.09	0.11	0.19	0.33	0.35	0.40	0.43	0.08	0.09	0.23	0.28	0.34	0.46	0.50
All fish[b]	L_p	150	6.25	7.03	8.15	9.61	10.02	10.60	11.16	5.79	6.30	7.33	8.56	9.06	9.90	10.24
Fish without swim bladder[c]	L_E	216	1.45							1.34						
	L_{pk}	213	0.04	0.06	0.08	0.10	0.11	0.19	0.21	0.04	0.05	0.07	0.08	0.09	0.16	0.18
Fish with swim bladder[c]	L_E	203	4.34							3.90						
	L_{pk}	207	0.08	0.10	0.15	0.30	0.33	0.38	0.41	0.07	0.08	0.13	0.26	0.28	0.33	0.46
All fish[c]	L_E	186	9.85							8.92						

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.

[a] FHWG (2008), Stadler and Woodbury (2009)

[b] Andersson et al. (2007), Wysocki et al. (2007), Mueller-Blenkle et al. (2010), Purser and Radford (2011)

[c] Popper et al. (2014)

Table 30. Acoustic radial distances ($R_{95\%}$ in km) to thresholds for fish (GARFO 2020) for 5 m jacket foundations using a 2,500 kJ hammer energy with 0 dB attenuation.

Faunal group	Metric	Threshold (dB)	Hammer energy (kJ)							
			L01				L02			
			1,200	1,400	1,800	2,500	1,200	1,400	1,800	2,500
Small fish[a]	L_E	183	11.94				10.38			
	L_{pk}	206	0.29	0.33	0.21	0.14	0.26	0.28	0.21	0.13
Large fish[a]	L_E	187	9.94				8.68			
	L_{pk}	206	0.29	0.33	0.21	0.14	0.26	0.28	0.21	0.13
All fish[b]	L_p	150	9.82	9.63	10.16	7.98	9.07	9.28	8.36	3.10
Fish without swim bladder[c]	L_E	216	0.88				0.78			
	L_{pk}	213	0.10	0.10	0.07	0.06	0.08	0.08	0.05	0.07
Fish with swim bladder[c]	L_E	203	3.82				3.21			
	L_{pk}	207	0.27	0.30	0.17	0.12	0.24	0.27	0.19	0.12
All fish[c]	L_E	186	10.44				9.10			

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; large fish are defined as having a total mass of greater than or equal to 2 g.

[a] FHWG (2008), Stadler and Woodbury (2009)

[b] Andersson et al. (2007), Wysocki et al. (2007), Mueller-Blenkle et al. (2010), Purser and Radford (2011)

[c] Popper et al. (2014)

Table 31. Acoustic radial distances ($R_{95\%}$ in km) to thresholds for fishfor 5 m jacket foundations using a 2,500 kJ hammer energy with 0 dB attenuation and a post-piling 2 dB shift.

Faunal group	Metric	Threshold (dB)	Hammer energy (kJ)							
			L01				L02			
			1,200	1,400	1,800	2,500	1,200	1,400	1,800	2,500
Small fish[a]	L_E	183	12.99				11.31			
	L_{pk}	206	0.39	0.37	0.28	0.23	0.33	0.32	0.25	0.14
Large fish[a]	L_E	187	10.95				9.52			
	L_{pk}	206	0.39	0.37	0.28	0.23	0.33	0.32	0.25	0.14
All fish[b]	L_p	150	10.79	10.62	11.13	8.90	9.92	10.14	9.22	3.32
Fish without swim bladder[c]	L_E	216	1.18				1.03			
	L_{pk}	213	0.17	0.11	0.09	0.07	0.14	0.12	0.07	0.08
Fish with swim bladder[c]	L_E	203	4.42				3.78			
	L_{pk}	207	0.33	0.35	0.25	0.15	0.31	0.30	0.24	0.13
All fish[c]	L_E	186	11.43				9.94			

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; large fish are defined as having a total mass of greater than or equal to 2 g.

[a] FHWG (2008), Stadler and Woodbury (2009)

[b] Andersson et al. (2007), Wysocki et al. (2007), Mueller-Blenkle et al. (2010), Purser and Radford (2011)

[c] Popper et al. (2014)

5. Discussion

Impact pile driving generates broadband sounds with maximum sound energy at frequencies <500 Hz. This work evaluated the effects associated with the construction of an offshore wind farm with four foundation configurations: two monopile foundations, one with 12 m monopiles and one with 15 m monopiles, and two jacketed foundation types, one pre-piled and one post-piled. Of the two monopile diameters, only the 15 m was included in the construction schedules used for exposure modeling. Larger piles with larger hammers generally produce sounds at lower frequencies than smaller piles and smaller hammers, although a variety of factors ultimately contribute to the sound levels experienced by marine animals. The peak sound energy for the 5 m jacket pin piles occurred at a slightly higher frequency than for the monopiles, at approximately 200 Hz for the 2,500 kJ hammer energy (Figure 10). In contrast, most of the sound energy produced by the monopiles, for any hammer energy, was below 100 Hz (Figures 11 and 12). While differences in frequency content are important, this needs to be assessed in the context of the hearing range of the animals receiving sounds (see Appendix D). Most fish and sea turtles hear at low frequencies, <1,000 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. To account for this, sound fields are adjusted when assessing injury (SEL) and behavioral disruption (Wood et al. 2012) by discounting sound levels in frequency bands according to hearing group auditory weighting functions (see Appendix D). The most sensitive hearing range for 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 less 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, 12 m and 15 m monopiles could reasonably be expected to have greater impacts than pin piles, and they do in some circumstances. Radial distances to the peak sound levels (PK) are longer for monopiles than pin piles (see 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 14 to 16); though exposures associated with injury criteria are primarily predicted to occur as a result of exceeding the SEL 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 (NOAA 2005) .

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, 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 reduction in propagated sound.

The analysis for all pile types predicted the number of individual animals potentially exposed to sound levels above SEL and PK injury threshold criteria using only noise mitigation. The exposures summarized here assume 10 dB of attenuation was achieved using a noise abatement system (NAS) although results at 0, 6, 10, and 15 dB were also assessed to provide context. For critically endangered North Atlantic right whale (NARW), a simulation with conservative assumptions and no mitigation other than NAS resulted in fewer than 1 potential injurious exposure. The foundation type with the longest exposure ranges for marine mammals was the post-piled jacket foundation, with an exposure range of 1.06 km to the SEL injury criteria threshold for NARW (Table 16). The only species with exposures exceeding PK injury threshold criteria at 10 dB attenuation were harbor porpoise (Table 16). Exposure modeling results for behavioral thresholds were assessed using both NOAA (2005) and Wood et al. (2012) for marine mammals. The model results predicted that fewer than 10 individual NARWs would be exposed to sound levels that could elicit a behavioral response (Tables 17 and 18). Exposure ranges to behavioral thresholds were longest for post-piled jacket foundations, at 12.8 km from the pile for NARW.

Using criteria described by Finneran et al. (2017) less than two sea turtles are predicted to be exposed above the regulatory-defined threshold for injury (Tables 26 and 27), with a maximum exposure range of 180 m from the 15 m monopile (Table 23). The criteria described by McCauley et al. (2000) and Finneran et al. (2017) that is potentially associated with behavioral response results in less than 46 exposures for Kemp's ridley, leatherback, or green sea turtles. However, the density for loggerhead turtles is predicted to be an order of magnitude higher than any of the other sea turtle species, and this is reflected in the higher behavioral exposures with up to 1,300 exceedances at 10 dB attenuation (Tables 26 and 27). For turtles, exposure ranges to behavioral criteria thresholds are longest for the 15 m monopile, at up to 1.4 km from the source (Table 23). Exposure ranges to behavioral thresholds for jacketed foundations are substantially lower at less than 800 m for all turtle species (Tables 23 to 25).

Atlantic Shores is committed to implement monitoring and mitigation measures specified in the BOEM lease documentation for the lease area, including seasonal restrictions on construction activity, piling energy ramp up, Protected Species Observers (PSOs), Passive Acoustic Monitoring (PAM), and species-specific exclusion zones. After mitigation measures are implemented, the residual risk of impacts is expected to be significantly reduced.

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.boem.gov/uploadedFiles/BOEM/Renewable_Energy_Program/State_Activities/BOEM%20RI_MA_Revised%20EA_22May2013.pdf.

[CeTAP] Cetacean and Turtle Assessment Program, University of Rhode Island. 1982. *A Characterization of marine mammals and turtles in the mid- and North Atlantic aeas of the US Outer Continental Shelf, final report*. Contract AA551-CT8-48. Bureau of Land Management, Washington, DC.

[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). 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. 2020. *GARFO Acoustics Tool: Analyzing the effects of pile driving on ESA-listed species in the Greater Atlantic Region* https://s3.amazonaws.com/media.fisheries.noaa.gov/2020-09/GARFO-Sect7-PileDriving-AcousticsTool-09142020.xlsx?.Egxagq5Dh4dpIwJQsmN1gV0nggnk5qX.

[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.

Marine Mammal Protection Act of 1972 as Amended. 2015. United States Pub. L. No. 92-522, 16 U.S.C. 1361 (21 Oct 1972). http://www.nmfs.noaa.gov/pr/laws/mmpa/text.htm.

[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://www.nefsc.noaa.gov/publications/crd/crd1103/1103.pdf.

[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://nefsc.noaa.gov/psb/AMAPPS/docs/NMFS_AMAPPS_2011_annual_report_final_BOEM.pdf.

[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://nefsc.noaa.gov/psb/AMAPPS/docs/NMFS_AMAPPS_2012_annual_report_FINAL.pdf.

[NEFSC] Northeast Fisheries Science Center and [SEFSC] Southeast Fisheries Science Center. 2014a. *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://nefsc.noaa.gov/psb/AMAPPS/docs/NMFS_AMAPPS_2014_annual_report_Final.pdf.

[NEFSC] Northeast Fisheries Science Center and [SEFSC] Southeast Fisheries Science Center. 2014b. *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://nefsc.noaa.gov/psb/AMAPPS/docs/NMFS_AMAPPS_2013_annual_report_FINAL3.pdf.

[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. http://www.nmfs.noaa.gov/pr/pdfs/fr/fr70-1871.pdf.

[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.

[USFWS] US Fish and Wildlife Service. 2014. *West Indian manatee (Trichechus manatus) Florida stock (Florida subspecies, Trichechus manatus latirostris)*. https://www.fws.gov/northflorida/manatee/SARS/20140123_FR00001606_Final_SAR_WIM_FL_Stock.pdf.

[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://doi.org/10.1579/0044-7447(2007)36[636:SBORRR]2.0.CO;2.

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.

Au, W.W.L. and M.C. Hastings. 2008. *Principles of Marine Bioacoustics*. Springer, New York. 510 p. https://doi.org/10.1007/978-0-387-78365-9.

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.

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.

Bellmann, 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).

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/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.

Cranford, T.W. and P. Krysl. 2015. Fin whale sound reception mechanisms: Skull vibration enables low-frequency hearing. *PLOS ONE* 10(1). https://doi.org/10.1371/journal.pone.0116222.

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

Dahlheim, M.E. and D.K. Ljungblad. 1990. Preliminary hearing study on gray whales (*Eschrichtius robustus*) in the field. *In* Thomas, J.A. and R.A. Kastelein (eds.). *Sensory Abilities of Cetaceans*. Volume 196. Springer US. pp. 335-346.

Davis, G.E., M.F. Baumgartner, J.M. Bonnell, J. Bell, C. Berchok, J. Bort Thornton, S. Brault, G. Buchanan, R.A. Charif, et al. 2017. Long-term passive acoustic recordings track the changing distribution of North Atlantic right whales (*Eubalaena glacialis*) from 2004 to 2014. *Scientific Reports* 7(1): 1-12. https://doi.org/10.1038/s41598-017-13359-3.

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.

GEBCO Compilation Group. 2019. GEBCO 2019 Grid. https://www.gebco.net/data_and_products/gridded_bathymetry_data/gebco_2019/gebco_2019_info.html.

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

Hannay, D.E. and R.G. Racca. 2005b. *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.

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://www.nefsc.noaa.gov/publications/tm/tm245/.

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 (draft)*. NOAA Technical Memorandum, Woods Hole, MA, USA.

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., D.A. Helweg, and P.W.B. Moore. 2001. A bandpass filter-bank model of auditory sensitivity in the humpback whale. *Aquatic Mammals* 27(2): 82-91. https://www.aquaticmammalsjournal.org/share/AquaticMammalsIssueArchives/2001/AquaticMammals_27-02/27-02_Houser.PDF.

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.

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.

Madsen, P.T., M. Wahlberg, J. Tougaard, K. Lucke, and P.L. Tyack. 2006. Wind turbine underwater noise and marine mammals: Implications of current knowledge and data needs. *Marine Ecology Progress Series* 309: 279-295. https://www.int-res.com/abstracts/meps/v309/p279-295/.

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. http://www.nmfs.noaa.gov/pr/pdfs/permits/bp_openwater_90dayreport_appendices.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. *Giant Manta Ray (Manta birostris)* (webpage). https://www.fisheries.noaa.gov/species/giant-manta-ray. (Accessed 11 Jun 2020).

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

Normandeau Associates Inc. and APEM Inc. 2018. *Digital Aerial Baseline Survey of Marine Wildlife in Support of Offshore Wind Energy: Summer 2018 Taxonomic Analysis Summary Report*. Report by Normandeau Associates Inc. and APEM Inc. for New York State Energy Research and Development Authority. https://remote.normandeau.com/docs/NYSERDA_Summer_2018_Taxonomic_Analysis_Summary_Report.pdf.

Normandeau Associates Inc. and APEM Inc. 2019a. *Digital Aerial Baseline Survey of Marine Wildlife in Support of Offshore Wind Energy: Spring 2019 Taxonomic Analysis Summary Report*. Report by Normandeau Associates Inc. and APEM Inc. for New York State Energy Research and Development Authority. https://remote.normandeau.com/docs/NYSERDA_Spring_2019_Taxonomic_Analysis_Summary_Report.pdf.

Normandeau Associates Inc. and APEM Inc. 2019b. *Digital Aerial Baseline Survey of Marine Wildlife in Support of Offshore Wind Energy: Fall 2018 Taxonomic Analysis Summary Report*. Report by Normandeau Associates Inc. and APEM Inc. for New York State Energy Research and Development Authority. https://remote.normandeau.com/docs/NYSERDA_Fall_2018_Taxonomic_Analysis_Summary_Report.pdf.

Normandeau Associates Inc. and APEM Ltd. 2019. *Digital Aerial Baseline Survey of Marine Wildlife in Support of Offshore Wind Energy: Summer 2016–Spring 2018 Fourth Interim Report*. Second annual report by Normandeau Associates Inc. and APEM Ltd. for New York State Energy Research. 149 p. https://remote.normandeau.com/docs/NYSERDA_2016-2018_4th_Semi-Annual_report.pdf.

Normandeau Associates Inc. and APEM Inc. 2020. *Digital Aerial Baseline Survey of Marine Wildlife in Support of Offshore Wind Energy: Winter 2018-2019 Taxonomic Analysis Summary Report*. Report by Normandeau Associates Inc. and APEM Inc. for New York State Energy Research and Development Authority. https://remote.normandeau.com/docs/NYSERDA_Winter_2018_19_Taxonomic_Analysis_Summary_Report.pdf.

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.

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.

Parks, S.E., C.W. Clark, and P.L. Tyack. 2007. Short-and long-term changes in right whale calling behavior: The potential effects of noise on acoustic communication. *Journal of the Acoustical Society of America* 122(6): 3725-3731. https://doi.org/10.1121/1.2799904.

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/.

Popper, A.N., A.D. Hawkins, R.R. Fay, D.A. Mann, S. Bartol, T.J. Carlson, S. Coombs, W.T. Ellison, R.L. Gentry, et al. 2014. *Sound Exposure Guidelines for Fishes and Sea Turtles: A Technical Report prepared by ANSI-Accredited Standards Committee S3/SC1 and registered with ANSI*. ASA S3/SC1.4 TR-2014. SpringerBriefs in Oceanography. ASA Press and Springer. https://doi.org/10.1007/978-3-319-06659-2.

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.

Reichmuth, C., J. Mulsow, J.J. Finneran, D.S. Houser, and A.Y. Supin. 2007. Measurement and Response Characteristics of Auditory Brainstem Responses in Pinnipeds. *Aquatic Mammals* 33(1): 132-150.

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.

Richardson, W.J., C.R. Greene, Jr., C.I. Malme, and D.H. Thomson. 1995. *Marine Mammals and Noise*. Academic Press, San Diego, CA, USA. 576 p.

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.

Sills, J.M., B.L. Southall, and C. Reichmuth. 2014. Amphibious hearing in spotted seals (*Phoca largha*): Underwater audiograms, aerial audiograms and critical ratio measurements. *Journal of Experimental Biology* 217(5): 726-734. http://jeb.biologists.org/content/jexbio/217/5/726.full.pdf.

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.

Stone, K.M., S.M. Leiter, R.D. Kenney, B.C. Wikgren, J.L. Thompson, J.K. Taylor, and S.D. Kraus. 2017. Distribution and abundance of cetaceans in a wind energy development area offshore of Massachusetts and Rhode Island. *Journal of Coastal Conservation* 21(4): 527-543.

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

Tougaard, J., P.T. Madsen, and M. Wahlberg. 2008. Underwater noise from construction and operation of offshore wind farms. *Bioacoustics* 17(1-3): 143-146. https://doi.org/10.1080/09524622.2008.9753795.

Tubelli, A.A., A. Zosuls, D.R. Ketten, and D.C. Mountain. 2012. Prediction of a mysticete audiogram via finite element analysis of the middle ear. *In* Popper, A.N. and A.D. Hawkins (eds.). *The Effects of Noise on Aquatic Life*. Volume 730. Springer, New York. pp. 57-59. https://doi.org/10.1007/978-1-4419-7311-5_12.

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.

Wartzok, D. and D.R. Ketten. 1999. Marine Mammal Sensory Systems. (Chapter 4) *In* Reynolds, J. and S. Rommel (eds.). *Biology of Marine Mammals*. Smithsonian Institution Press, Washington, DC. pp. 117-175.

Whitt, A.D., K. Dudzinski, and J.R. Laliberté. 2013. North Atlantic right whale distribution and seasonal occurrence in nearshore waters off New Jersey, USA, and implications for management. *Endangered Species Research* 20(1): 59-69. https://doi.org/10.3354/esr00486.

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://www.south-stream-transport.com/media/documents/pdf/en/2014/07/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 Atlantic Shores.

Three different foundation types (Table B-1) are being considered for the Atlantic Shores Project foundations using four piles to secure a jacket structure and monopile foundations consisting of single piles. For jacket foundation models, the piles are assumed to be vertical and driven to a penetration depth of 55 m with self-penetration of 15 m. For monopile foundation models, the piles are assumed to be vertical and driven to a penetration depth of 45 m with self-penetration of 15 m. While pile penetrations across the Project will vary, these values were chosen as maximum penetration depths. The estimated number of strikes required to install piles to completion were obtained from Atlantic Shores 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
Jacket foundation	
Modeling method	Finite-difference structural model of pile vibration based on thin-shell theory; Hammer forcing functions computed using GRLWEAP
Impact hammer energy	2,500 kJ
Ram weight	1,227.32 kN
Helmet weight	711 kN
Strike rate (min^{-1})	30
Estimated number of strikes to drive pile	6,750
Expected penetration	70 m
Modeled seabed penetration	10, 20, 15, and 10 m
Pile length	76 m
Pile diameter	5 m
Pile wall thickness	72 mm
L_E accumulation	Per-pulse sound exposures assumed to be equal for a given hammer energy, summed over expected number of strikes
15 m 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	4,400 kJ
Ram weight	2,157 kN
Helmet weight	2,351 kN
Strike rate (min^{-1})	30
Estimated number of strikes to drive pile	15,387
Expected penetration	60 m
Modeled seabed penetration	8, 3, 4, 5, 10, 9 and 6 m

Parameter	Description
Pile length	105 m
Pile diameter	tapered 8 to 15 m
Pile wall thickness	162 mm
12 m 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	4,400 kJ
Ram weight	2,157 kN
Helmet weight	2,351 kN
Strike rate (min^{-1})	30
Estimated number of strikes to drive pile	12,350
Expected penetration	60 m
Modeled seabed penetration	5, 5, 15, 15 and 5 m
Pile length	101 m
Pile diameter	tapered 8 to 12 m
Pile wall thickness	130 mm
Environmental parameters for all pile types	
Sound speed profile	GDEM data averaged over region
Bathymetry	GEBCO_2019 grid
Geoacoustics	Elastic seabed properties based on description of surficial sediment samples
Quake (shaft and toe)	Shaft: 2.54 mm; Toe: 2.54 mm (Jacket), 2.862 mm (12 m Monopile) and 2.837 mm (15 m Monopile)
Shaft damping	0.164 s/m
Toe damping	0.49 s/m
Shaft resistance	64, 76, 81, 83% (for each energy level – Jackets) 53, 59, 70, 73, 78% (for each energy level – 12 m Monopile) 56, 61, 64, 67, 73, 76, 78% (for each energy level – 15 m Monopile)
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
Source representation	Vertical line array
Frequency range	10 to 25,000 Hz
Synthetic trace length	400 ms (Jacket), 400 ms (12 m Monopile), 350 ms (15 m 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 air guns, 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 µPa²·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 one second. 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:

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

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

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:

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

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 one second 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 one minute 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) 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).

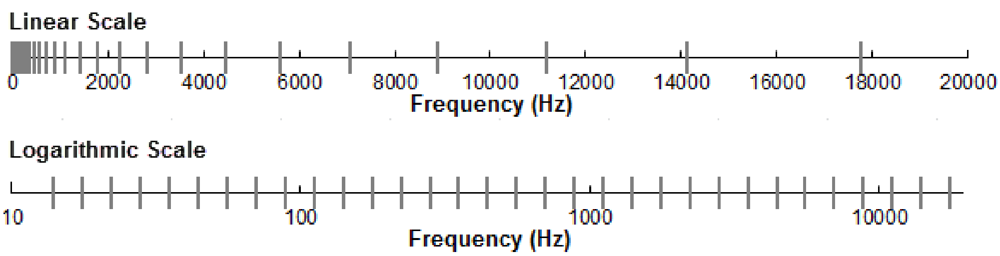

Figure C-1. Decidecade frequency bands (vertical lines) shown on a linear frequency scale and a logarithmic scale.

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 modelling 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.

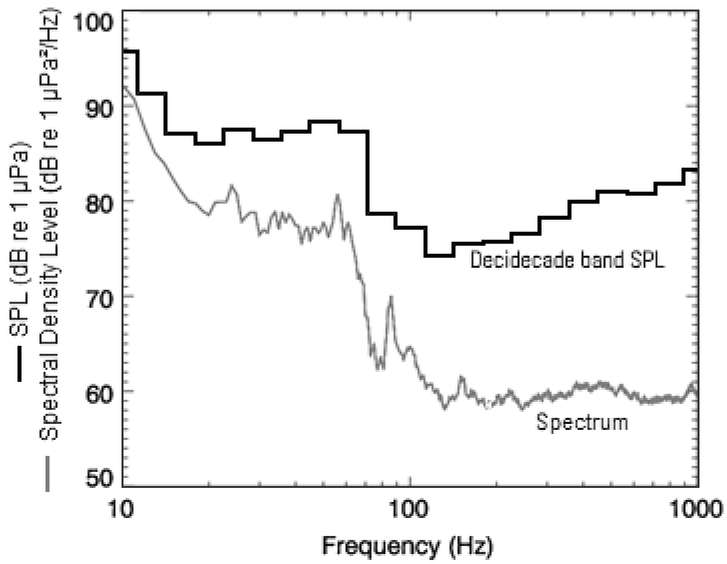

Figure C-2. Sound pressure spectral density levels and the corresponding decidecade band sound pressure levels of example ambient noise shown on a logarithmic frequency scale.

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).

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.

In 2017, the Criteria and Thresholds for US Navy Acoustic and Explosive Effects Analysis (Finneran et al. 2017) updated the auditory weighting functions to include sea turtles. The sea turtle weighting curve uses the same equation used for marine mammal auditory weighting functions (Equation D-1). Parameters are provided in Table D-1.

Table D-1. Parameters for the auditory weighting functions recommended by NMFS (2018) and Finneran et al. (2017).

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
Sea turtles	1.4	2	77	440	2.35

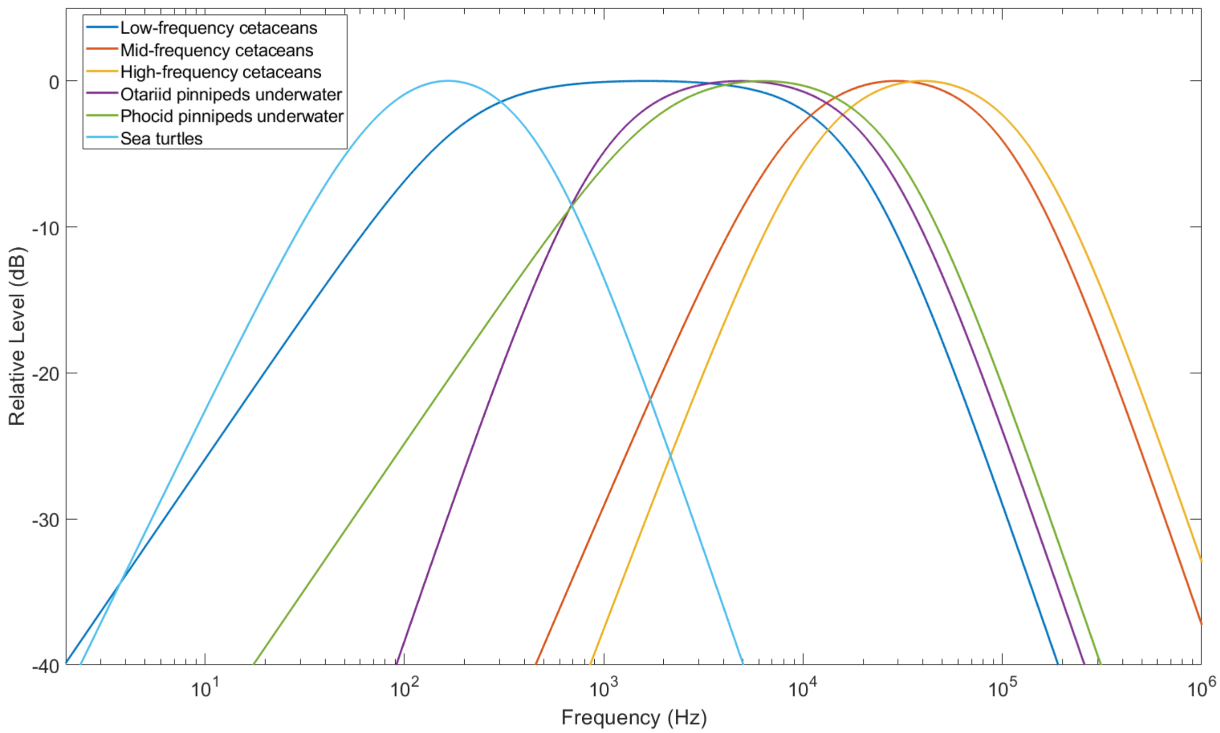

Figure D-1. Auditory weighting functions for the functional marine mammal hearing groups as recommended by NMFS (2018).

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; and
- 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:

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

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-2 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

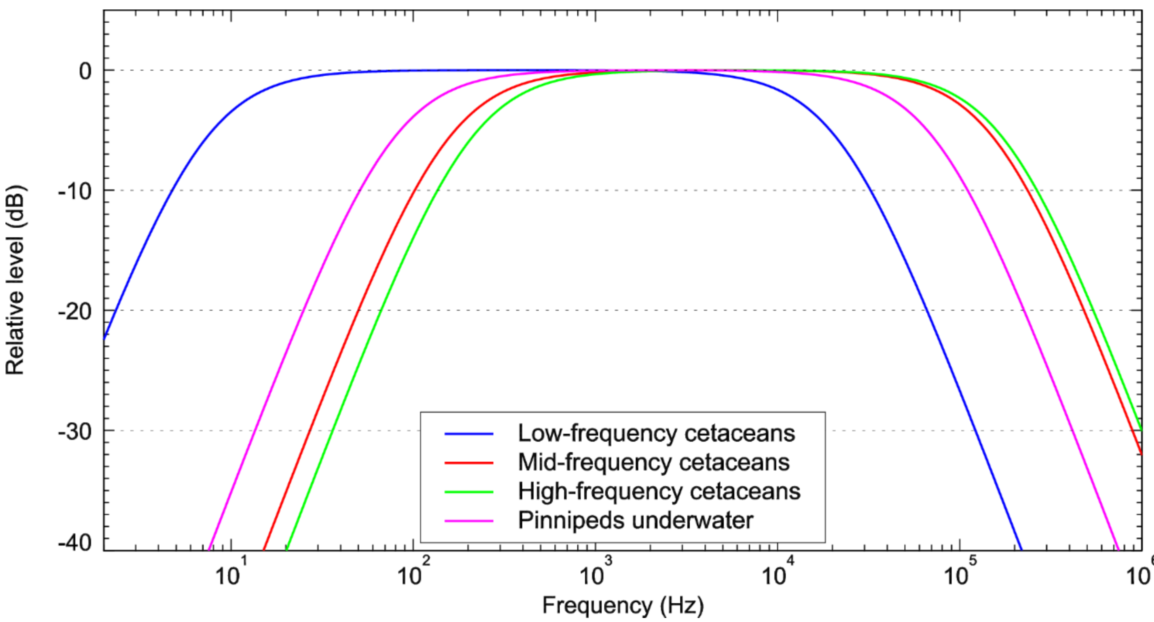

Figure D-2. Auditory weighting functions for the functional marine mammal hearing groups as recommended by Southall et al. (2007).

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.5). MacGillivray (2014) describes the theory behind the physical model in more detail.

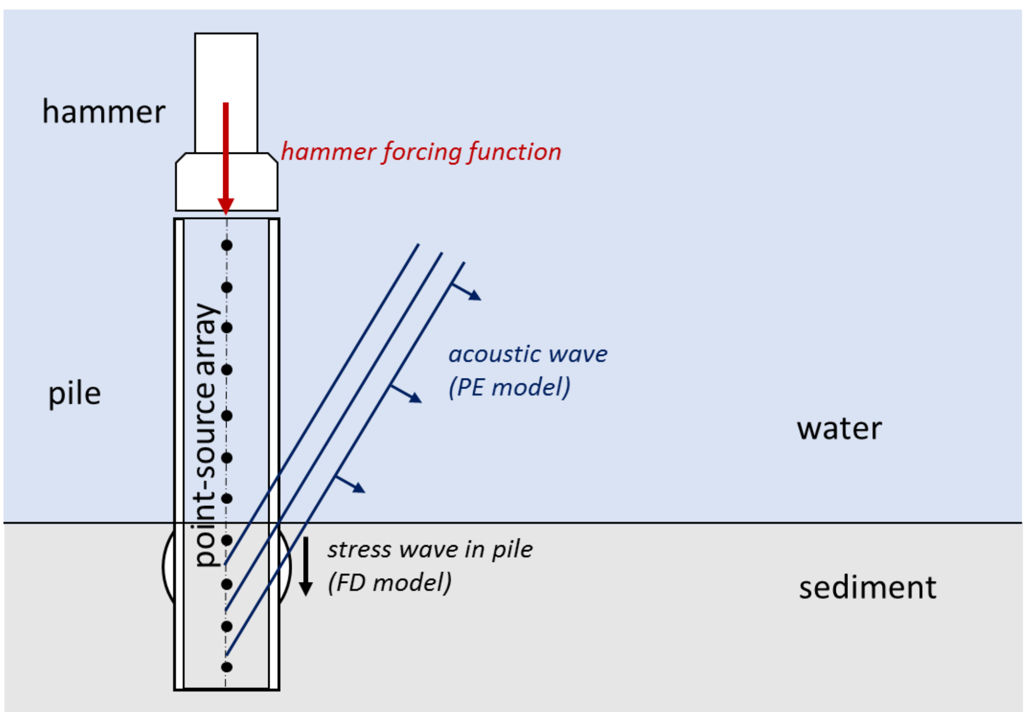

Figure E-1. Physical model geometry for impact driving of a cylindrical pile (vertical cross-section). The hammer forcing function is used with the finite difference (FD) model to compute the stress wave vibration in the pile. A vertical array of point sources is used with the parabolic equation (PE) 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 obtained from GEBCO 2019 grid for the general lease area.

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)
0–7.5	Sand	2.086–2.096	1,764–1,774	0.88–0.878	300	3.65
7.5–15		2.096–2.106	1,774–1,784	0.878–0.876		
15–25		2.106–2.119	1,784–1,796	0.876–0.873		
25–55		2.119–2.159	1,796–1,834	0.873–0.864		
55–80		2.159–2.191	1,834–1,864	0.864–0.855		
80–220		2.191–2.360	1,864–2,018	0.855–0.798		
220–360		2.360–2.508	2,017–2,150	0.798–0.732		
360–500		2.508–2.634	2,150–2, 263	0.732–0.665		
>500		2.634	2,263	0.665		

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 U.S. 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 during the summer months, from June to August (Figure E-2). Water depths in the Atlantic Shores Project area are less than 40 m; sound speed profiles for the shallow water are provided in (Figure E-3). An average profile, obtained by calculating the mean of all profiles shown in Figure E-2 was assumed representative of summer for the area for modeling purposes.

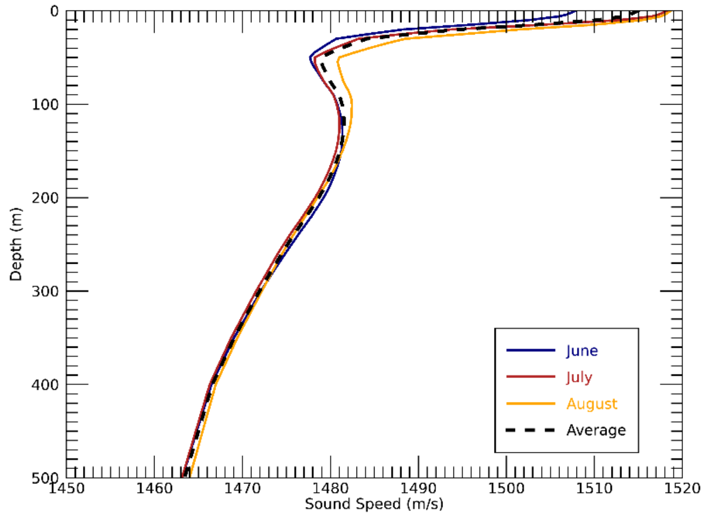

Figure E-2. Sound speed profiles for the months of June through August for the Project area, and the mean summer profile used in the modeling and obtained by taking the average of all profiles.

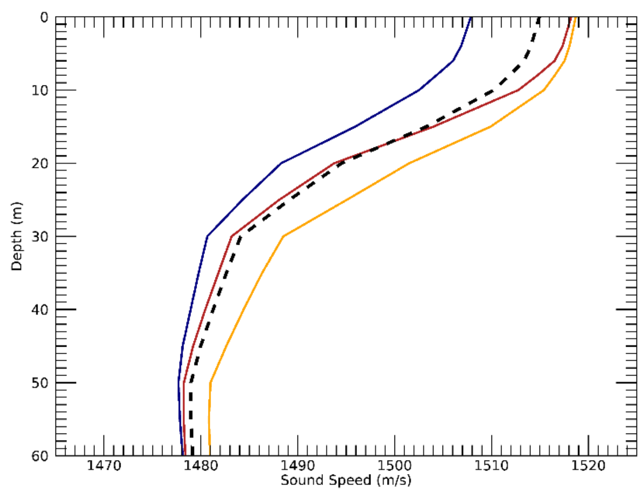

Figure E-3. Sound speed profiles up to 60 m depth for the months of June through August for the Project area, and the mean summer profile used in the modeling and obtained by taking the average of all profiles.

E.3. Transmission Loss

The propagation of sound through the environment was modelled 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 2005b, 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.

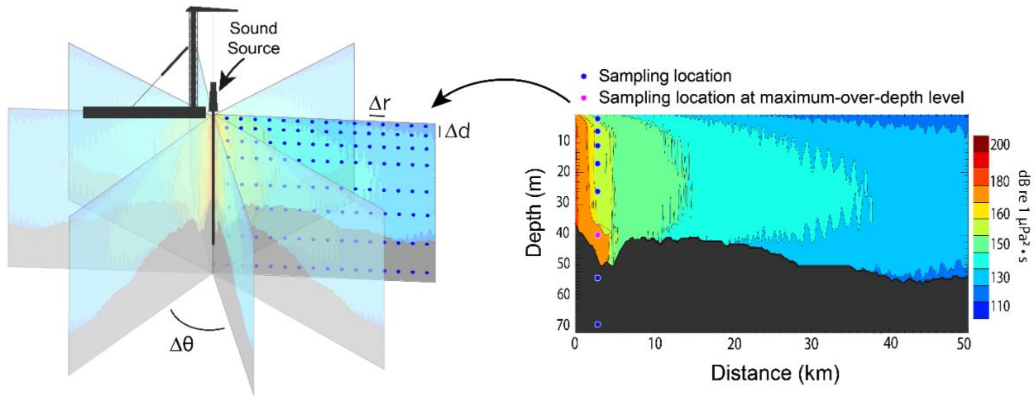

Figure E-4. Modeled three-dimensional sound field (N×2-D method) and maximum-over-depth modeling approach. Sampling locations are shown as blue dots on both figures. On the right panel, the pink dot represents the sampling location where the sound level is maximum over the water column. This maximum-over-depth 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 2,048 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.

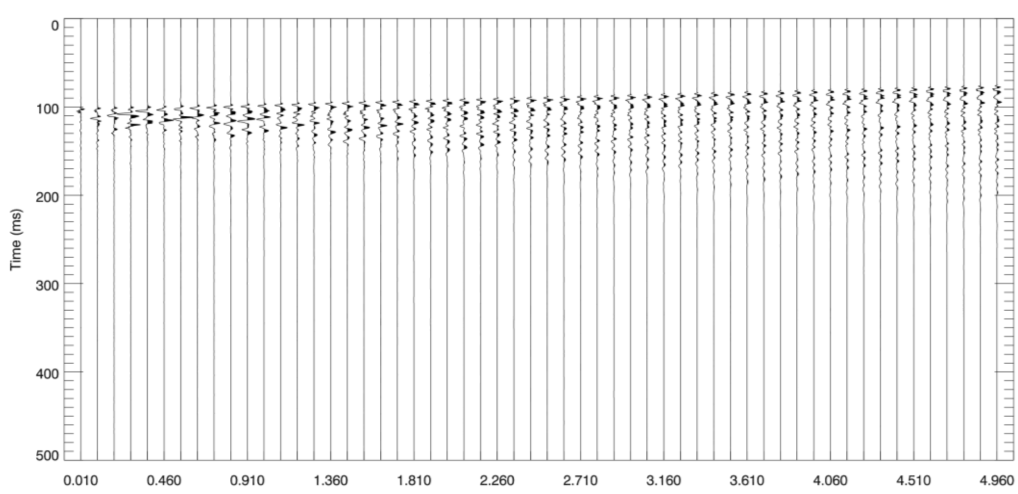

Figure E-5. Example of synthetic pressure waveforms computed by FWRAM at multiple range offsets. Receiver depth is 35 m and the amplitudes of the pressure traces have been normalised for display purposes.

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% 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% 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.

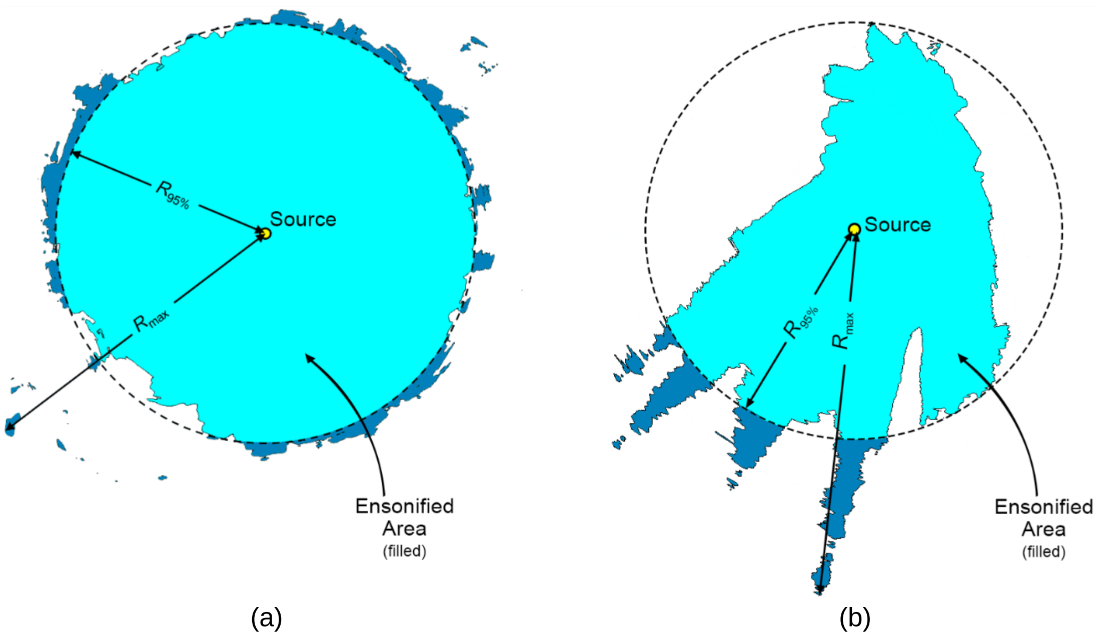

Figure E-6. Sample areas ensonified to an arbitrary sound level with R_{max} and $R_{95\%}$ ranges shown for two different scenarios. (a) Largely symmetric sound level contour with small protrusions. (b) Strongly asymmetric sound level contour with long protrusions. Light blue indicates the ensonified 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 U.S. and Canadian Arctic, Canadian and southern U.S. waters, Greenland, Russia and Australia (Hannay and Racca 2005a, 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 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% farthest such points were excluded (see Appendix E.6). Ranges are calculated on unweighted and weighted sound fields described in Appendix D. 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

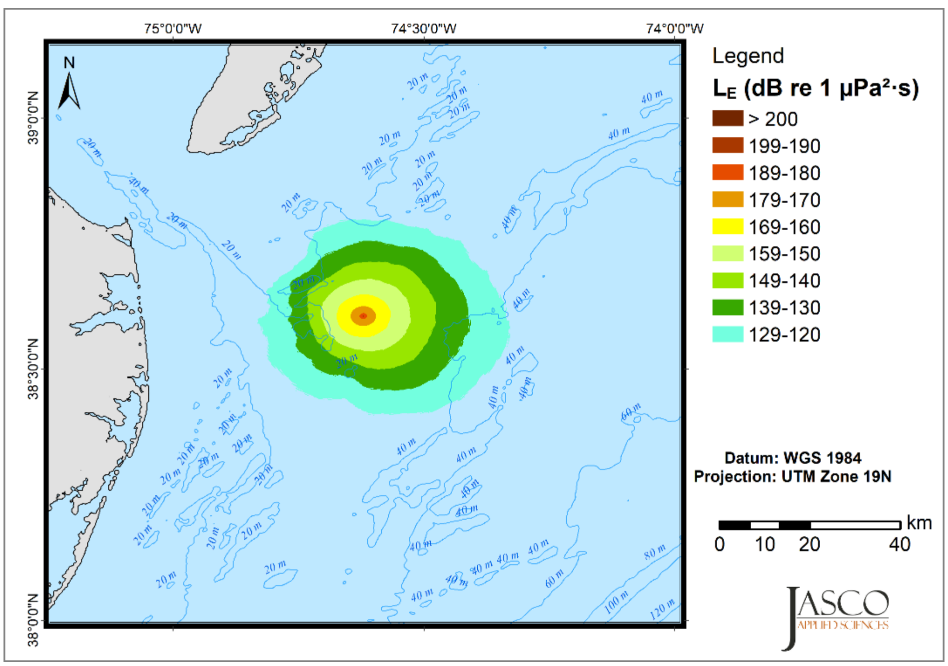

Figure F-1. Unweighted single-strike sound exposure level (SEL) for a 12 m pile at Location L01, summer sound speed profile and energy level of 4,400 kJ.

Table F-1. Distance (km) to single strike sound exposure level (SEL) for a 12 m pile at location L01 using a Menck MHU4400S hammer operating at 1,400 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	0.26	0.25	0.05	0.05	-	-	-	-	-	-	0.17	0.17
170	1.41	1.32	0.30	0.28	-	-	-	-	-	-	0.87	0.83
160	3.71	3.38	1.66	1.47	-	-	-	-	0.09	0.08	3.00	2.76
150	6.88	6.01	4.19	3.78	-	-	-	-	0.48	0.47	6.38	5.48
140	10.81	9.50	7.85	6.82	0.09	0.09	0.04	0.04	2.17	1.98	10.26	8.96
130	16.01	13.70	12.41	10.88	0.80	0.61	0.42	0.29	5.16	4.63	15.48	13.23
120	21.42	18.67	18.36	15.78	2.90	2.30	1.95	1.58	9.37	8.21	21.08	18.28

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

Table F-2. Distance (km) to single strike sound exposure level (SEL) for a 12 m pile at location L01 using a Menck MHU4400S hammer operating at 1,800 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	0.09	0.08	-	-	-	-	-	-	-	-	0.04	0.04
180	0.39	0.38	0.09	0.08	-	-	-	-	-	-	0.22	0.20
170	1.71	1.60	0.43	0.41	-	-	-	-	0.02	0.02	1.20	1.14
160	4.22	3.84	2.00	1.83	-	-	-	-	0.13	0.13	3.53	3.26
150	7.56	6.58	4.74	4.29	0.02	0.02	-	-	0.67	0.64	6.90	6.00
140	11.47	10.18	8.55	7.40	0.13	0.13	0.08	0.08	2.63	2.40	10.90	9.60
130	17.00	14.49	13.13	11.54	1.22	0.84	0.61	0.53	5.94	5.21	16.23	13.92
120	22.10	19.46	19.16	16.61	3.56	2.94	2.51	1.95	10.40	9.04	21.72	19.01

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

Table F-3. Distance (km) to single strike sound exposure level (SEL) for a 12 m pile at location L01 using a Menck MHU4400S hammer operating at 2,000 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	0.10	0.10	-	-	-	-	-	-	-	-	0.05	0.05
180	0.48	0.46	0.10	0.10	-	-	-	-	-	-	0.26	0.25
170	2.00	1.86	0.53	0.51	-	-	-	-	0.02	0.02	1.41	1.32
160	4.55	4.12	2.27	2.04	-	-	-	-	0.16	0.16	3.90	3.54
150	7.94	6.94	5.18	4.63	0.03	0.03	-	-	0.82	0.76	7.35	6.39
140	12.14	10.71	9.17	7.97	0.15	0.14	0.09	0.09	2.90	2.68	11.54	10.23
130	17.90	15.28	14.32	12.26	1.30	1.01	0.63	0.59	6.40	5.61	17.39	14.82
120	23.25	20.39	20.08	17.49	3.78	3.16	2.53	2.05	10.95	9.57	22.78	20.01

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

Table F-4. Distance (km) to single strike sound exposure level (SEL) for a 12 m pile at location L01 using a Menck MHU4400S hammer operating at 3,000 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	0.13	0.13	0.02	0.02	-	-	-	-	-	-	0.06	0.06
180	0.66	0.63	0.15	0.15	-	-	-	-	-	-	0.41	0.39
170	2.39	2.22	0.73	0.69	-	-	-	-	0.03	0.03	1.92	1.69
160	5.22	4.65	2.84	2.55	-	-	-	-	0.22	0.22	4.61	4.12
150	8.93	7.72	6.18	5.38	0.03	0.03	0.02	0.02	1.15	1.10	8.29	7.23
140	13.46	11.77	10.32	9.09	0.26	0.24	0.14	0.13	3.68	3.39	13.05	11.34
130	19.22	16.67	15.94	13.68	1.92	1.54	1.22	0.84	7.50	6.58	18.92	16.28
120	25.63	22.02	21.97	19.13	4.71	3.96	3.34	2.82	12.52	10.88	25.14	21.69

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

Table F-5. Distance (km) to single strike sound exposure level (SEL) for a 12 m pile at location L01 using a Menck MHU4400S hammer operating at 4,400 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	0.03	0.03	-	-	-	-	-	-	-	-	-	-
190	0.19	0.18	0.03	0.03	-	-	-	-	-	-	0.12	0.12
180	0.99	0.95	0.21	0.20	-	-	-	-	-	-	0.58	0.56
170	3.03	2.80	1.07	1.01	-	-	-	-	0.06	0.06	2.34	2.17
160	6.10	5.31	3.43	3.17	-	-	-	-	0.35	0.34	5.35	4.73
150	9.84	8.55	6.98	6.06	0.09	0.09	0.06	0.04	1.78	1.65	9.22	8.01
140	14.78	12.68	11.40	10.04	0.80	0.62	0.43	0.35	4.66	4.21	14.31	12.22
130	20.44	17.75	17.39	14.97	2.91	2.37	1.96	1.61	8.78	7.79	20.06	17.38
120	27.46	23.32	23.66	20.62	6.35	5.27	4.76	4.01	14.62	12.49	26.98	22.94

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

Table F-6. Distance (km) to single strike sound exposure level (SEL) for a 15 m pile at location L01 using a Menck MHU4400S hammer operating at 480 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	0.15	0.14	0.02	0.02	-	-	-	-	-	-	0.07	0.06
170	0.77	0.74	0.15	0.14	-	-	-	-	-	-	0.40	0.38
160	2.54	2.34	0.72	0.68	-	-	-	-	0.03	0.03	1.78	1.65
150	5.16	4.61	2.66	2.44	-	-	-	-	0.21	0.20	4.36	3.95
140	8.59	7.45	5.82	5.07	0.03	0.03	0.02	0.02	1.10	1.05	7.88	6.85
130	12.79	11.24	9.83	8.50	0.25	0.24	0.13	0.13	3.46	3.18	12.15	10.72
120	18.42	15.86	15.04	12.87	1.92	1.51	1.20	0.83	7.31	6.22	17.94	15.40

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

Table F-7. Distance (km) to single strike sound exposure level (SEL) for a 15 m pile at location L01 using a Menck MHU4400S hammer operating at 800 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	0.03	0.03	-	-	-	-	-	-	-	-	-	-
180	0.19	0.18	0.03	0.03	-	-	-	-	-	-	0.13	0.13
170	1.00	0.95	0.19	0.19	-	-	-	-	-	-	0.61	0.58
160	3.07	2.85	1.08	1.00	-	-	-	-	0.05	0.05	2.34	2.17
150	6.12	5.33	3.39	3.09	-	-	-	-	0.32	0.30	5.24	4.67
140	9.62	8.40	6.68	5.82	0.06	0.06	0.03	0.03	1.60	1.46	8.93	7.73
130	14.28	12.25	10.69	9.45	0.53	0.45	0.23	0.22	4.24	3.86	13.34	11.67
120	19.53	16.95	16.18	13.91	2.14	1.86	1.55	1.24	8.21	7.11	18.96	16.41

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

Table F-8. Distance (km) to single strike sound exposure level (SEL) for a 15 m pile at location L01 using a Menck MHU4400S hammer operating at 1,600 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	0.09	0.09	-	-	-	-	-	-	-	-	0.03	0.03
180	0.38	0.36	0.08	0.07	-	-	-	-	-	-	0.19	0.19
170	1.68	1.58	0.38	0.37	-	-	-	-	-	-	1.08	1.01
160	4.04	3.72	1.77	1.64	-	-	-	-	0.12	0.12	3.34	3.06
150	7.25	6.32	4.38	4.00	0.02	0.02	-	-	0.59	0.57	6.50	5.69
140	10.97	9.72	7.92	6.94	0.11	0.10	0.06	0.06	2.34	2.17	10.30	9.06
130	16.03	13.76	12.39	10.88	0.84	0.77	0.48	0.43	5.46	4.82	15.38	13.17
120	21.38	18.58	18.32	15.72	3.30	2.61	1.99	1.68	9.62	8.42	20.88	18.13

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

Table F-9. Distance (km) to single strike sound exposure level (SEL) for a 15 m pile at location L01 using a Menck MHU4400S hammer operating at 2,500 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	0.13	0.13	0.02	0.02	-	-	-	-	-	-	0.08	0.08
180	0.63	0.60	0.14	0.14	-	-	-	-	-	-	0.37	0.36
170	2.37	2.20	0.75	0.71	-	-	-	-	0.03	0.03	1.75	1.61
160	5.06	4.57	2.60	2.37	-	-	-	-	0.19	0.19	4.34	3.93
150	8.51	7.40	5.58	4.96	0.03	0.03	-	-	1.03	0.98	7.75	6.75
140	12.70	11.10	9.51	8.28	0.22	0.20	0.10	0.09	3.26	3.03	12.05	10.53
130	18.14	15.58	14.69	12.47	1.53	1.23	0.81	0.72	6.86	5.92	17.49	15.04
120	23.30	20.55	20.38	17.62	4.05	3.39	2.91	2.37	11.24	9.90	22.81	20.10

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

Table F-10. Distance (km) to single strike sound exposure level (SEL) for a 15 m pile at location L01 using a Menck MHU4400S hammer operating at 3,000 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	0.15	0.14	0.03	0.03	-	-	-	-	-	-	0.07	0.06
180	0.70	0.68	0.16	0.15	-	-	-	-	-	-	0.43	0.42
170	2.50	2.32	0.78	0.69	-	-	-	-	0.03	0.03	1.97	1.76
160	5.28	4.72	2.83	2.55	-	-	-	-	0.21	0.20	4.60	4.13
150	8.91	7.69	6.12	5.30	0.03	0.03	0.02	0.02	1.15	1.07	8.24	7.13
140	13.21	11.58	10.17	8.81	0.23	0.22	0.12	0.10	3.60	3.26	12.71	11.10
130	18.88	16.26	15.37	13.17	1.56	1.24	0.85	0.77	7.30	6.26	18.56	15.82
120	24.65	21.39	21.12	18.38	4.44	3.58	3.29	2.48	11.90	10.36	24.14	21.00

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

Table F-11. Distance (km) to single strike sound exposure level (SEL) for a 15 m pile at location L01 using a Menck MHU4400S hammer operating at 4,000 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	0.03	0.03	-	-	-	-	-	-	-	-	-	-
190	0.17	0.16	0.03	0.03	-	-	-	-	-	-	0.10	0.09
180	0.83	0.78	0.19	0.18	-	-	-	-	-	-	0.49	0.47
170	2.70	2.53	0.92	0.88	-	-	-	-	0.04	0.04	2.10	1.93
160	5.76	5.04	3.17	2.89	-	-	-	-	0.25	0.23	5.04	4.51
150	9.52	8.23	6.66	5.75	0.03	0.03	0.02	0.02	1.37	1.26	8.92	7.70
140	14.33	12.29	10.86	9.52	0.24	0.23	0.13	0.12	3.97	3.60	13.52	11.84
130	19.78	17.21	16.57	14.10	1.73	1.31	0.98	0.80	7.76	6.78	19.30	16.78
120	26.12	22.44	22.09	19.45	4.60	3.74	3.31	2.70	12.56	11.04	25.65	22.08

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

Table F-12. Distance (km) to single strike sound exposure level (SEL) for a 15 m pile at location L01 using a Menck MHU4400S hammer operating at 4,400 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	0.03	0.03	-	-	-	-	-	-	-	-	0.02	0.02
190	0.19	0.19	0.03	0.03	-	-	-	-	-	-	0.13	0.12
180	0.99	0.96	0.22	0.21	-	-	-	-	-	-	0.59	0.57
170	3.08	2.85	1.13	1.07	-	-	-	-	0.06	0.06	2.37	2.22
160	6.18	5.40	3.63	3.27	-	-	-	-	0.33	0.31	5.50	4.87
150	9.94	8.74	7.12	6.21	0.06	0.06	0.03	0.03	1.68	1.59	9.53	8.25
140	15.16	12.91	11.48	10.17	0.47	0.43	0.22	0.20	4.48	4.03	14.71	12.48
130	20.66	17.93	17.46	14.99	2.08	1.73	1.41	1.22	8.45	7.43	20.28	17.59
120	27.47	23.37	23.33	20.45	5.40	4.40	3.90	3.23	13.78	11.88	27.00	23.03

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

Table F-13. Distance (km) to single strike sound exposure level (SEL) for a 5 m pile at location L01 using an IHC S-2,500 hammer operating at 1,200 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	0.03	0.03	-	-	-	-	-	-	-	-	0.03	0.03
180	0.23	0.22	0.10	0.10	-	-	-	-	-	-	0.19	0.18
170	1.17	1.11	0.51	0.49	-	-	-	-	0.07	0.06	0.90	0.84
160	3.70	3.35	2.28	2.11	0.03	0.03	0.02	0.02	0.48	0.45	3.39	3.06
150	7.54	6.59	5.71	5.19	0.23	0.22	0.13	0.12	2.17	1.95	7.12	6.22
140	12.71	11.12	11.07	9.49	1.56	1.25	0.85	0.78	5.70	4.97	12.17	10.67
130	19.48	16.81	17.34	15.10	4.46	3.63	3.30	2.56	10.48	9.14	18.76	16.27
120	27.32	23.17	25.31	21.41	8.14	6.96	6.54	5.36	16.98	14.35	26.51	22.55

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

Table F-14. Distance (km) to single strike sound exposure level (SEL) for a 5 m pile at location L01 using an IHC S-2,500 hammer operating at 1,200 kJ, with 2 dB shift for post-piling installation.

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	-	-	-	-	-	-	0.03	0.03
180	0.30	0.29	0.13	0.13	-	-	-	-	-	-	0.24	0.23
170	1.64	1.48	0.72	0.70	-	-	-	-	0.11	0.10	1.22	1.15
160	4.32	3.94	3.11	2.73	0.04	0.04	0.03	0.03	0.66	0.63	3.88	3.56
150	8.49	7.39	6.86	5.96	0.43	0.34	0.16	0.15	2.86	2.41	8.03	6.97
140	14.31	12.10	12.00	10.56	1.97	1.63	1.30	1.15	6.83	5.72	13.61	11.62
130	20.72	17.95	18.80	16.32	5.08	4.23	3.63	3.12	11.62	10.12	20.28	17.48
120	29.19	24.58	27.02	22.81	9.18	7.71	7.18	6.02	18.52	15.49	28.64	23.90

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

Table F-15. Distance (km) to single strike sound exposure level (SEL) for a 5 m pile at location L01 using an IHC S-2,500 hammer operating at 1,400 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	0.04	0.04	-	-	-	-	-	-	-	-	0.03	0.03
180	0.24	0.23	0.11	0.11	-	-	-	-	-	-	0.20	0.19
170	1.28	1.18	0.63	0.59	-	-	-	-	0.07	0.07	1.03	0.94
160	3.80	3.52	2.42	2.19	0.03	0.03	0.02	0.02	0.49	0.46	3.43	3.17
150	7.67	6.76	5.92	5.30	0.24	0.22	0.13	0.12	2.37	1.99	7.22	6.36
140	13.06	11.26	11.09	9.64	1.69	1.27	0.86	0.79	5.78	5.05	12.35	10.81
130	19.52	16.97	17.38	15.26	4.46	3.67	3.30	2.65	10.53	9.26	19.08	16.45
120	27.58	23.34	25.34	21.59	8.32	7.05	6.54	5.44	17.00	14.47	26.98	22.74

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

Table F-16. Distance (km) to single strike sound exposure level (SEL) for a 5 m pile at location L01 using an IHC S-2,500 hammer operating at 1,400 kJ, with 2 dB shift for post-piling installation.

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	0.33	0.31	0.15	0.14	-	-	-	-	-	-	0.26	0.24
170	1.69	1.58	0.81	0.73	-	-	-	-	0.11	0.10	1.31	1.23
160	4.66	4.08	3.18	2.82	0.06	0.06	0.03	0.03	0.66	0.64	4.15	3.68
150	8.62	7.56	6.90	6.06	0.44	0.37	0.18	0.16	2.87	2.47	8.26	7.13
140	14.33	12.31	12.41	10.69	1.98	1.65	1.31	1.20	6.85	5.81	13.82	11.79
130	20.87	18.12	19.02	16.47	5.36	4.28	3.78	3.17	11.96	10.22	20.44	17.64
120	29.65	24.75	27.28	22.98	9.19	7.82	7.19	6.11	18.52	15.62	28.69	24.11

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

Table F-17. Distance (km) to single strike sound exposure level (SEL) for a 5 m pile at location L01 using an IHC S-2,500 hammer operating at 1,800 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	0.26	0.13	0.13	-	-	-	-	-	-	0.23	0.23
170	1.54	1.40	0.69	0.66	-	-	-	-	0.09	0.08	1.16	1.10
160	4.24	3.81	2.89	2.54	0.03	0.03	0.03	0.03	0.64	0.60	3.80	3.51
150	8.26	7.24	6.46	5.76	0.26	0.24	0.14	0.13	2.55	2.16	7.97	6.88
140	13.83	11.94	11.68	10.26	1.92	1.54	1.22	0.84	6.16	5.42	13.28	11.49
130	20.46	17.74	18.36	15.98	4.76	3.97	3.34	2.83	11.18	9.75	19.98	17.28
120	29.11	24.24	26.48	22.40	8.65	7.40	6.74	5.77	17.52	15.06	28.11	23.66

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

Table F-18. Distance (km) to single strike sound exposure level (SEL) for a 5 m pile at location L01 using an IHC S-2,500 hammer operating at 1,800 kJ, with 2 dB shift for post-piling installation.

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	-	-	-	-	-	-	0.05	0.05
180	0.39	0.37	0.19	0.18	-	-	-	-	-	-	0.30	0.28
170	1.99	1.80	1.08	0.90	-	-	-	-	0.13	0.12	1.64	1.49
160	4.90	4.41	3.42	3.14	0.06	0.06	0.03	0.03	0.86	0.79	4.68	4.09
150	9.41	8.13	7.37	6.54	0.52	0.44	0.23	0.22	3.29	2.79	8.98	7.70
140	15.27	12.99	13.08	11.31	2.14	1.85	1.55	1.24	7.30	6.17	14.79	12.52
130	21.73	18.92	19.88	17.20	5.48	4.58	3.96	3.33	12.50	10.70	21.26	18.43
120	30.73	25.67	28.62	23.81	9.59	8.16	7.57	6.41	18.92	16.22	29.71	25.05

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

Table F-19. Distance (km) to single strike sound exposure level (SEL) for a 5 m pile at location L01 using an IHC S-2,500 hammer operating at 2,500 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	-	-	-	-	-	-	-	-	0.02	0.02
180	0.17	0.16	0.06	0.06	-	-	-	-	-	-	0.12	0.12
170	0.83	0.78	0.39	0.37	-	-	-	-	0.05	0.05	0.66	0.64
160	3.02	2.82	1.79	1.68	0.03	0.03	-	-	0.29	0.28	2.67	2.48
150	6.68	5.84	4.97	4.51	0.15	0.14	0.09	0.08	1.76	1.61	6.26	5.48
140	11.53	10.17	10.01	8.57	1.24	0.89	0.63	0.57	4.82	4.24	11.19	9.76
130	18.14	15.67	15.93	13.95	3.61	3.08	2.52	2.01	9.50	8.18	17.50	15.16
120	25.87	21.93	23.56	20.15	7.44	6.17	5.86	4.75	15.52	13.20	24.82	21.39

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

Table F-20. Distance (km) to single strike sound exposure level (SEL) for a 5 m pile at location L01 using an IHC S-2,500 hammer operating at 2,500 kJ, with 2 dB shift for post-piling installation.

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	-	-	-	-	-	-	-	-	0.03	0.03
180	0.22	0.22	0.10	0.10	-	-	-	-	-	-	0.18	0.18
170	1.14	1.08	0.56	0.49	-	-	-	-	0.07	0.06	0.86	0.83
160	3.59	3.27	2.32	2.11	0.03	0.03	0.02	0.02	0.48	0.45	3.40	3.03
150	7.53	6.57	5.80	5.20	0.23	0.22	0.12	0.11	2.17	1.94	7.12	6.24
140	12.76	11.14	11.06	9.52	1.56	1.25	0.85	0.78	5.69	4.95	12.27	10.73
130	19.50	16.89	17.36	15.16	4.44	3.61	3.29	2.52	10.48	9.12	18.96	16.39
120	27.55	23.28	25.33	21.49	8.14	6.92	6.36	5.33	16.98	14.33	26.96	22.72

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

F.1.2. Location L02

Table F-21. Distance (km) to single strike sound exposure level (SEL) for a 12 m pile at location L02 using a Menck MHU4400S hammer operating at 1,400 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	0.31	0.31	0.07	0.07	-	-	-	-	-	-	0.17	0.17
170	1.33	1.25	0.37	0.36	-	-	-	-	-	-	0.94	0.90
160	3.23	3.02	1.58	1.48	-	-	-	-	0.11	0.11	2.77	2.61
150	6.10	5.56	3.93	3.60	-	-	-	-	0.58	0.56	5.64	5.17
140	9.61	8.59	7.08	6.48	0.10	0.09	0.06	0.06	2.07	1.96	9.26	8.24
130	14.25	12.49	11.36	9.97	0.77	0.72	0.41	0.39	4.92	4.48	13.75	12.12
120	19.57	17.03	16.44	14.47	2.69	2.26	1.92	1.49	8.78	7.82	19.27	16.67

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

Table F-22. Distance (km) to single strike sound exposure level (SEL) for a 12 m pile at location L02 using a Menck MHU4400S hammer operating at 1,800 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	0.09	0.08	-	-	-	-	-	-	-	-	0.04	0.04
180	0.40	0.38	0.10	0.10	-	-	-	-	-	-	0.23	0.23
170	1.54	1.48	0.50	0.47	-	-	-	-	0.03	0.03	1.20	1.12
160	3.66	3.40	1.83	1.74	-	-	-	-	0.15	0.14	3.18	2.94
150	6.56	5.99	4.37	3.99	0.02	0.02	-	-	0.74	0.71	6.14	5.60
140	10.23	9.10	7.64	6.94	0.13	0.12	0.07	0.07	2.49	2.32	9.84	8.73
130	14.91	13.12	11.97	10.51	1.13	0.80	0.58	0.50	5.43	4.97	14.51	12.74
120	20.22	17.82	17.37	15.13	3.11	2.66	2.36	1.88	9.60	8.45	19.92	17.41

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

Table F-23. Distance (km) to single strike sound exposure level (SEL) for a 12 m pile at location L02 using a Menck MHU4400S hammer operating at 2,000 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	0.10	0.10	0.02	0.02	-	-	-	-	-	-	0.06	0.06
180	0.50	0.47	0.12	0.12	-	-	-	-	-	-	0.32	0.32
170	1.76	1.66	0.61	0.59	-	-	-	-	0.03	0.03	1.38	1.31
160	3.97	3.68	2.10	1.99	-	-	-	-	0.17	0.16	3.53	3.26
150	7.02	6.38	4.84	4.41	0.04	0.04	-	-	0.90	0.86	6.59	6.03
140	10.99	9.65	8.24	7.48	0.19	0.17	0.10	0.09	2.78	2.62	10.55	9.34
130	15.82	13.89	12.86	11.27	1.25	1.12	0.77	0.72	5.95	5.44	15.44	13.56
120	21.39	18.95	18.58	16.01	3.72	3.04	2.67	2.22	10.43	9.07	21.01	18.56

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

Table F-24. Distance (km) to single strike sound exposure level (SEL) for a 12 m pile at location L02 using a Menck MHU4400S hammer operating at 3,000 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	-	-	-	-	-	-	0.10	0.09
180	0.71	0.67	0.17	0.16	-	-	-	-	-	-	0.47	0.43
170	2.17	2.06	0.88	0.84	-	-	-	-	0.05	0.05	1.78	1.68
160	4.69	4.32	2.74	2.58	-	-	-	-	0.30	0.29	4.24	3.90
150	7.92	7.18	5.73	5.27	0.10	0.07	0.05	0.05	1.47	1.36	7.53	6.85
140	12.33	10.76	9.78	8.66	0.76	0.58	0.24	0.23	3.85	3.62	11.96	10.46
130	17.77	15.36	14.85	13.04	2.38	2.02	1.57	1.30	7.92	6.92	17.15	15.07
120	23.89	21.27	20.76	18.36	5.47	4.72	4.10	3.46	12.96	11.24	23.46	20.91

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

Table F-25. Distance (km) to single strike sound exposure level (SEL) for a 12 m pile at location L02 using a Menck MHU4400S hammer operating at 4,400 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	0.03	0.03	-	-	-	-	-	-	-	-	0.02	0.02
190	0.19	0.19	0.04	0.04	-	-	-	-	-	-	0.13	0.13
180	0.96	0.92	0.23	0.23	-	-	-	-	-	-	0.66	0.64
170	2.69	2.51	1.21	1.11	-	-	-	-	0.09	0.09	2.22	2.09
160	5.32	4.89	3.29	3.05	0.02	0.02	-	-	0.47	0.45	4.89	4.49
150	8.71	7.82	6.46	5.90	0.13	0.12	0.07	0.07	1.95	1.79	8.27	7.49
140	13.26	11.61	10.61	9.47	1.13	0.80	0.58	0.51	5.03	4.37	12.86	11.25
130	18.90	16.29	15.98	14.06	3.11	2.66	2.36	1.88	9.10	7.99	18.54	15.97
120	25.28	22.50	22.49	19.93	6.67	5.72	5.10	4.32	14.56	12.58	24.78	22.11

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

Table F-26. Distance (km) to single strike sound exposure level (SEL) for a 15 m pile at location L02 using a Menck MHU4400S hammer operating at 480 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	0.03	0.03	-	-	-	-	-	-	-	-	-	-
180	0.15	0.14	0.03	0.03	-	-	-	-	-	-	0.09	0.09
170	0.74	0.70	0.15	0.15	-	-	-	-	-	-	0.45	0.42
160	2.14	2.04	0.80	0.76	-	-	-	-	0.04	0.04	1.70	1.58
150	4.55	4.15	2.48	2.33	-	-	-	-	0.23	0.22	3.96	3.66
140	7.47	6.81	5.24	4.79	0.05	0.05	0.02	0.02	1.19	1.07	7.05	6.41
130	11.52	10.07	8.72	7.84	0.23	0.23	0.13	0.13	3.19	3.00	11.05	9.69
120	16.29	14.30	13.31	11.70	1.57	1.35	1.13	0.80	6.57	5.95	15.84	13.92

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

Table F-27. Distance (km) to single strike sound exposure level (SEL) for a 15 m pile at location L02 using a Menck MHU4400S hammer operating at 800 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	0.03	0.03	-	-	-	-	-	-	-	-	0.02	0.02
180	0.18	0.17	0.03	0.03	-	-	-	-	-	-	0.12	0.12
170	0.94	0.89	0.20	0.20	-	-	-	-	-	-	0.62	0.59
160	2.56	2.42	1.07	1.00	-	-	-	-	0.06	0.06	2.05	1.95
150	5.09	4.67	2.94	2.74	-	-	-	-	0.34	0.33	4.55	4.18
140	8.15	7.39	5.82	5.35	0.06	0.06	0.05	0.05	1.47	1.39	7.68	6.98
130	12.35	10.77	9.57	8.52	0.45	0.42	0.20	0.19	3.84	3.56	11.92	10.37
120	17.35	15.13	14.36	12.66	2.32	1.84	1.30	1.16	7.30	6.66	16.79	14.78

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

Table F-28. Distance (km) to single strike sound exposure level (SEL) for a 15 m pile at location L02 using a Menck MHU4400S hammer operating at 1,600 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	0.07	0.07	-	-	-	-	-	-	-	-	0.03	0.03
180	0.35	0.34	0.09	0.09	-	-	-	-	-	-	0.20	0.20
170	1.44	1.36	0.40	0.38	-	-	-	-	0.02	0.02	1.06	0.98
160	3.39	3.16	1.62	1.54	-	-	-	-	0.12	0.12	2.87	2.67
150	6.17	5.64	3.94	3.62	0.02	0.02	-	-	0.62	0.59	5.65	5.18
140	9.61	8.57	7.06	6.44	0.10	0.10	0.06	0.06	2.20	2.02	9.17	8.15
130	14.04	12.38	11.23	9.88	0.80	0.74	0.44	0.41	5.07	4.55	13.61	11.96
120	19.45	16.85	16.35	14.34	3.06	2.46	1.97	1.64	9.09	7.92	19.07	16.46

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

Table F-29. Distance (km) to single strike sound exposure level (SEL) for a 15 m pile at location L02 using a Menck MHU4400S hammer operating at 2,500 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	0.12	0.12	0.02	0.02	-	-	-	-	-	-	0.09	0.08
180	0.63	0.59	0.14	0.13	-	-	-	-	-	-	0.38	0.37
170	1.99	1.90	0.72	0.68	-	-	-	-	0.03	0.03	1.57	1.49
160	4.36	3.97	2.29	2.17	-	-	-	-	0.19	0.18	3.79	3.49
150	7.27	6.60	4.99	4.58	0.03	0.03	-	-	1.01	0.95	6.80	6.20
140	11.20	9.79	8.34	7.53	0.19	0.17	0.10	0.09	2.93	2.72	10.60	9.41
130	15.82	13.90	12.81	11.20	1.24	1.12	0.77	0.72	6.01	5.49	15.33	13.50
120	21.20	18.75	18.23	15.80	3.72	3.03	2.67	2.21	10.43	9.02	20.77	18.28

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

Table F-30. Distance (km) to single strike sound exposure level (SEL) for a 15 m pile at location L02 using a Menck MHU4400S hammer operating at 3,000 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	0.03	0.03	-	-	-	-	-	-	-	-	-	-
190	0.14	0.13	0.03	0.03	-	-	-	-	-	-	0.10	0.09
180	0.71	0.68	0.16	0.16	-	-	-	-	-	-	0.47	0.44
170	2.18	2.05	0.86	0.81	-	-	-	-	0.04	0.04	1.77	1.67
160	4.66	4.26	2.64	2.44	-	-	-	-	0.24	0.23	4.21	3.84
150	7.72	7.04	5.47	5.02	0.05	0.05	0.02	0.02	1.24	1.16	7.31	6.68
140	11.93	10.41	9.19	8.15	0.23	0.23	0.13	0.12	3.42	3.13	11.54	10.06
130	16.79	14.75	13.76	12.15	1.57	1.32	1.13	0.80	6.67	6.09	16.38	14.41
120	22.69	20.10	19.47	16.93	4.17	3.63	3.08	2.60	11.39	9.92	22.28	19.67

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

Table F-31. Distance (km) to single strike sound exposure level (SEL) for a 15 m pile at location L02 using a Menck MHU4400S hammer operating at 4,000 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	0.03	0.03	-	-	-	-	-	-	-	-	0.02	0.02
190	0.17	0.16	0.03	0.03	-	-	-	-	-	-	0.12	0.12
180	0.87	0.82	0.21	0.21	-	-	-	-	-	-	0.59	0.56
170	2.50	2.35	1.11	1.05	-	-	-	-	0.06	0.06	2.06	1.96
160	5.13	4.71	3.10	2.88	-	-	-	-	0.36	0.34	4.73	4.35
150	8.51	7.66	6.25	5.69	0.07	0.07	0.05	0.05	1.61	1.49	8.08	7.35
140	12.96	11.33	10.20	9.12	0.59	0.54	0.23	0.23	4.16	3.82	12.61	11.01
130	18.40	15.91	15.29	13.50	2.38	1.96	1.56	1.25	8.02	7.12	18.10	15.63
120	24.56	21.84	21.25	18.87	5.47	4.67	3.97	3.40	13.08	11.31	24.23	21.50

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

Table F-32. Distance (km) to single strike sound exposure level (SEL) for a 15 m pile at location L02 using a Menck MHU4400S hammer operating at 4,400 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	0.03	0.03	-	-	-	-	-	-	-	-	0.02	0.02
190	0.19	0.19	0.04	0.04	-	-	-	-	-	-	0.14	0.13
180	0.98	0.94	0.24	0.23	-	-	-	-	-	-	0.69	0.66
170	2.73	2.56	1.28	1.16	-	-	-	-	0.09	0.09	2.28	2.16
160	5.41	4.98	3.35	3.13	-	-	-	-	0.45	0.44	5.02	4.61
150	8.90	7.97	6.56	6.00	0.10	0.10	0.06	0.06	1.86	1.70	8.50	7.66
140	13.42	11.78	10.81	9.54	0.79	0.74	0.43	0.40	4.75	4.21	13.10	11.44
130	19.02	16.43	16.00	14.08	2.77	2.34	1.96	1.56	8.69	7.67	18.67	16.13
120	25.38	22.56	22.38	19.80	6.11	5.23	4.68	3.86	14.06	12.07	25.02	22.22

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

Table F-33. Distance (km) to single strike sound exposure level (SEL) for a 5 m pile at location L02 using an IHC S-2,500 hammer operating at 1,200 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	-	-	-	-	-	-	-	-	0.04	0.04
180	0.25	0.24	0.13	0.13	-	-	-	-	-	-	0.20	0.20
170	1.35	1.26	0.63	0.61	-	-	-	-	0.07	0.07	1.09	1.02
160	3.53	3.27	2.43	2.22	0.05	0.05	0.02	0.02	0.54	0.48	3.35	3.02
150	7.09	6.43	5.68	5.17	0.23	0.23	0.13	0.12	2.38	2.00	6.73	6.12
140	11.94	10.44	10.43	9.16	1.57	1.31	1.13	0.80	5.55	5.03	11.54	10.04
130	18.11	15.59	16.41	14.17	4.17	3.63	3.09	2.60	10.85	9.11	17.35	15.08
120	25.38	22.36	23.30	20.67	8.16	6.93	6.35	5.41	15.91	14.05	24.74	21.68

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

Table F-34. Distance (km) to single strike sound exposure level (SEL) for a 5 m pile at location L02 using an IHC S-2,500 hammer operating at 1,200 kJ, with 2 dB shift for post-piling installation.

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	0.17	-	-	-	-	-	-	0.28	0.27
170	1.64	1.52	0.85	0.82	-	-	-	-	0.12	0.12	1.42	1.32
160	4.22	3.85	3.03	2.73	0.06	0.06	0.04	0.04	0.79	0.75	3.88	3.57
150	8.00	7.15	6.44	5.89	0.44	0.41	0.20	0.18	2.95	2.58	7.64	6.83
140	13.13	11.37	11.54	10.04	2.32	1.79	1.29	1.15	6.45	5.74	12.43	10.93
130	19.32	16.72	17.63	15.27	5.08	4.25	3.73	3.05	11.78	10.06	18.74	16.16
120	27.46	23.66	25.26	22.10	8.83	7.69	7.17	6.07	17.38	15.07	26.40	23.00

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

Table F-35. Distance (km) to single strike sound exposure level (SEL) for a 5 m pile at location L02 using an IHC S-2,500 hammer operating at 1,400 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	0.02	0.02	-	-	-	-	-	-	0.05	0.05
180	0.29	0.28	0.14	0.14	-	-	-	-	-	-	0.22	0.21
170	1.39	1.31	0.71	0.68	-	-	-	-	0.10	0.10	1.21	1.09
160	3.77	3.45	2.63	2.37	0.05	0.05	0.03	0.03	0.57	0.54	3.40	3.18
150	7.32	6.68	5.84	5.40	0.26	0.25	0.17	0.15	2.59	2.24	7.03	6.34
140	12.33	10.69	10.89	9.42	1.90	1.47	1.20	0.93	5.84	5.24	11.92	10.30
130	18.48	15.93	16.85	14.52	4.64	3.76	3.11	2.69	10.92	9.41	17.80	15.44
120	26.07	22.78	23.80	21.14	8.28	7.17	6.60	5.60	16.89	14.35	25.30	22.11

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

Table F-36. Distance (km) to single strike sound exposure level (SEL) for a 5 m pile at location L02 using an IHC S-2,500 hammer operating at 1,400 kJ, with 2 dB shift for post-piling installation.

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	0.43	0.41	0.19	0.19	-	-	-	-	0.02	0.02	0.33	0.32
170	1.77	1.64	0.98	0.93	-	-	-	-	0.13	0.13	1.53	1.43
160	4.47	4.02	3.05	2.87	0.06	0.06	0.05	0.05	0.86	0.79	4.03	3.73
150	8.14	7.42	6.78	6.10	0.45	0.43	0.22	0.19	3.07	2.66	7.73	7.08
140	13.32	11.70	11.92	10.33	2.34	1.86	1.51	1.18	6.61	5.98	12.87	11.22
130	19.63	17.13	18.20	15.61	5.11	4.38	3.84	3.18	11.81	10.37	19.18	16.52
120	28.08	24.08	25.84	22.54	9.61	7.95	7.28	6.26	17.66	15.41	27.11	23.41

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

Table F-37. Distance (km) to single strike sound exposure level (SEL) for a 5 m pile at location L02 using an IHC S-2,500 hammer operating at 1,800 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	0.03	0.03	-	-	-	-	-	-	-	-	0.03	0.03
180	0.20	0.20	0.11	0.11	-	-	-	-	-	-	0.17	0.16
170	1.02	0.98	0.54	0.52	-	-	-	-	0.06	0.06	0.83	0.79
160	3.06	2.88	2.11	1.95	0.05	0.05	0.02	0.02	0.45	0.44	3.00	2.64
150	6.48	5.93	5.30	4.78	0.21	0.19	0.11	0.11	2.20	1.88	6.19	5.61
140	11.35	9.90	9.96	8.68	1.51	1.18	0.81	0.75	5.36	4.73	10.69	9.50
130	17.34	14.99	15.60	13.62	3.96	3.37	2.77	2.40	9.99	8.72	16.56	14.47
120	24.33	21.65	22.53	19.96	7.79	6.63	6.02	5.09	15.46	13.60	23.77	20.95

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

Table F-38. Distance (km) to single strike sound exposure level (SEL) for a 5 m pile at location L02 using an IHC S-2,500 hammer operating at 1,800 kJ, with 2 dB shift for post-piling installation.

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	0.27	0.26	0.15	0.14	-	-	-	-	-	-	0.21	0.21
170	1.38	1.29	0.71	0.68	-	-	-	-	0.11	0.11	1.10	1.05
160	3.65	3.40	2.65	2.42	0.06	0.06	0.03	0.03	0.74	0.66	3.39	3.15
150	7.32	6.66	5.96	5.48	0.41	0.40	0.18	0.17	2.68	2.29	7.03	6.31
140	12.37	10.76	10.91	9.58	1.95	1.52	1.24	1.10	6.06	5.42	11.94	10.34
130	18.70	16.06	17.28	14.71	4.70	3.94	3.41	2.92	11.33	9.65	18.02	15.51
120	26.41	23.00	24.25	21.43	8.59	7.36	6.67	5.76	17.32	14.61	25.35	22.30

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

Table F-39. Distance (km) to single strike sound exposure level (SEL) for a 5 m pile at location L02 using a IHC S-2,500 hammer operating at 2,500 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	0.06	0.06	-	-	-	-	-	-	-	-	-	-
170	0.17	0.17	0.03	0.03	-	-	-	-	-	-	0.09	0.09
160	0.77	0.73	0.18	0.17	-	-	-	-	-	-	0.46	0.43
150	2.26	2.12	0.91	0.87	-	-	-	-	0.10	0.10	1.70	1.60
140	4.65	4.26	2.88	2.61	0.05	0.05	0.02	0.02	0.54	0.50	4.05	3.75
130	7.80	7.12	5.98	5.47	0.22	0.19	0.12	0.11	2.36	1.94	7.41	6.75
120	12.41	10.88	10.47	9.26	1.53	1.19	0.81	0.76	5.41	4.85	11.99	10.52

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

Table F-40. Distance (km) to single strike sound exposure level (SEL) for a 5 m pile at location L02 using a IHC S-2,500 hammer operating at 2,500 kJ, with 2 dB shift for post-piling installation.

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	0.07	0.07	-	-	-	-	-	-	-	-	0.02	0.02
170	0.23	0.23	0.05	0.05	-	-	-	-	-	-	0.12	0.12
160	0.99	0.94	0.24	0.23	-	-	-	-	-	-	0.61	0.58
150	2.66	2.46	1.20	1.11	-	-	-	-	0.13	0.13	2.08	1.96
140	5.21	4.76	3.37	3.12	0.06	0.06	0.04	0.04	0.79	0.74	4.71	4.32
130	8.70	7.79	6.77	6.13	0.41	0.40	0.19	0.17	2.74	2.44	8.15	7.43
120	13.61	11.83	11.74	10.12	1.96	1.53	1.24	1.11	6.16	5.57	13.12	11.40

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% farthest such points were excluded (see Appendix E.6). Ranges are calculated on unweighted and weighted sound fields described in Appendix D. 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% farthest such points were excluded. All calculations use an average summer sound speed profile.

F.2.1. Location L01

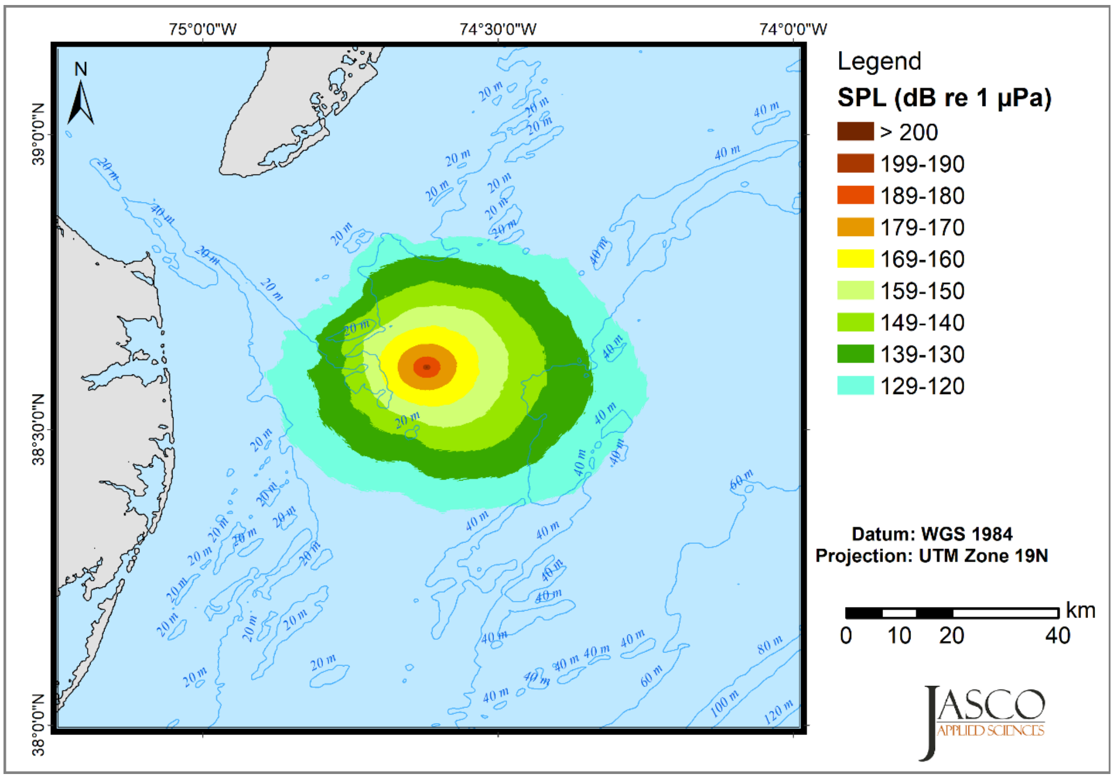

Figure F-2. Unweighted single-strike sound pressure level (SPL) for a 12 m pile at location L01, summer sound speed profile and energy level of 4,400 kJ.

Table F-41. Distance (km) to the single strike sound pressure level (SPL) for a 12 m pile at location L01 using a Menck MHU4400 hammer operating at 1,400 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 $R_{95\%}$
200	0.03	0.03	0.03	0.03	-	-	-	-	-	-
190	0.22	0.21	0.21	0.20	0.02	0.02	-	-	0.06	0.06
180	1.20	1.13	1.18	1.12	0.15	0.14	0.06	0.06	0.43	0.42
170	3.19	2.99	3.17	2.97	0.68	0.65	0.40	0.37	1.99	1.79
160	5.74	5.03	5.70	5.00	2.67	2.50	2.00	1.80	3.98	3.59
150	9.37	8.16	9.36	8.13	5.20	4.62	3.99	3.63	7.58	6.57
140	13.95	12.14	13.94	12.12	9.35	8.15	7.88	6.89	12.03	10.53
130	19.54	16.99	19.54	16.97	14.74	12.62	12.89	11.26	17.92	15.30
120	25.70	22.20	25.69	22.18	20.78	18.03	19.22	16.64	23.63	20.61

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

Table F-42. Distance (km) to the single strike sound pressure level (SPL) for a 12 m pile at location L01 using a Menck MHU4400 hammer operating at 1,800 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 $R_{95\%}$
200	0.06	0.05	0.05	0.05	-	-	-	-	-	-
190	0.34	0.33	0.33	0.32	0.03	0.03	-	-	0.12	0.11
180	1.54	1.42	1.52	1.40	0.19	0.18	0.10	0.10	0.57	0.55
170	3.45	3.23	3.43	3.22	0.92	0.88	0.54	0.52	2.33	2.14
160	6.40	5.54	6.38	5.52	3.04	2.84	2.28	2.08	4.42	4.03
150	9.97	8.78	9.95	8.76	5.82	5.09	4.50	4.07	8.15	7.06
140	14.95	12.78	14.85	12.76	10.14	8.74	8.55	7.45	12.71	11.10
130	20.34	17.65	20.30	17.63	15.55	13.38	13.83	12.00	18.62	15.98
120	26.96	22.95	26.96	22.93	21.63	18.90	20.09	17.55	24.79	21.41

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

Table F-43. Distance (km) to the single strike sound pressure level (SPL) for a 12 m pile at location L01 using a Menck MHU4400 hammer operating at 2,000 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 $R_{95\%}$
200	0.09	0.09	0.08	0.08	-	-	-	-	0.02	0.02
190	0.41	0.39	0.39	0.38	0.03	0.03	0.02	0.02	0.15	0.14
180	1.77	1.64	1.71	1.62	0.22	0.21	0.13	0.13	0.67	0.63
170	3.64	3.37	3.62	3.36	1.13	1.07	0.64	0.61	2.63	2.37
160	6.68	5.83	6.68	5.81	3.30	3.08	2.64	2.39	4.78	4.36
150	10.55	9.25	10.50	9.23	6.40	5.56	5.04	4.48	8.67	7.57
140	15.67	13.43	15.65	13.41	10.69	9.41	9.29	8.09	13.46	11.78
130	21.15	18.40	21.14	18.38	16.59	14.22	14.84	12.72	19.46	16.86
120	28.32	23.92	28.31	23.90	22.66	19.81	21.06	18.29	26.04	22.35

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

Table F-44. Distance (km) to the single strike sound pressure level (SPL) for a 12 m pile at location L01 using a Menck MHU4400 hammer operating at 3,000 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 $R_{95\%}$
200	0.12	0.12	0.11	0.11	-	-	-	-	0.03	0.03
190	0.57	0.55	0.56	0.54	0.06	0.06	0.03	0.03	0.19	0.19
180	2.12	1.98	2.10	1.96	0.33	0.31	0.21	0.20	0.95	0.91
170	4.04	3.70	4.02	3.68	1.72	1.59	0.97	0.93	3.05	2.86
160	7.43	6.44	7.40	6.42	3.70	3.44	3.13	2.93	5.82	5.06
150	11.49	10.20	11.47	10.18	7.46	6.45	6.16	5.36	9.90	8.62
140	17.23	14.75	17.21	14.73	12.12	10.72	10.66	9.36	15.29	13.07
130	22.76	19.93	22.74	19.91	18.62	15.92	16.65	14.40	21.14	18.37
120	30.73	25.75	30.49	25.73	25.16	21.71	23.21	20.21	28.75	24.25

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

Table F-45. Distance (km) to the single strike sound pressure level (SPL) for a 12 m pile at location L01 using a Menck MHU4400 hammer operating at 4,400 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 $R_{95\%}$
200	0.17	0.16	0.16	0.16	-	-	-	-	0.05	0.05
190	0.84	0.80	0.82	0.78	0.09	0.08	0.05	0.05	0.25	0.23
180	2.69	2.50	2.67	2.48	0.52	0.50	0.26	0.25	1.34	1.24
170	4.72	4.26	4.70	4.24	2.12	1.96	1.54	1.35	3.39	3.16
160	8.20	7.12	8.17	7.10	4.34	3.90	3.46	3.26	6.46	5.67
150	12.49	10.99	12.45	10.97	8.28	7.24	7.09	6.18	10.70	9.44
140	18.34	15.74	18.34	15.73	13.50	11.76	11.97	10.56	16.54	14.10
130	24.18	21.06	24.17	21.04	19.98	17.31	18.60	15.96	22.37	19.60
120	32.46	27.11	32.45	27.09	27.84	23.43	25.92	22.06	30.75	25.77

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

Table F-46. Distance (km) to the single strike sound pressure level (SPL) for a 15 m pile at location L01 using a Menck MHU4400 hammer operating at 480 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 $R_{95\%}$
200	0.02	0.02	-	-	-	-	-	-	-	-
190	0.13	0.13	0.13	0.13	-	-	-	-	0.03	0.03
180	0.65	0.62	0.62	0.60	0.05	0.05	0.03	0.03	0.17	0.17
170	2.29	2.12	2.24	2.07	0.27	0.24	0.17	0.17	0.87	0.84
160	4.04	3.69	4.01	3.66	1.48	1.34	0.82	0.78	2.88	2.68
150	7.16	6.25	7.13	6.23	3.43	3.21	2.90	2.68	5.24	4.69
140	10.99	9.71	10.95	9.69	6.78	5.90	5.50	4.85	9.19	7.99
130	16.21	13.90	16.19	13.88	11.25	9.90	10.01	8.62	14.30	12.21
120	21.69	18.89	21.68	18.87	17.18	14.89	15.69	13.48	20.04	17.37

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

Table F-47. Distance (km) to the single strike sound pressure level (SPL) for a 15 m pile at location L01 using a Menck MHU4400 hammer operating at 800 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 $R_{95\%}$
200	0.03	0.03	0.03	0.03	-	-	-	-	-	-
190	0.17	0.16	0.17	0.16	-	-	-	-	0.05	0.05
180	0.86	0.81	0.84	0.79	0.08	0.07	0.03	0.03	0.26	0.26
170	2.71	2.54	2.70	2.52	0.43	0.41	0.22	0.22	1.34	1.24
160	4.72	4.28	4.70	4.26	2.01	1.84	1.20	1.14	3.33	3.11
150	8.14	7.03	8.12	7.01	3.90	3.58	3.30	3.08	6.20	5.43
140	12.09	10.66	12.08	10.63	7.62	6.62	6.38	5.57	10.20	8.88
130	17.43	15.00	17.41	14.98	12.32	10.79	10.86	9.52	15.34	13.15
120	22.76	19.95	22.74	19.93	18.60	15.95	16.76	14.60	21.10	18.31

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

Table F-48. Distance (km) to the single strike sound pressure level (SPL) for a 15 m pile at location L01 using a Menck MHU4400 hammer operating at 1,600 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 $R_{95\%}$
200	0.06	0.06	0.05	0.05	-	-	-	-	-	-
190	0.33	0.32	0.32	0.30	0.02	0.02	-	-	0.10	0.10
180	1.44	1.36	1.44	1.35	0.16	0.15	0.07	0.07	0.52	0.49
170	3.27	3.08	3.24	3.06	0.77	0.73	0.43	0.40	2.04	1.90
160	5.88	5.15	5.86	5.13	2.71	2.53	2.01	1.83	3.96	3.59
150	9.35	8.15	9.32	8.13	5.00	4.45	3.77	3.55	7.33	6.39
140	13.65	11.93	13.57	11.90	8.96	7.80	7.58	6.63	11.49	10.18
130	19.06	16.51	19.04	16.49	14.30	12.21	12.49	10.95	17.17	14.77
120	24.85	21.62	24.84	21.61	20.38	17.64	18.68	16.29	22.82	20.07

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

Table F-49. Distance (km) to the single strike sound pressure level (SPL) for a 15 m pile at location L01 using a Menck MHU4400 hammer operating at 2,500 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 $R_{95\%}$
200	0.12	0.12	0.11	0.11	-	-	-	-	0.03	0.03
190	0.56	0.54	0.56	0.53	0.05	0.05	0.03	0.03	0.17	0.17
180	2.07	1.94	2.05	1.92	0.25	0.23	0.15	0.15	0.84	0.80
170	3.97	3.62	3.92	3.60	1.36	1.23	0.79	0.75	2.86	2.65
160	7.11	6.20	7.05	6.18	3.40	3.16	2.76	2.52	5.14	4.62
150	10.89	9.61	10.87	9.58	6.48	5.68	5.21	4.63	8.98	7.80
140	15.95	13.66	15.92	13.64	10.82	9.50	9.39	8.19	13.62	11.89
130	21.36	18.49	21.34	18.47	16.59	14.25	14.85	12.81	19.50	16.88
120	28.09	23.90	28.07	23.88	22.65	19.79	21.10	18.35	25.91	22.28

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

Table F-50. Distance (km) to the single strike sound pressure level (SPL) for a 15 m pile at location L01 using a Menck MHU4400 hammer operating at 3,000 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 $R_{95\%}$
200	0.13	0.13	0.12	0.12	-	-	-	-	0.03	0.03
190	0.62	0.59	0.60	0.58	0.06	0.06	0.03	0.03	0.19	0.19
180	2.27	2.10	2.23	2.04	0.31	0.30	0.19	0.18	0.95	0.91
170	4.06	3.73	4.04	3.71	1.67	1.49	0.92	0.87	3.01	2.83
160	7.35	6.40	7.33	6.38	3.60	3.32	3.01	2.82	5.54	4.91
150	11.28	10.02	11.26	9.99	7.02	6.11	5.80	5.04	9.58	8.31
140	16.81	14.33	16.79	14.30	11.50	10.15	10.18	8.79	14.72	12.57
130	22.01	19.28	22.01	19.26	17.52	15.07	15.70	13.50	20.38	17.68
120	29.50	24.85	29.48	24.83	23.67	20.64	21.82	19.10	27.39	23.22

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

Table F-51. Distance (km) to the single strike sound pressure level (SPL) for a 15 m pile at location L01 using a Menck MHU4400 hammer operating at 4,000 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 $R_{95\%}$
200	0.15	0.14	0.14	0.13	-	-	-	-	0.03	0.03
190	0.70	0.67	0.68	0.65	0.06	0.06	0.03	0.03	0.22	0.21
180	2.46	2.25	2.39	2.23	0.43	0.41	0.22	0.22	1.18	1.12
170	4.38	3.97	4.36	3.95	2.01	1.83	1.15	1.09	3.20	3.02
160	7.85	6.80	7.83	6.77	3.90	3.57	3.28	3.04	6.16	5.37
150	12.08	10.60	12.07	10.59	7.70	6.68	6.40	5.58	10.26	8.97
140	17.73	15.18	17.71	15.16	12.43	10.92	10.83	9.52	15.65	13.40
130	22.97	20.26	22.97	20.25	18.64	16.04	16.77	14.44	21.38	18.59
120	30.84	25.96	30.84	25.94	25.14	21.70	22.91	20.13	28.80	24.37

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

Table F-52. Distance (km) to the single strike sound pressure level (SPL) for a 15 m pile at location L01 using a Menck MHU4400 hammer operating at 4,400 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 $R_{95\%}$
200	0.17	0.16	0.17	0.16	-	-	-	-	0.05	0.05
190	0.85	0.81	0.83	0.80	0.09	0.09	0.05	0.05	0.28	0.27
180	2.71	2.53	2.69	2.51	0.54	0.51	0.28	0.25	1.52	1.38
170	4.74	4.31	4.72	4.29	2.30	2.09	1.55	1.38	3.42	3.19
160	8.30	7.23	8.29	7.21	4.36	3.94	3.45	3.24	6.68	5.78
150	12.75	11.16	12.74	11.14	8.29	7.24	6.98	6.08	10.90	9.57
140	18.58	15.88	18.58	15.87	13.36	11.66	11.57	10.29	16.63	14.18
130	24.18	21.10	24.16	21.08	19.55	17.01	17.98	15.48	22.31	19.53
120	32.14	26.97	32.13	26.96	26.98	22.84	24.82	21.28	30.14	25.47

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

Table F-53. Distance (km) to the single strike sound pressure level (SPL) for a 5 m pile at location L01 using an IHC S-2,500 hammer operating at 1,200 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 $R_{95\%}$
200	0.03	0.03	0.03	0.03	-	-	-	-	-	-
190	0.20	0.19	0.20	0.19	0.06	0.06	0.05	0.05	0.12	0.11
180	1.05	0.98	1.03	0.96	0.37	0.34	0.29	0.27	0.65	0.63
170	3.33	3.03	3.32	3.02	1.78	1.67	1.56	1.35	2.54	2.28
160	6.38	5.63	6.38	5.62	4.34	3.92	3.75	3.55	5.37	4.83
150	11.20	9.82	11.19	9.81	9.16	7.81	8.28	7.19	10.27	8.98
140	17.50	15.19	17.48	15.18	15.25	13.02	14.44	12.25	16.52	14.37
130	24.84	21.39	24.84	21.38	22.18	19.12	21.20	18.19	23.77	20.58
120	34.23	28.49	34.23	28.48	31.74	26.22	30.20	25.21	33.25	27.72

Note: 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 5 m pile at location L01 using an IHC S-2,500 hammer operating at 1,200 kJ, with 2 dB shift for post-piling installation.

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 $R_{95\%}$
200	0.05	0.05	0.05	0.05	-	-	-	-	0.02	0.02
190	0.26	0.25	0.26	0.25	0.09	0.09	0.06	0.06	0.16	0.16
180	1.33	1.26	1.32	1.25	0.51	0.48	0.44	0.41	0.85	0.82
170	3.62	3.40	3.61	3.39	2.22	2.08	1.99	1.73	3.18	2.86
160	7.17	6.36	7.16	6.35	5.01	4.57	4.58	4.08	6.26	5.56
150	12.28	10.79	12.27	10.78	10.23	8.73	9.53	8.08	11.26	9.94
140	18.80	16.41	18.80	16.40	16.35	14.22	15.51	13.41	17.94	15.57
130	26.96	22.73	26.96	22.72	23.77	20.46	22.73	19.53	25.88	21.92
120	36.06	30.08	36.05	30.07	33.25	27.75	32.24	26.73	35.24	29.27

Note: 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 5 m pile at location L01 using an IHC S-2,500 hammer operating at 1,400 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 $R_{95\%}$
200	0.03	0.03	0.03	0.03	-	-	-	-	-	-
190	0.22	0.21	0.21	0.21	0.06	0.06	0.05	0.05	0.12	0.12
180	1.14	1.08	1.13	1.07	0.42	0.38	0.29	0.28	0.67	0.65
170	3.31	3.09	3.30	3.08	1.81	1.70	1.59	1.46	2.61	2.40
160	6.28	5.54	6.28	5.52	4.11	3.73	3.66	3.46	5.23	4.70
150	11.07	9.63	11.05	9.61	8.74	7.59	8.20	6.97	10.24	8.77
140	17.16	14.94	17.16	14.93	15.01	12.72	13.92	11.95	16.20	14.06
130	24.32	21.05	24.32	21.04	21.94	18.76	20.72	17.87	23.57	20.24
120	33.74	28.11	33.74	28.10	31.24	25.83	29.69	24.82	32.76	27.33

Note: 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 5 m pile at location L01 using an IHC S-2,500 hammer operating at 1,400 kJ, with 2 dB shift for post-piling installation.

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 $R_{95\%}$
200	0.05	0.05	0.05	0.05	-	-	-	-	0.03	0.03
190	0.27	0.27	0.27	0.26	0.10	0.09	0.07	0.07	0.18	0.17
180	1.57	1.42	1.56	1.41	0.51	0.50	0.45	0.43	0.92	0.85
170	3.53	3.32	3.53	3.32	2.26	2.11	2.03	1.77	3.18	2.91
160	7.12	6.23	7.12	6.22	4.93	4.42	4.40	3.91	6.02	5.39
150	12.07	10.62	12.05	10.61	10.01	8.49	9.17	7.85	11.17	9.74
140	18.66	16.13	18.66	16.12	15.93	13.91	15.25	13.10	17.48	15.27
130	26.47	22.39	26.47	22.38	23.56	20.10	22.22	19.17	25.33	21.58
120	35.53	29.65	35.53	29.64	32.77	27.35	31.76	26.32	34.72	28.87

Note: 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 5 m pile at location L01 using an IHC S-2,500 hammer operating at 1,800 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 $R_{95\%}$
200	0.04	0.04	0.03	0.03	-	-	-	-	0.02	0.02
190	0.24	0.23	0.23	0.23	0.08	0.08	0.06	0.06	0.15	0.14
180	1.20	1.15	1.20	1.14	0.48	0.46	0.32	0.31	0.81	0.73
170	3.40	3.16	3.39	3.16	2.15	1.93	1.77	1.66	2.99	2.75
160	6.71	5.88	6.69	5.86	4.56	4.07	4.00	3.59	5.67	5.05
150	11.52	10.16	11.52	10.15	9.24	8.01	8.41	7.34	10.67	9.28
140	17.98	15.59	17.98	15.58	15.44	13.26	14.57	12.44	16.78	14.71
130	25.36	21.80	25.36	21.79	22.67	19.40	21.36	18.42	24.31	20.94
120	34.70	28.90	34.70	28.89	31.78	26.51	30.72	25.46	33.75	28.08

Note: 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 5 m pile at location L01 using an IHC S-2,500 hammer operating at 1,800 kJ, with 2 dB shift for post-piling installation.

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 $R_{95\%}$
200	0.06	0.06	0.06	0.06	-	-	-	-	0.03	0.03
190	0.32	0.31	0.31	0.31	0.12	0.12	0.09	0.09	0.22	0.21
180	1.68	1.57	1.67	1.57	0.68	0.65	0.50	0.48	1.11	1.06
170	3.72	3.46	3.70	3.45	2.70	2.41	2.21	2.04	3.31	3.09
160	7.54	6.60	7.54	6.59	5.19	4.73	4.62	4.23	6.64	5.79
150	12.75	11.13	12.74	11.12	10.26	8.94	9.60	8.24	11.70	10.27
140	19.48	16.80	19.46	16.79	16.65	14.48	15.70	13.62	18.34	15.93
130	27.31	23.13	27.31	23.12	24.29	20.73	23.19	19.76	26.45	22.30
120	36.61	30.53	36.61	30.52	33.75	28.05	32.72	26.99	35.53	29.65

Note: 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 5 m pile at location L01 using an IHC S-2,500 hammer operating at 2,500 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 $R_{95\%}$
200	0.02	0.02	0.02	0.02	-	-	-	-	-	-
190	0.14	0.13	0.13	0.13	0.05	0.05	0.03	0.03	0.07	0.07
180	0.70	0.67	0.69	0.67	0.27	0.26	0.20	0.19	0.45	0.43
170	2.66	2.47	2.65	2.45	1.38	1.29	1.12	1.06	2.03	1.89
160	4.76	4.31	4.75	4.30	3.37	3.10	3.18	2.93	3.83	3.60
150	9.24	7.98	9.16	7.96	6.91	6.08	6.36	5.52	8.24	7.19
140	15.25	12.89	15.25	12.88	12.49	10.81	11.52	10.01	14.31	12.08
130	21.73	18.86	21.73	18.85	19.18	16.67	18.06	15.79	20.82	18.05
120	30.73	25.64	30.73	25.63	27.58	23.26	26.50	22.25	29.68	24.83

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

Table F-60. Distance (km) to the single strike sound pressure level (SPL) for a 5 m pile at location L01 using an IHC S-2,500 hammer operating at 2,500 kJ, with 2 dB shift for post-piling installation.

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 $R_{95\%}$
200	0.03	0.03	0.03	0.03	-	-	-	-	-	-
190	0.19	0.19	0.19	0.19	0.06	0.06	0.05	0.05	0.11	0.11
180	1.02	0.91	1.00	0.88	0.38	0.34	0.29	0.28	0.65	0.63
170	2.99	2.81	2.98	2.81	1.78	1.66	1.53	1.33	2.48	2.26
160	5.50	4.89	5.50	4.88	3.70	3.49	3.57	3.21	4.70	4.22
150	10.24	8.90	10.24	8.89	7.82	6.93	7.35	6.31	9.41	8.09
140	16.20	14.05	16.20	14.04	13.80	11.91	12.98	11.11	15.66	13.21
130	23.22	20.16	23.21	20.15	20.72	17.86	19.50	17.00	22.64	19.33
120	32.70	27.10	32.70	27.09	29.68	24.75	28.26	23.70	31.72	26.29

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

F.2.2. Location L02

Table F-61. Distance (km) to the single strike sound pressure level (SPL) for a 12 m pile at location L02 using a Menck MHU4400 hammer operating at 1,400 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 $R_{95\%}$
200	0.05	0.05	0.05	0.05	-	-	-	-	-	-
190	0.26	0.25	0.24	0.23	0.03	0.03	-	-	0.10	0.10
180	1.15	1.10	1.15	1.09	0.16	0.16	0.10	0.10	0.50	0.47
170	2.81	2.67	2.81	2.66	0.86	0.81	0.48	0.46	1.85	1.75
160	5.04	4.62	5.01	4.60	2.66	2.46	1.89	1.78	3.67	3.44
150	8.24	7.45	8.22	7.43	4.95	4.53	3.91	3.58	6.83	6.24
140	12.58	10.93	12.57	10.92	8.53	7.72	7.29	6.67	10.96	9.65
130	17.77	15.38	17.76	15.36	13.29	11.70	11.91	10.44	15.96	14.01
120	23.64	20.99	23.62	20.98	19.16	16.58	17.59	15.28	21.75	19.29

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

Table F-62. Distance (km) to the single strike sound pressure level (SPL) for a 12 m pile at location L02 using a Menck MHU4400 hammer operating at 1,800 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 $R_{95\%}$
200	0.07	0.07	0.07	0.07	-	-	-	-	0.02	0.02
190	0.34	0.33	0.33	0.32	0.03	0.03	0.02	0.02	0.13	0.13
180	1.38	1.32	1.38	1.31	0.21	0.20	0.13	0.13	0.65	0.61
170	3.01	2.86	3.00	2.85	1.06	0.98	0.63	0.60	2.14	2.03
160	5.48	5.02	5.45	5.00	2.83	2.67	2.24	2.08	4.11	3.77
150	8.80	7.89	8.76	7.87	5.36	4.93	4.31	3.95	7.30	6.66
140	13.13	11.50	13.10	11.48	9.23	8.18	7.85	7.12	11.58	10.14
130	18.48	15.96	18.46	15.94	14.06	12.38	12.68	11.05	16.56	14.60
120	24.53	21.75	24.51	21.73	19.94	17.43	18.72	16.05	22.78	20.19

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

Table F-63. Distance (km) to the single strike sound pressure level (SPL) for a 12 m pile at location L02 using a Menck MHU4400 hammer operating at 2,000 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 $R_{95\%}$
200	0.09	0.08	0.09	0.08	-	-	-	-	0.03	0.03
190	0.42	0.40	0.41	0.39	0.05	0.05	0.03	0.03	0.15	0.15
180	1.58	1.51	1.56	1.49	0.25	0.24	0.16	0.15	0.79	0.74
170	3.20	3.01	3.19	3.00	1.36	1.27	0.80	0.75	2.49	2.35
160	5.87	5.38	5.85	5.36	3.04	2.89	2.59	2.42	4.55	4.17
150	9.36	8.39	9.34	8.37	5.96	5.44	4.89	4.48	7.93	7.18
140	13.98	12.30	13.97	12.28	9.99	8.87	8.58	7.79	12.41	10.84
130	19.45	16.84	19.44	16.82	15.06	13.29	13.61	11.96	17.82	15.48
120	25.71	22.84	25.70	22.83	21.03	18.64	19.54	17.08	24.17	21.39

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

Table F-64. Distance (km) to the single strike sound pressure level (SPL) for a 12 m pile at location L02 using a Menck MHU4400 hammer operating at 3,000 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 $R_{95\%}$
200	0.12	0.12	0.12	0.12	-	-	-	-	0.03	0.03
190	0.61	0.58	0.60	0.57	0.10	0.10	0.05	0.05	0.21	0.21
180	1.97	1.87	1.95	1.85	0.42	0.41	0.25	0.24	1.12	1.06
170	3.68	3.44	3.67	3.43	1.80	1.69	1.35	1.26	2.86	2.70
160	6.68	6.10	6.62	6.08	3.70	3.46	3.04	2.88	5.41	4.98
150	10.60	9.41	10.59	9.40	7.20	6.54	6.11	5.61	9.26	8.25
140	15.57	13.71	15.56	13.69	11.92	10.41	10.87	9.38	14.09	12.42
130	21.35	18.96	21.35	18.94	17.78	15.33	16.21	14.21	19.93	17.46
120	28.97	24.99	28.79	24.97	24.38	21.73	23.21	20.38	27.48	23.85

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

Table F-65. Distance (km) to the single strike sound pressure level (SPL) for a 12 m pile at location L02 using a Menck MHU4400 hammer operating at 4,400 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 $R_{95\%}$
200	0.16	0.16	0.16	0.15	0.02	0.02	-	-	0.06	0.06
190	0.86	0.81	0.84	0.80	0.13	0.13	0.06	0.06	0.34	0.33
180	2.39	2.26	2.37	2.24	0.62	0.60	0.36	0.35	1.42	1.34
170	4.24	3.91	4.22	3.89	2.24	2.09	1.64	1.52	3.13	2.94
160	7.31	6.68	7.30	6.66	4.31	3.96	3.47	3.25	6.05	5.54
150	11.54	10.08	11.53	10.07	8.00	7.23	6.88	6.33	10.09	8.93
140	16.51	14.54	16.50	14.53	12.90	11.32	11.86	10.33	15.11	13.34
130	22.81	20.21	22.81	20.19	19.15	16.48	17.80	15.40	21.22	18.73
120	30.70	26.20	30.59	26.19	26.59	23.21	24.87	22.03	29.10	25.08

Note: 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 15 m pile at location L02 using a Menck MHU4400 hammer operating at 480 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 $R_{95\%}$
200	0.02	0.02	0.02	0.02	-	-	-	-	-	-
190	0.13	0.13	0.12	0.12	-	-	-	-	0.03	0.03
180	0.63	0.60	0.62	0.59	0.06	0.06	0.03	0.03	0.19	0.18
170	1.94	1.84	1.92	1.82	0.35	0.34	0.17	0.17	0.99	0.92
160	3.58	3.34	3.56	3.32	1.51	1.39	0.94	0.90	2.70	2.55
150	6.35	5.79	6.34	5.77	3.23	3.04	2.73	2.59	4.95	4.55
140	9.92	8.81	9.89	8.79	6.28	5.73	5.23	4.76	8.29	7.50
130	14.38	12.70	14.37	12.69	10.42	9.21	9.08	8.15	12.80	11.18
120	19.75	17.24	19.72	17.22	15.51	13.69	14.14	12.48	18.24	15.81

Note: 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 15 m pile at location L02 using a Menck MHU4400 hammer operating at 800 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 $R_{95\%}$
200	0.03	0.03	0.03	0.03	-	-	-	-	-	-
190	0.15	0.15	0.15	0.15	-	-	-	-	0.05	0.05
180	0.81	0.78	0.80	0.77	0.10	0.10	0.05	0.05	0.29	0.28
170	2.29	2.18	2.27	2.16	0.48	0.46	0.25	0.24	1.30	1.20
160	4.01	3.72	3.99	3.70	1.81	1.72	1.31	1.18	2.91	2.76
150	6.88	6.30	6.87	6.28	3.65	3.42	2.99	2.82	5.47	5.02
140	10.60	9.41	10.59	9.39	6.88	6.31	5.81	5.35	8.97	8.08
130	15.27	13.46	15.25	13.44	11.36	9.94	10.01	8.89	13.64	12.01
120	20.76	18.30	20.74	18.28	16.86	14.65	15.28	13.46	19.30	16.72

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

Table F-68. Distance (km) to the single strike sound pressure level (SPL) for a 15 m pile at location L02 using a Menck MHU4400 hammer operating at 1,600 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 $R_{95\%}$
200	0.06	0.06	0.06	0.06	-	-	-	-	-	-
190	0.30	0.30	0.30	0.29	0.03	0.03	-	-	0.11	0.11
180	1.29	1.20	1.27	1.18	0.16	0.16	0.10	0.10	0.54	0.51
170	2.79	2.66	2.79	2.65	0.86	0.81	0.50	0.47	1.87	1.78
160	5.02	4.62	5.00	4.60	2.53	2.41	1.85	1.76	3.63	3.39
150	8.07	7.33	8.05	7.31	4.71	4.33	3.70	3.48	6.61	6.06
140	12.27	10.68	12.25	10.66	8.20	7.47	7.06	6.44	10.57	9.37
130	17.11	15.02	17.09	15.00	12.97	11.36	11.78	10.23	15.50	13.63
120	23.08	20.50	23.07	20.48	18.79	16.27	17.38	15.09	21.23	18.80

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

Table F-69. Distance (km) to the single strike sound pressure level (SPL) for a 15 m pile at location L02 using a Menck MHU4400 hammer operating at 2,500 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 $R_{95\%}$
200	0.11	0.11	0.11	0.11	-	-	-	-	0.03	0.03
190	0.53	0.51	0.53	0.50	0.05	0.05	0.03	0.03	0.16	0.16
180	1.78	1.70	1.77	1.68	0.32	0.31	0.16	0.16	0.90	0.86
170	3.43	3.21	3.42	3.20	1.38	1.30	0.85	0.79	2.58	2.44
160	6.17	5.63	6.15	5.61	3.10	2.91	2.56	2.43	4.75	4.35
150	9.62	8.56	9.61	8.55	5.96	5.45	4.90	4.48	8.01	7.25
140	14.01	12.35	14.00	12.33	9.95	8.78	8.50	7.68	12.37	10.78
130	19.28	16.71	19.27	16.70	14.86	13.04	13.29	11.71	17.53	15.29
120	25.36	22.54	25.26	22.53	20.67	18.20	19.24	16.71	23.62	20.99

Note: 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 15 m pile at location L02 using a Menck MHU4400 hammer operating at 3,000 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 $R_{95\%}$
200	0.12	0.12	0.12	0.12	-	-	-	-	0.03	0.03
190	0.62	0.59	0.61	0.58	0.07	0.07	0.04	0.04	0.21	0.21
180	1.96	1.87	1.95	1.85	0.39	0.37	0.21	0.21	1.11	1.02
170	3.63	3.39	3.61	3.37	1.64	1.54	1.11	1.03	2.74	2.62
160	6.53	5.93	6.51	5.92	3.41	3.20	2.79	2.66	5.15	4.73
150	10.18	9.06	10.16	9.04	6.55	5.99	5.40	4.99	8.60	7.78
140	14.88	13.08	14.85	13.06	10.64	9.51	9.32	8.38	13.20	11.56
130	20.20	17.74	20.20	17.72	15.96	14.00	14.53	12.73	18.72	16.21
120	26.83	23.66	26.81	23.65	22.30	19.64	20.56	18.04	25.06	22.24

Note: 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 15 m pile at location L02 using a Menck MHU4400 hammer operating at 4,000 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 $R_{95\%}$
200	0.15	0.15	0.15	0.14	-	-	-	-	0.05	0.05
190	0.75	0.72	0.74	0.70	0.11	0.11	0.05	0.05	0.31	0.30
180	2.27	2.14	2.25	2.12	0.56	0.54	0.33	0.33	1.38	1.30
170	4.07	3.75	4.05	3.73	2.05	1.94	1.43	1.37	3.01	2.85
160	7.13	6.52	7.12	6.51	4.09	3.75	3.27	3.04	5.89	5.40
150	11.29	9.90	11.27	9.89	7.60	6.90	6.47	5.91	9.82	8.71
140	16.26	14.27	16.22	14.25	12.31	10.74	10.99	9.64	14.69	12.95
130	22.05	19.60	22.04	19.58	18.13	15.65	16.42	14.42	20.40	17.98
120	29.47	25.43	29.47	25.41	24.79	22.00	23.27	20.57	27.86	24.20

Note: 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 15 m pile at location L02 using a Menck MHU4400 hammer operating at 4,400 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 $R_{95\%}$
200	0.17	0.16	0.16	0.16	0.02	0.02	-	-	0.06	0.06
190	0.87	0.82	0.86	0.81	0.13	0.13	0.06	0.06	0.35	0.34
180	2.46	2.31	2.44	2.29	0.65	0.61	0.37	0.36	1.52	1.41
170	4.38	4.00	4.36	3.98	2.27	2.14	1.65	1.54	3.21	3.01
160	7.44	6.80	7.43	6.79	4.45	4.05	3.53	3.26	6.25	5.68
150	11.66	10.24	11.66	10.23	8.04	7.30	6.88	6.31	10.18	9.09
140	16.76	14.72	16.75	14.71	12.87	11.30	11.77	10.20	15.25	13.46
130	22.85	20.35	22.85	20.33	18.95	16.33	17.39	15.17	21.23	18.77
120	30.57	26.21	30.56	26.20	26.13	22.93	24.29	21.60	29.03	24.99

Note: 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 5 m pile at location L02 using an IHC S-2,500 hammer operating at 1,200 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 $R_{95\%}$
200	0.03	0.03	0.03	0.03	-	-	-	-	0.02	0.02
190	0.21	0.21	0.21	0.21	0.07	0.07	0.06	0.06	0.15	0.15
180	1.10	1.05	1.09	1.05	0.43	0.42	0.34	0.33	0.71	0.68
170	3.07	2.91	3.06	2.91	1.94	1.71	1.58	1.47	2.62	2.40
160	5.80	5.34	5.80	5.33	4.16	3.78	3.63	3.39	5.08	4.66
150	10.16	9.07	10.16	9.07	8.14	7.37	7.61	6.83	9.51	8.40
140	15.97	13.89	15.97	13.88	14.06	12.01	12.97	11.36	15.09	13.18
130	22.79	20.11	22.79	20.10	20.28	17.74	19.47	16.87	21.75	19.26
120	31.88	26.91	31.88	26.90	29.13	24.88	28.03	24.02	31.26	26.20

Note: 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 5 m pile at location L02 using an IHC S-2,500 hammer operating at 1,200 kJ, with 2 dB shift for post-piling installation.

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 $R_{95\%}$
200	0.06	0.06	0.06	0.06	-	-	-	-	0.03	0.03
190	0.31	0.31	0.31	0.30	0.12	0.12	0.07	0.07	0.19	0.19
180	1.43	1.34	1.42	1.33	0.61	0.59	0.50	0.44	1.00	0.95
170	3.39	3.22	3.39	3.21	2.32	2.19	1.99	1.88	3.05	2.86
160	6.67	6.01	6.66	6.00	4.88	4.43	4.44	3.91	5.78	5.35
150	11.35	9.92	11.35	9.91	9.50	8.24	8.62	7.66	10.48	9.28
140	17.33	14.96	17.32	14.95	15.09	13.10	14.52	12.42	16.44	14.27
130	24.29	21.54	24.28	21.53	21.83	19.21	20.89	18.26	23.32	20.76
120	34.29	28.40	34.28	28.40	31.36	26.33	29.77	25.41	32.97	27.69

Note: 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 5 m pile at location L02 using an IHC S-2,500 hammer operating at 1,400 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 $R_{95\%}$
200	0.05	0.05	0.05	0.05	-	-	-	-	0.03	0.03
190	0.24	0.23	0.24	0.23	0.07	0.07	0.06	0.06	0.16	0.16
180	1.31	1.18	1.30	1.16	0.52	0.50	0.40	0.38	0.79	0.77
170	3.05	2.90	3.05	2.90	2.00	1.88	1.63	1.54	2.70	2.54
160	6.06	5.50	6.05	5.49	4.42	3.91	3.78	3.45	5.34	4.81
150	10.51	9.28	10.50	9.27	8.43	7.58	7.92	7.03	9.66	8.59
140	16.13	14.15	16.12	14.14	14.12	12.27	13.17	11.61	15.26	13.45
130	23.20	20.47	23.19	20.47	20.66	18.07	19.93	17.18	22.17	19.60
120	32.41	27.25	32.41	27.24	29.60	25.20	28.51	24.34	31.39	26.55

Note: 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 5 m pile at location L02 using an IHC S-2,500 hammer operating at 1,400 kJ, with 2 dB shift for post-piling installation.

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 $R_{95\%}$
200	0.06	0.06	0.06	0.06	-	-	-	-	0.03	0.03
190	0.35	0.34	0.35	0.34	0.14	0.13	0.10	0.10	0.21	0.21
180	1.58	1.47	1.55	1.46	0.70	0.64	0.54	0.52	1.07	1.02
170	3.39	3.19	3.39	3.19	2.50	2.30	2.22	1.94	3.04	2.86
160	6.80	6.17	6.79	6.17	5.04	4.58	4.72	4.09	6.07	5.50
150	11.54	10.14	11.54	10.13	9.54	8.43	9.05	7.90	10.89	9.46
140	17.52	15.21	17.51	15.20	15.22	13.34	14.64	12.64	16.82	14.52
130	24.78	21.85	24.78	21.84	22.32	19.57	21.12	18.61	23.79	21.09
120	34.75	28.77	34.74	28.76	31.85	26.67	30.32	25.75	33.77	28.06

Note: 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 5 m pile at location L02 using an IHC S-2,500 hammer operating at 1,800 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 $R_{95\%}$
200	0.03	0.03	0.03	0.03	-	-	-	-	-	-
190	0.17	0.17	0.17	0.17	0.06	0.06	0.05	0.05	0.12	0.12
180	0.88	0.83	0.87	0.82	0.38	0.36	0.26	0.25	0.60	0.56
170	2.69	2.54	2.68	2.54	1.60	1.52	1.34	1.27	2.26	2.08
160	5.16	4.71	5.15	4.70	3.63	3.36	3.24	3.04	4.61	4.12
150	9.31	8.36	9.31	8.35	7.60	6.81	6.81	6.29	8.64	7.75
140	14.96	13.07	14.96	13.06	12.91	11.30	12.26	10.70	14.24	12.40
130	21.41	19.01	21.39	19.00	19.46	16.84	18.73	16.07	20.71	18.20
120	30.75	25.91	30.74	25.90	28.04	24.00	26.76	23.13	29.63	25.24

Note: 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 5 m pile at location L02 using an IHC S-2,500 hammer operating at 1,800 kJ, with 2 dB shift for post-piling installation.

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 $R_{95\%}$
200	0.05	0.05	0.05	0.05	-	-	-	-	0.02	0.02
190	0.23	0.23	0.23	0.22	0.10	0.10	0.06	0.06	0.16	0.16
180	1.19	1.08	1.18	1.08	0.53	0.52	0.41	0.40	0.79	0.77
170	3.00	2.78	3.00	2.77	2.09	1.90	1.67	1.57	2.65	2.51
160	5.85	5.39	5.83	5.38	4.44	3.93	3.83	3.49	5.29	4.75
150	10.45	9.22	10.42	9.21	8.52	7.63	7.94	7.12	9.66	8.58
140	16.14	14.13	16.13	14.12	14.50	12.37	13.50	11.73	15.39	13.48
130	23.23	20.52	23.23	20.51	20.89	18.23	19.96	17.35	22.32	19.70
120	32.45	27.37	32.45	27.36	29.74	25.36	28.66	24.51	31.84	26.69

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

Table F-79. Distance (km) to the single strike sound pressure level (SPL) for a 5 m pile at location L02 using an IHC S-2,500 hammer operating at 2,500 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 $R_{95\%}$
200	-	-	-	-	-	-	-	-	-	-
190	0.05	0.05	0.05	0.05	-	-	-	-	-	-
180	0.16	0.16	0.15	0.15	-	-	-	-	0.03	0.03
170	0.66	0.63	0.65	0.62	0.10	0.10	0.06	0.06	0.21	0.20
160	1.98	1.88	1.96	1.86	0.53	0.51	0.36	0.34	1.05	0.99
150	3.28	3.10	3.27	3.09	1.95	1.81	1.55	1.44	2.54	2.42
140	5.46	5.02	5.43	5.00	3.41	3.24	3.12	3.00	4.29	3.97
130	9.01	8.13	9.00	8.12	6.52	5.95	5.73	5.32	8.02	7.19
120	14.07	12.33	14.06	12.32	11.54	10.05	10.89	9.36	13.11	11.34

Note: 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 5 m pile at location L02 using an IHC S-2,500 hammer operating at 2,500 kJ, with 2 dB shift for post-piling installation.

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 $R_{95\%}$
200	-	-	-	-	-	-	-	-	-	-
190	0.06	0.06	0.06	0.06	-	-	-	-	-	-
180	0.20	0.19	0.19	0.19	0.02	0.02	-	-	0.06	0.06
170	0.86	0.81	0.83	0.80	0.14	0.14	0.10	0.10	0.31	0.30
160	2.28	2.15	2.26	2.14	0.69	0.66	0.52	0.50	1.38	1.30
150	3.49	3.32	3.49	3.31	2.28	2.17	1.96	1.82	2.97	2.72
140	6.11	5.59	6.10	5.57	3.67	3.48	3.41	3.24	5.05	4.59
130	10.00	8.88	9.98	8.87	7.45	6.68	6.73	6.03	8.88	7.96
120	15.18	13.34	15.18	13.33	12.55	10.98	11.81	10.28	14.18	12.38

Note: 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

Table F-81. Distance (km) to the single strike peak pressure level (PK) for a 12 m pile using a Menck MHU4400S hammer.

Level (L_{pk})	Flat R_{max}				
	Hammer energy (kJ)				
	1,400	1,800	2,000	3,000	4,400
230	0.00	0.00	0.00	0.00	0.01
219	0.04	0.05	0.06	0.07	0.08
218	0.05	0.05	0.06	0.07	0.09
216	0.06	0.07	0.08	0.09	0.11
213	0.08	0.09	0.10	0.12	0.20
210	0.10	0.11	0.16	0.22	0.33
207	0.17	0.20	0.22	0.36	0.41
206	0.19	0.21	0.32	0.38	0.44
202	0.35	0.43	0.48	0.60	0.72
200	0.46	0.52	0.66	0.76	0.96

Table F-82. Distance (km) to the single strike peak pressure level (PK) for a 15 m pile using a Menck MHU440S hammer.

Level (L_{pk})	Flat R_{max}						
	Hammer energy (kJ)						
	480	800	1,600	2,500	3,000	4,000	4,400
230	0.00	0.00	0.00	0.00	0.01	0.01	0.01
219	0.01	0.01	0.04	0.06	0.07	0.08	0.08
218	0.01	0.01	0.05	0.06	0.07	0.09	0.09
216	0.01	0.04	0.06	0.08	0.09	0.10	0.11
213	0.04	0.06	0.08	0.10	0.11	0.19	0.21
210	0.06	0.08	0.10	0.13	0.19	0.24	0.32
207	0.08	0.10	0.15	0.30	0.33	0.38	0.41
206	0.09	0.11	0.19	0.33	0.35	0.40	0.43
202	0.12	0.29	0.36	0.47	0.64	0.64	0.78
200	0.28	0.34	0.47	0.68	0.86	0.80	0.96

Table F-83. Distance (km) to the single strike peak pressure level (PK) for a 5 m pin pile using an IHC S-2,500 hammer.

Level (L_{pk})	Flat R_{max}			
	Hammer energy (kJ)			
	1,200	1,400	1,800	2,500
230	0.00	0.00	0.00	0.00
219	0.06	0.05	0.03	0.02
218	0.07	0.06	0.04	0.03
216	0.08	0.08	0.05	0.04
213	0.10	0.10	0.07	0.06
210	0.19	0.19	0.11	0.08
207	0.27	0.30	0.17	0.12
206	0.29	0.33	0.21	0.14
202	0.50	0.43	0.38	0.28
200	0.56	0.52	0.48	0.35

Table F-84. Distance (km) to the single strike peak pressure level (PK) for a 5 m pin pile using an IHC S-2,500 hammer, with 2 dB shift for post-piling installation.

Level (L_{pk})	Flat R_{max}			
	Hammer energy (kJ)			
	1,200	1,400	1,800	2,500
230	0.00	0.00	0.00	0.00
219	0.00	0.00	0.00	0.01
218	0.07	0.07	0.05	0.03
216	0.08	0.08	0.05	0.04
213	0.09	0.09	0.07	0.05
210	0.17	0.11	0.09	0.07
207	0.21	0.26	0.14	0.10
206	0.33	0.35	0.25	0.15
202	0.39	0.37	0.28	0.23
200	0.56	0.52	0.48	0.35

F.3.2. Location L02

Table F-85. Distance (km) to the single strike peak pressure level (PK) for a 12 m pile using an Menck MHU4400S hammer.

Level (L_{pk})	Flat R_{max}				
	Hammer energy (kJ)				
	1,400	1,800	2,000	3,000	4,400
230	0.00	0.00	0.00	0.00	0.01
219	0.03	0.04	0.05	0.06	0.06
218	0.04	0.05	0.05	0.06	0.07
216	0.05	0.06	0.06	0.08	0.09
213	0.07	0.07	0.08	0.13	0.17
210	0.09	0.09	0.14	0.25	0.29
207	0.15	0.22	0.25	0.30	0.37
206	0.22	0.25	0.27	0.35	0.47
202	0.35	0.41	0.45	0.58	0.74
200	0.44	0.46	0.56	0.76	0.86

Table F-86. Distance (km) to the single strike peak pressure level (PK) for a 15 m pile using an Menck MHU440S hammer.

Level (L_{pk})	Flat R_{max}						
	Hammer energy (kJ)						
	480	800	1,600	2,500	3,000	4,000	4,400
230	0.00	0.00	0.00	0.01	0.01	0.01	0.01
219	0.01	0.01	0.04	0.05	0.06	0.07	0.07
218	0.01	0.02	0.04	0.05	0.06	0.07	0.08
216	0.01	0.03	0.05	0.06	0.07	0.09	0.10
213	0.04	0.05	0.07	0.08	0.09	0.16	0.18
210	0.05	0.07	0.09	0.13	0.17	0.27	0.29
207	0.07	0.08	0.13	0.26	0.28	0.33	0.46
206	0.08	0.09	0.23	0.28	0.34	0.46	0.50
202	0.12	0.25	0.38	0.45	0.49	0.64	0.78
200	0.24	0.28	0.44	0.62	0.62	3.00	3.00

Table F-87. Distance (km) to the single strike peak pressure level (PK) for a 5 m pin pile at location L02 using an IHC S-2,500 hammer.

Level (L_{pk})	Flat R_{max}			
	Hammer energy (kJ)			
	1,200	1,400	1,800	2,500
230	0.00	0.00	0.00	0.00
219	0.05	0.05	0.03	0.02
218	0.05	0.05	0.04	0.03
216	0.07	0.07	0.05	0.04
213	0.08	0.08	0.07	0.06
210	0.16	0.16	0.11	0.08
207	0.24	0.27	0.17	0.12
206	0.26	0.28	0.21	0.14
202	0.41	0.37	0.38	0.28
200	0.48	0.48	0.48	0.35

Table F-88. Distance (km) to the single strike peak pressure level (PK) for a 5 m pin pile at location L02 using an IHC S-2,500 hammer, with 2 dB shift for post-piling installation.

Level (L_{pk})	Flat R_{max}			
	Hammer energy (kJ)			
	1,200	1,400	1,800	2,500
230	0.00	0.00	0.00	0.01
219	0.00	0.00	0.01	0.01
218	0.06	0.06	0.03	0.04
216	0.07	0.07	0.04	0.05
213	0.08	0.08	0.05	0.06
210	0.14	0.12	0.07	0.08
207	0.22	0.25	0.12	0.11
206	0.31	0.30	0.24	0.13
202	0.33	0.32	0.25	0.14
200	0.48	0.48	0.35	0.17

F.4. Ranges to Per-Pile SEL Thresholds

Table F-89. Ranges ($R_{95\%}$ in km) to cumulative SEL injury thresholds for one 12 m monopile 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	7.80	5.70	4.49	3.13	7.46	5.52	4.34	2.99
Mid-frequency cetaceans	185	0.12	0.03	0.02	0.00	0.17	0.06	0.04	0.00
High-frequency cetaceans	155	4.34	2.75	1.80	0.99	4.76	3.05	2.23	1.20
Phocid pinnipeds	185	2.16	0.99	0.54	0.22	2.28	1.16	0.68	0.28
Sea turtles	204	3.11	1.72	1.00	0.47	2.90	1.69	1.08	0.54

Table F-90. Ranges ($R_{95\%}$ in km) to cumulative SEL injury thresholds for one 15 m monopile using a Menck MHU4400S hammer with attenuation at two selected 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	8.29	6.10	4.87	3.50	7.82	5.88	4.68	3.31
Mid-frequency cetaceans	185	0.11	0.03	0.02	0.00	0.17	0.06	0.03	0.00
High-frequency cetaceans	155	4.28	2.69	1.72	0.87	4.71	3.02	2.20	1.19
Phocid pinnipeds	185	2.34	1.14	0.63	0.26	2.43	1.30	0.76	0.34
Sea turtles	204	3.50	2.02	1.28	0.60	3.24	1.95	1.30	0.66

Table F-91. Ranges ($R_{95\%}$ in km) to cumulative SEL injury thresholds for four 5 m jackets using an IHC S-2,500 hammer with attenuation at two selected 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	10.29	7.44	5.78	4.04	9.12	6.61	5.13	3.51
Mid-frequency cetaceans	185	1.23	0.46	0.20	0.08	1.13	0.41	0.17	0.07
High-frequency cetaceans	155	8.78	6.49	5.15	3.69	8.22	6.06	4.75	3.33
Phocid pinnipeds	185	4.76	2.83	1.75	0.89	4.33	2.58	1.54	0.81
Sea turtles	204	3.19	1.68	1.01	0.41	2.73	1.46	0.84	0.40

Table F-92. Ranges ($R_{95\%}$ in km) to cumulative SEL injury thresholds for four 5 m jackets using an IHC S-2,500 hammer with attenuation at two selected modeling locations (L01 and L02), with 2 dB shift for post-piling installation.

Hearing group	Threshold (dB)	L01				L02			
		Attenuation level (dB)				Attenuation level (dB)			
		0	6	10	15	0	6	10	15
Low-frequency cetaceans	183	11.35	8.34	6.57	4.68	10.01	7.40	5.86	4.16
Mid-frequency cetaceans	185	1.57	0.62	0.24	0.10	1.31	0.70	0.23	0.09
High-frequency cetaceans	155	9.61	7.25	5.86	4.27	9.00	6.75	5.41	3.82
Phocid pinnipeds	185	5.48	3.39	2.26	1.26	5.02	3.04	1.99	1.14
Sea turtles	204	3.75	2.14	1.26	0.63	3.21	1.80	1.11	0.55

F.5. Ranges to Thresholds for Fish

Table F-93. Expected scenario modeled for monopile acoustic radial distances ($R_{95\%}$ in km) to thresholds for fish - 12 m monopiles using a 4,400 kJ hammer with 6 dB attenuation.

Faunal group	Metric	Threshold (dB)	Hammer energy (kJ)									
			L01					L02				
			1,400	1,800	2,000	3,000	4,400	1,400	1,800	2,000	3,000	4,400
Small fish[a]	L_E	183	8.13					7.47				
	L_{pk}	206	0.09	0.10	0.10	0.18	0.21	0.07	0.08	0.09	0.16	0.25
Large fish[a]	L_E	187	6.72					6.24				
	L_{pk}	206	0.09	0.10	0.10	0.18	0.21	0.07	0.08	0.09	0.16	0.25
All fish[b]	L_p	150	6.15	6.68	7.04	7.81	8.59	5.69	6.11	6.50	7.32	7.94
Fish without swim bladder[c]	L_E	216	0.49					0.51				
	L_{pk}	213	0.04	0.05	0.06	0.07	0.08	0.03	0.04	0.05	0.06	0.06
Fish with swim bladder[c]	L_E	203	2.52					2.26				
	L_{pk}	207	0.08	0.09	0.10	0.12	0.20	0.07	0.07	0.08	0.13	0.17
All fish[c]	L_E	186	7.05					6.54				

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.
[a] FHWG (2008), Stadler and Woodbury (2009)
[b] Andersson et al. (2007), Wysocki et al. (2007), Mueller-Blenkle et al. (2010), Purser and Radford (2011)
[c] Popper et al. (2014)

Table F-94. Expected scenario modeled for monopile acoustic radial distances ($R_{95\%}$ in km) to thresholds for fish - 12 m monopiles using a 4,400 kJ hammer with 10 dB attenuation.

Faunal group	Metric	Threshold (dB)	Hammer energy (kJ)									
			L01					L02				
			1,400	1,800	2,000	3,000	4,400	1,400	1,800	2,000	3,000	4,400
Small fish[a]	L_E	183	6.72					6.24				
	L_{pk}	206	0.06	0.07	0.08	0.09	0.11	0.05	0.06	0.06	0.08	0.09
Large fish[a]	L_E	187	5.57					5.12				
	L_{pk}	206	0.06	0.07	0.08	0.09	0.11	0.05	0.06	0.06	0.08	0.09
All fish[b]	L_p	150	5.03	5.54	5.83	6.44	7.12	4.62	5.02	5.38	6.10	6.68
Fish without swim bladder[c]	L_E	216	0.22					0.27				
	L_{pk}	213	0.01	0.01	0.01	0.03	0.05	0.01	0.01	0.03	0.04	0.04
Fish with swim bladder[c]	L_E	203	1.68					1.57				
	L_{pk}	207	0.05	0.06	0.07	0.08	0.10	0.05	0.05	0.06	0.07	0.08
All fish[c]	L_E	186	5.83					5.4				

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.
[a] FHWG (2008), Stadler and Woodbury (2009)
[b] Andersson et al. (2007), Wysocki et al. (2007), Mueller-Blenkle et al. (2010), Purser and Radford (2011)
[c] Popper et al. (2014)

Table F-95. Expected scenario modeled for monopile acoustic radial distances ($R_{95\%}$ in km) to thresholds for fish - 12 m monopiles using a 4,400 kJ hammer with 15 dB attenuation.

Faunal group	Metric	Threshold (dB)	Hammer energy (kJ)									
			L01					L02				
			1,400	1,800	2,000	3,000	4,400	1,400	1,800	2,000	3,000	4,400
Small fish[a]	L_E	183	5.27					4.85				
	L_{pk}	206	0.01	0.02	0.04	0.05	0.06	0.02	0.03	0.04	0.05	0.05
Large fish[a]	L_E	187	4.20					3.8				
	L_{pk}	206	0.01	0.02	0.04	0.05	0.06	0.02	0.03	0.04	0.05	0.05
All fish[b]	L_p	150	3.73	4.20	4.46	4.99	5.62	3.39	3.73	4.05	4.69	5.24
Fish without swim bladder[c]	L_E	216	0.12					0.12				
	L_{pk}	213	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.01	0.01	0.01
Fish with swim bladder[c]	L_E	203	0.91					0.89				
	L_{pk}	207	0.01	0.01	0.02	0.05	0.06	0.01	0.03	0.03	0.04	0.05
All fish[c]	L_E	186	4.45					4.06				

L_{pk}= unweighted peak sound pressure (dB re 1 μPa); L_E = unweighted sound exposure level (dB re 1 $\mu Pa^2 \cdot s$); L_p= unweighted sound pressure (dB re 1 μPa). Small fish are defined as having a total mass of less than 2 g.

[a] FHWG (2008), Stadler and Woodbury (2009)

[b] Andersson et al. (2007), Wysocki et al. (2007), Mueller-Blenkle et al. (2010), Purser and Radford (2011)

[c] Popper et al. (2014)

Table F-96. Expected scenario modeled for monopile acoustic radial distances ($R_{95\%}$ in km) to thresholds for fish - 15 m monopiles using a 4,400 kJ hammer with 6 dB attenuation.

Faunal group	Metric	Threshold (dB)	Hammer energy (kJ)													
			L01							L02						
			480	800	1,600	2,500	3,000	4,000	4,400	480	800	1,600	2,500	3,000	4,000	4,400
Small fish[a]	L_E	183	8.67							7.89						
	L_{pk}	206	0.05	0.06	0.09	0.11	0.16	0.20	0.22	0.04	0.05	0.07	0.09	0.14	0.18	0.25
Large fish[a]	L_E	187	7.22							6.65						
	L_{pk}	206	0.05	0.06	0.09	0.11	0.16	0.20	0.22	0.04	0.05	0.07	0.09	0.14	0.18	0.25
All fish[b]	L_p	150	4.63	5.33	6.25	7.43	7.72	8.22	8.72	4.24	4.72	5.65	6.72	7.09	7.78	8.07
Fish without swim bladder[c]	L_E	216	0.62							0.64						
	L_{pk}	213	0.01	0.01	0.04	0.06	0.07	0.08	0.08	0.01	0.01	0.04	0.05	0.06	0.07	0.07
Fish with swim bladder[c]	L_E	203	2.89							2.57						
	L_{pk}	207	0.04	0.06	0.08	0.10	0.11	0.19	0.21	0.04	0.05	0.07	0.08	0.09	0.16	0.18
All fish[c]	L_E	186	7.56							6.95						

L_{pk}= unweighted peak sound pressure (dB re 1 μPa); L_E = unweighted sound exposure level (dB re 1 $\mu Pa^2 \cdot s$); L_p= unweighted sound pressure (dB re 1 μPa). Small fish are defined as having a total mass of less than 2 g.

[a] FHWG (2008), Stadler and Woodbury (2009)

[b] Andersson et al. (2007), Wysocki et al. (2007), Mueller-Blenkle et al. (2010), Purser and Radford (2011)

[c] Popper et al. (2014)

Table F-97. Expected scenario modeled for monopile acoustic radial distances ($R_{95\%}$ in km) to thresholds for fish - 15 m monopiles using a 4,400 kJ hammer with 10 dB attenuation.

Faunal group	Metric	Threshold (dB)	Hammer energy (kJ)													
			L01							L02						
			480	800	1,600	2,500	3,000	4,000	4,400	480	800	1,600	2,500	3,000	4,000	4,400
Small fish[a]	L_E	183	7.22							6.65						
	L_{pk}	206	0.01	0.04	0.06	0.08	0.09	0.10	0.11	0.01	0.03	0.05	0.06	0.07	0.09	0.10
Large fish[a]	L_E	187	5.99							5.51						
	L_{pk}	206	0.01	0.04	0.06	0.08	0.09	0.10	0.11	0.01	0.03	0.05	0.06	0.07	0.09	0.10
All fish[b]	L_p	150	3.69	4.28	5.15	6.20	6.40	6.80	7.23	3.34	3.72	4.62	5.63	5.93	6.52	6.80
Fish without swim bladder[c]	L_E	216	0.32							0.34						
	L_{pk}	213	0.00	0.00	0.01	0.02	0.04	0.05	0.05	0.00	0.01	0.01	0.03	0.04	0.04	0.05
Fish with swim bladder[c]	L_E	203	1.97							1.81						
	L_{pk}	207	0.01	0.02	0.05	0.07	0.08	0.09	0.1	0.01	0.03	0.05	0.06	0.07	0.08	0.09
All fish[c]	L_E	186	6.27							5.79						

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.
[a] FHWG (2008), Stadler and Woodbury (2009)
[b] Andersson et al. (2007), Wysocki et al. (2007), Mueller-Blenkle et al. (2010), Purser and Radford (2011)
[c] Popper et al. (2014)

Table F-98. Expected scenario modeled for monopile acoustic radial distances ($R_{95\%}$ in km) to thresholds for fish - 15 m monopiles using a 4,400 kJ hammer with 15 dB attenuation.

Faunal group	Metric	Threshold (dB)	Hammer energy (kJ)													
			L01							L02						
			480	800	1,600	2,500	3,000	4,000	4,400	480	800	1,600	2,500	3,000	4,000	4,400
Small fish[a]	L_E	183	5.70							5.24						
	L_{pk}	206	0.00	0.01	0.02	0.04	0.05	0.06	0.07	0.01	0.01	0.03	0.04	0.05	0.05	0.06
Large fish[a]	L_E	187	4.6							4.17						
	L_{pk}	206	0.00	0.01	0.02	0.04	0.05	0.06	0.07	0.01	0.01	0.03	0.04	0.05	0.05	0.06
All fish[b]	L_p	150	2.97	3.29	3.90	4.84	5.01	5.32	5.68	2.62	2.84	3.46	4.34	4.58	5.09	5.36
Fish without swim bladder[c]	L_E	216	0.15							0.15						
	L_{pk}	213	0.00	0.00	0.0	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.01	0.01	0.01	0.01
Fish with swim bladder[c]	L_E	203	1.13							1.09						
	L_{pk}	207	0.00	0.01	0.01	0.04	0.05	0.06	0.06	0	0.01	0.01	0.03	0.04	0.05	0.05
All fish[c]	L_E	186	4.86							4.44						

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.
[a] FHWG (2008), Stadler and Woodbury (2009)
[b] Andersson et al. (2007), Wysocki et al. (2007), Mueller-Blenkle et al. (2010), Purser and Radford (2011)
[c] Popper et al. (2014)

Table F-99. Expected scenario modeled for jacket foundation acoustic radial distances ($R_{95\%}$ in km) to thresholds for fish-5 m jacket pin piles using a 2,500 kJ hammer with 6 dB attenuation.

Faunal group	Metric	Threshold (dB)	Hammer energy (kJ)							
			L01				L02			
			1,200	1,400	1,800	2,500	1,200	1,400	1,800	2,500
Small fish[a]	L_E	183	9.00				7.87			
	L_{pk}	206	0.10	0.11	0.08	0.06	0.09	0.09	0.06	0.07
Large fish[a]	L_E	187	7.24				6.37			
	L_{pk}	206	0.10	0.11	0.08	0.06	0.09	0.09	0.06	0.07
All fish[b]	L_p	150	7.12	6.98	7.40	5.59	6.73	6.90	6.07	2.35
Fish without swim bladder[c]	L_E	216	0.31				0.30			
	L_{pk}	213	0.06	0.05	0.03	0.02	0.05	0.05	0.02	0.03
Fish with swim bladder[c]	L_E	203	2.22				1.84			
	L_{pk}	207	0.10	0.10	0.07	0.06	0.08	0.08	0.05	0.07
All fish[c]	L_E	186	7.66				6.74			

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.
[a] FHWG (2008), Stadler and Woodbury (2009)
[b] Andersson et al. (2007), Wysocki et al. (2007), Mueller-Blenkle et al. (2010), Purser and Radford (2011)
[c] Popper et al. (2014)

Table F-100. Expected scenario modeled for jacket foundation acoustic radial distances ($R_{95\%}$ in km) to thresholds for fish-5 m jacket pin piles using a 2,500 kJ hammer with 6 dB attenuation and with 2 dB shift for post-piling installation (OSS foundation).

Faunal group	Metric	Threshold (dB)	Hammer energy (kJ)							
			L01				L02			
			1,200	1,400	1,800	2,500	1,200	1,400	1,800	2,500
Small fish[a]	L_E	183	9.94				8.68			
	L_{pk}	206	0.19	0.19	0.11	0.08	0.16	0.16	0.09	0.10
Large fish[a]	L_E	187	8.13				7.11			
	L_{pk}	206	0.19	0.19	0.11	0.08	0.16	0.16	0.09	0.10
All fish[b]	L_p	150	7.98	7.82	8.28	6.33	7.47	7.64	6.78	2.57
Fish without swim bladder[c]	L_E	216	0.46				0.42			
	L_{pk}	213	0.07	0.07	0.05	0.03	0.06	0.06	0.03	0.04
Fish with swim bladder[c]	L_E	203	2.77				2.26			
	L_{pk}	207	0.17	0.11	0.09	0.07	0.14	0.12	0.07	0.08
All fish[c]	L_E	186	8.56				7.48			

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.
[a] FHWG (2008), Stadler and Woodbury (2009)
[b] Andersson et al. (2007), Wysocki et al. (2007), Mueller-Blenkle et al. (2010), Purser and Radford (2011)
[c] Popper et al. (2014)

Table F-101. Expected scenario modeled for jacket foundation acoustic radial distances ($R_{95\%}$ in km) to thresholds for fish-5 m jacket pin piles using a 2,500 kJ hammer with 10 dB attenuation.

Faunal group	**Metric**	**Threshold (dB)**	**Hammer energy (kJ)**							
			L01				**L02**			
			1,200	1,400	1,800	2,500	1,200	1,400	1,800	2,500
Small fish[a]	L_E	183	7.24				6.37			
	L_{pk}	206	0.08	0.08	0.05	0.04	0.07	0.07	0.04	0.05
Large fish[a]	L_E	187	5.72				5			
	L_{pk}	206	0.08	0.08	0.05	0.04	0.07	0.07	0.04	0.05
All fish[b]	L_p	150	5.63	5.54	5.88	4.31	5.34	5.50	4.71	1.88
Fish without swim bladder[c]	L_E	216	0.18				0.16			
	L_{pk}	213	0.01	0.01	0.02	0.01	0.02	0.01	0.01	0.02
Fish with swim bladder[c]	L_E	203	1.42				1.23			
	L_{pk}	207	0.07	0.07	0.05	0.03	0.06	0.06	0.03	0.04
All fish[c]	L_E	186	6.07				5.34			

Note: L_{pk}= unweighted peak sound pressure (dB re 1 μPa); L_E = unweighted sound exposure level (dB re 1 $\mu Pa^2 \cdot s$); L_p= unweighted sound pressure (dB re 1 μPa). Small fish are defined as having a total mass of less than 2 g.
[a] FHWG (2008), Stadler and Woodbury (2009)
[b] Andersson et al. (2007), Wysocki et al. (2007), Mueller-Blenkle et al. (2010), Purser and Radford (2011)
[c] Popper et al. (2014)

Table F-102. Expected scenario modeled for jacket foundation acoustic radial distances ($R_{95\%}$ in km) to thresholds for fish-5 m jacket pin piles using a 2,500 kJ hammer with 10 dB attenuation and with 2 dB shift for post-piling installation (OSS foundation).

Faunal group	**Metric**	**Threshold (dB)**	**Hammer energy (kJ)**							
			L01				**L02**			
			1,200	1,400	1,800	2,500	1,200	1,400	1,800	2,500
Small fish[a]	L_E	183	8.13				7.11			
	L_{pk}	206	0.09	0.09	0.07	0.05	0.08	0.08	0.05	0.06
Large fish[a]	L_E	187	6.45				5.68			
	L_{pk}	206	0.09	0.09	0.07	0.05	0.08	0.08	0.05	0.06
All fish[b]	L_p	150	6.36	6.23	6.60	4.89	6.01	6.17	5.39	2.15
Fish without swim bladder[c]	L_E	216	0.24				0.21			
	L_{pk}	213	0.02	0.02	0.02	0.02	0.04	0.03	0.02	0.02
Fish with swim bladder[c]	L_E	203	1.83				1.49			
	L_{pk}	207	0.09	0.09	0.06	0.04	0.07	0.07	0.04	0.05
All fish[c]	L_E	186	6.84				6.01			

Note: L_{pk}= unweighted peak sound pressure (dB re 1 μPa); L_E = unweighted sound exposure level (dB re 1 $\mu Pa^2 \cdot s$); L_p= unweighted sound pressure (dB re 1 μPa). Small fish are defined as having a total mass of less than 2 g.
[a] FHWG (2008), Stadler and Woodbury (2009)
[b] Andersson et al. (2007), Wysocki et al. (2007), Mueller-Blenkle et al. (2010), Purser and Radford (2011)
[c] Popper et al. (2014)

Table F-103. Expected scenario modeled for jacket foundation acoustic radial distances ($R_{95\%}$ in km) to thresholds for fish-5 m jacket pin piles using a 2,500 kJ hammer with 15 dB attenuation.

Faunal group	Metric	Threshold (dB)	Hammer energy (kJ)							
			L01				L02			
			1,200	1,400	1,800	2,500	1,200	1,400	1,800	2,500
Small fish[a]	L_E	183	5.35				4.68			
	L_{pk}	206	0.02	0.02	0.02	0.02	0.04	0.03	0.02	0.02
Large fish[a]	L_E	187	4.12				3.49			
	L_{pk}	206	0.02	0.02	0.02	0.02	0.04	0.03	0.02	0.02
All fish[b]	L_p	150	4.04	3.96	4.24	3.18	3.78	3.95	3.30	1.16
Fish without swim bladder[c]	L_E	216	0.07				0.06			
	L_{pk}	213	0.0	0.00	0.00	0.01	0.00	0.00	0.01	0.01
Fish with swim bladder[c]	L_E	203	0.66				0.59			
	L_{pk}	207	0.01	0.01	0.02	0.02	0.03	0.02	0.01	0.02
All fish[c]	L_E	186	4.42				3.78			

Note: 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.
[a] FHWG (2008), Stadler and Woodbury (2009)
[b] Andersson et al. (2007), Wysocki et al. (2007), Mueller-Blenkle et al. (2010), Purser and Radford (2011)
[c] Popper et al. (2014)

Table F-104. Expected scenario modeled for jacket foundation acoustic radial distances ($R_{95\%}$ in km) to thresholds for fish-5 m jacket pin piles using a 2,500 kJ hammer with 15 dB attenuation and with 2 dB shift for post-piling installation (OSS foundation).

Faunal group	Metric	Threshold (dB)	Hammer energy (kJ)							
			L01				L02			
			1,200	1,400	1,800	2,500	1,200	1,400	1,800	2,500
Small fish[a]	L_E	183	6.07				5.34			
	L_{pk}	206	0.06	0.05	0.03	0.02	0.05	0.05	0.02	0.03
Large fish[a]	L_E	187	4.73				4.07			
	L_{pk}	206	0.06	0.05	0.03	0.02	0.05	0.05	0.02	0.03
All fish[b]	L_p	150	4.62	4.54	4.85	3.53	4.38	4.59	3.81	1.44
Fish without swim bladder[c]	L_E	216	0.11				0.11			
	L_{pk}	213	0.01	0.00	0.01	0.01	0.01	0.01	0.01	0.01
Fish with swim bladder[c]	L_E	203	0.88				0.78			
	L_{pk}	207	0.05	0.03	0.03	0.02	0.04	0.04	0.02	0.03
All fish[c]	L_E	186	5.02				4.39			

Note: 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.
[a] FHWG (2008), Stadler and Woodbury (2009)
[b] Andersson et al. (2007), Wysocki et al. (2007), Mueller-Blenkle et al. (2010), Purser and Radford (2011)
[c] Popper et al. (2014)

Appendix G. Animal Movement and Exposure Modeling

To assess the risk of impacts from anthropogenic sound exposure, an estimate of the received sound levels for individuals of each species known to occur in 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 Project 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 (see 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	300
50%	160	20	60
90%	180	30	30

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	30

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 1,000 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 Level B or Level A 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 3, 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 Supplemental Results

G.2.1. Marine Mammal Exposure Range Estimates

Tables 3 to 5 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. The tables in this section are for foundation types not included in the 2-year construction schedules described in Table 3.

Table G-3. Monopile foundation (12 m diameter, one pile 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 (NMFS 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])	3.24	2.04	1.09	0.35	0.03	<0.01	0	0	6.38	4.60	3.52	2.80	6.55	4.75	3.64	2.82
Minke whale	1.93	0.89	0.33	0.04	0.02	0	0	0	5.75	4.30	3.37	2.69	6.00	4.43	3.42	2.69
Humpback whale	3.30	1.84	1.08	0.39	0.05	<0.01	<0.01	0	6.30	4.58	3.48	2.90	6.42	4.69	3.50	2.90
North Atlantic right whale[a] (25% foraging)	2.45	1.13	0.56	0.21	0.02	0	0	0	6.13	4.57	3.60	2.64	14.61	11.88	9.96	7.95
Mid-frequency cetaceans																
Atlantic white sided dolphin	0	0	0	0	0	0	0	0	6.03	4.38	3.37	2.71	3.28	2.36	1.73	0.87
Short-beaked common dolphin	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bottlenose dolphin Northern Coastal	0	0	0	0	0	0	0	0	6.71	4.97	3.91	3.07	3.87	2.65	2.06	0.99
Bottlenose dolphin	0	0	0	0	0	0	0	0	6.64	4.92	3.89	3.00	3.66	2.73	1.99	1.09
Risso's dolphin	0	0	0	0	<0.01	0	0	0	6.08	4.59	3.53	2.69	3.43	2.42	1.78	0.89
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	0	0	0	0	0	0	0
High-frequency cetaceans																
Harbor porpoise	1.54	0.70	0.39	0.02	0.59	0.24	0.16	0.05	6.28	4.52	3.59	2.72	20.78	17.22	14.72	12.00
Pinnipeds in water																
Gray seal	0.87	0.17	0.01	0.02	0.03	0.02	0	0	6.34	4.64	3.72	2.94	5.15	3.35	2.85	1.89
Harbor seal	0.83	0.14	<0.01	0	<0.01	<0.01	0	0	6.35	4.71	3.73	2.92	5.20	3.54	2.92	1.96

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

Table G-4. Monopile foundation (12 m diameter, two piles per day) exposure ranges ($ER_{95\%}$) in km to marine mammal Level A and Level B threshold criteria with sound attenuation.

Species	Level A								Level B							
	L_E (NMFS 2018)				L_{PK} (NMFS 2018)				L_p (NMFS 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])	3.21	1.98	1.30	0.33	0.04	0.01	0	0	6.28	4.54	3.62	2.83	6.51	4.68	3.65	2.86
Minke whale	1.98	0.85	0.38	0.07	0.04	<0.01	0	0	5.69	4.20	3.37	2.66	5.95	4.31	3.39	2.66
Humpback whale	3.35	1.87	1.01	0.37	0.03	0	0	0	6.14	4.64	3.62	2.75	6.31	4.73	3.64	2.75
North Atlantic right whale[a] (25% foraging)	2.45	1.19	0.67	0.33	0.04	0	0	0	6.02	4.41	3.48	2.75	14.65	11.67	9.96	7.88
Mid-frequency cetaceans																
Atlantic white sided dolphin	0	0	0	0	0	0	0	0	6.01	4.36	3.50	2.77	3.35	2.41	1.72	0.84
Short-beaked common dolphin	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bottlenose dolphin Northern Coastal	0	0	0	0	0	0	0	0	6.65	4.98	3.91	2.98	3.79	2.69	2.05	1.06
Bottlenose dolphin	0	0	0	0	0	0	0	0	6.61	4.92	3.96	3.05	3.79	2.66	1.88	1.10
Risso's dolphin	0	0	0	0	0	0	0	0	6.05	4.40	3.55	2.71	3.40	2.47	1.63	0.87
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	0	0	0	0	0	0	0
High-frequency cetaceans																
Harbor porpoise	1.54	0.73	0.32	0.03	0.56	0.24	0.16	0.06	6.01	4.58	3.49	2.79	20.58	16.87	14.52	11.77
Pinnipeds in water																
Gray seal	0.72	0.11	0	0	0.04	0	0	0	6.26	4.67	3.73	2.85	5.20	3.59	2.84	1.96
Harbor seal	0.62	0.09	<0.01	<0.01	0.03	<0.01	0	0	6.24	4.64	3.66	2.92	5.13	3.52	2.84	2.08

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

Table G-5. Monopile foundation (15 m diameter, two piles per day) exposure ranges ($ER_{95\%}$) in km to marine mammal Level A and Level B threshold criteria with sound attenuation.

Species	Level A								Level B							
	L_E (NMFS 2018)				L_{PK} (NMFS 2018)				L_p (NMFS 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])	3.45	2.15	1.83	0.45	0.05	0.02	0	0	6.33	4.67	3.74	2.85	6.56	4.78	3.79	2.91
Minke whale	2.15	0.95	0.41	0.07	0.05	<0.01	0	0	5.86	4.38	3.45	2.78	6.16	4.50	3.51	2.79
Humpback whale	3.53	2.08	1.29	0.42	0.04	0.02	<0.01	<0.01	6.32	4.66	3.68	2.87	6.52	4.76	3.72	2.88
North Atlantic right whale[a] (25% foraging)	2.68	1.37	0.72	0.39	0.04	0	0	0	6.24	4.58	3.61	2.84	14.89	11.94	10.20	8.07
Mid-frequency cetaceans																
Atlantic white sided dolphin	0	0	0	0	0	0	0	0	6.06	4.61	3.58	2.86	3.39	2.46	1.80	0.98
Short-beaked common dolphin	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bottlenose dolphin Northern Coastal	0	0	0	0	0	0	0	0	6.72	5.00	3.93	2.98	3.84	2.66	2.04	1.05
Bottlenose dolphin	0	0	0	0	0	0	0	0	6.66	5.00	4.03	3.04	3.84	2.65	1.96	1.14
Risso's dolphin	0.02	0	0	0	0	0	0	0	6.15	4.56	3.68	2.83	3.49	2.50	1.75	0.97
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	0	0	0	0	0	0	0
High-frequency cetaceans																
Harbor porpoise	1.41	0.72	0.28	0.03	0.63	0.28	0.17	0.07	6.23	4.61	3.61	2.87	19.94	16.57	13.96	11.60
Pinnipeds in water																
Gray seal	0.67	0.26	0	0	0.04	0.02	0	0	6.46	4.77	3.71	2.96	5.29	3.61	2.94	2.10
Harbor seal	0.61	0.11	<0.01	<0.01	0.05	<0.01	0	0	6.35	4.89	3.76	2.94	5.35	3.63	2.84	2.09

[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 jacket and monopile foundation schedules separated by year.

The yearly WTG monopile construction schedule presented in Table G-6 assumes the installation of 92, 15-m diameter monopile foundations supporting WTGs and 24, 5-m diameter pin piles supporting post-piled OSS jacket foundations during year one, and 109 15-m diameter monopiles supporting WTGs during year two.

The yearly WTG jacket construction schedule presented in Table G-7 assumes the installation of 93, 4-legged pre-piled jacket foundations with 5-m diameter pin piles supporting WTGs and 24, 5-m diameter pin piles supporting post-piled OSS jacket foundations during year one, and 108 4-legged pre-piled jacket foundations supporting WTGs during year two.

Table G-6. Construction schedule 1, separated by year. Total days of piling per month were used to estimate the number of marine mammal and sea turtle acoustic exposures for Atlantic Shores Wind.

Construction month	Schedule 1.1: Year One		Schedule 1.2: Year Two	
	WTG Monopile 15 m diameter MHU4400S (1 pile/day)	**OSS Jacket** 5 m diameter IHCS2500 (4 piles/day)	**WTG Monopile** 15 m diameter MHU4400S (1 pile/day)	**OSS Jacket** 5 m diameter IHCS2500 (4 piles/day)
May	5	0	5	0
Jun	15	0	15	0
Jul	15	12	27	0
Aug	13	12	25	0
Sep	18	0	18	0
Oct	20	0	13	0
Nov	5	0	5	0
Dec	1	0	1	0
Total # of days	**92**	**24**	**109**	**0**

Table G-7. Construction schedule 2, separated by year. Total days of piling per month were used to estimate the number of marine mammal and sea turtle acoustic exposures for Atlantic Shores Wind.

Construction month	Schedule 2.1: Year One		Schedule 2.2: Year Two	
	WTG Jacket 5 m diameter IHCS2500 (4 piles/day)	**OSS Jacket** 5 m diameter IHCS2500 (4 piles/day)	**WTG Jacket** 5 m diameter IHCS2500 (4 piles/day)	**OSS Jacket** 5 m diameter IHCS2500 (4 piles/day)
May	2	0	2	0
Jun	20	0	18	0
Jul	15	12	27	0
Aug	13	12	25	0
Sep	18	0	18	0
Oct	20	0	13	0
Nov	4	0	4	0
Dec	1	0	1	0
Total # of days	**93**	**24**	**108**	**0**

Table G-8. Construction schedule 1.1 : the mean number of modeled marine mammals estimated to experience sound levels above exposure criteria for different sound attenuation levels. The schedule includes the installation of both WTG and OSS foundations (Table G-6).

Species	Level A								Level B							
	L_E (NMFS 2018)				L_{pk} (NMFS 2018)				L_p (NMFS 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]	30.17	18.49	11.43	5.14	0.24	<0.01	0	0	54.27	39.30	31.64	24.80	47.77	32.47	24.97	18.17
Minke whale	31.08	12.95	4.89	1.00	0.05	<0.01	0	0	82.17	61.64	50.11	38.85	60.54	43.92	34.88	26.56
Humpback whale	5.95	3.30	1.76	0.65	0.03	<0.01	0	0	11.73	8.21	6.31	4.63	9.24	6.42	4.93	3.58
North Atlantic right whale[a] (25% foraging)	1.34	0.54	0.25	0.06	<0.01	<0.01	<0.01	<0.01	3.97	2.84	2.19	1.67	7.51	5.88	4.88	3.88
Sei whale[a]	0.32	0.20	0.12	0.05	<0.01	<0.01	0	0	0.60	0.43	0.35	0.27	0.53	0.36	0.28	0.20
Mid-frequency cetaceans																
Atlantic white sided dolphin	0.11	0.05	0.05	0	0	0	0	0	630.96	459.04	367.75	279.56	292.16	200.58	150.40	95.12
Short-beaked dolphin	0	0	0	0	0	0	0	0	0	0	0	0	34.66	10.61	3.86	0
Bottlenose dolphin Northern Coastal	1.03	0.21	0.10	0	0	0	0	0	307.16	177.97	127.20	81.39	141.52	83.59	56.45	31.52
Bottlenose dolphin	11.02	0.97	0	0	0	0	0	0	2,836.31	1,715.28	1,142.32	712.53	1,274.05	761.44	517.24	287.68
Risso's dolphin	0.02	<0.01	<0.01	0	<0.01	0	0	0	32.52	23.62	19.02	14.44	15.49	10.68	8.09	5.22
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	0	0	0	<0.01	0	0	0
High-frequency cetaceans																
Harbor porpoise	20.47	7.01	2.14	0.62	10.84	4.71	2.36	0.54	104.23	76.15	61.63	46.85	274.46	207.02	169.02	128.63
Pinnipeds in water																
Gray seal	7.26	2.28	0.56	0.10	0.17	0	0	0	82.34	54.40	39.86	29.66	53.09	33.65	25.60	17.19
Harbor seal	8.94	2.30	0.65	0.04	0.36	0.08	0	0	85.55	56.23	41.98	31.23	54.85	35.19	26.70	18.02

[a] Listed as Endangered under the ESA.

Table G-9. Construction schedule 1.2: the mean number of modeled marine mammals estimated to experience sound levels above exposure criteria for different sound attenuation levels. The schedule includes the installation of both WTG and OSS foundations (Table G-6).

Species	Level A								Level B							
	L_E (NMFS 2018)				L_{pk} (NMFS 2018)				L_p (NMFS 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]	19.92	12.19	7.51	3.18	0.22	0	0	0	39.84	29.00	23.39	18.41	35.04	23.80	18.57	13.64
Minke whale	16.20	5.99	1.91	0.37	0.03	0	0	0	51.73	39.55	32.39	25.82	38.52	28.36	22.57	17.33
Humpback whale	3.47	1.95	1.03	0.35	0.03	<0.01	0	0	7.63	5.43	4.19	3.12	6.02	4.25	3.26	2.38
North Atlantic right whale[b] (25% foraging)	1.12	0.44	0.20	0.04	<0.01	<0.01	<0.01	<0.01	3.52	2.55	1.97	1.52	6.55	5.14	4.27	3.41
Sei whale[b]	0.22	0.14	0.08	0.04	<0.01	0	0	0	0.45	0.33	0.26	0.21	0.39	0.27	0.21	0.15
Mid-frequency cetaceans																
Atlantic white sided dolphin	0	0	0	0	0	0	0	0	384.67	286.55	230.34	179.82	154.19	105.24	78.55	49.45
Short-beaked dolphin	0	0	0	0	0	0	0	0	0	0	0	0	23.99	5.22	0	0
Bottlenose dolphin Northern Coastal	0	0	0	0	0	0	0	0	279.73	167.56	121.32	79.66	111.53	65.70	44.13	24.13
Bottlenose dolphin	4.33	0	0	0	0	0	0	0	2,548.52	1,603.66	1,087.89	680.47	982.57	595.09	400.05	217.58
Risso's dolphin	0	0	0	0	0	0	0	0	32.52	23.95	19.34	14.84	13.45	9.22	6.95	4.42
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	0	0	0	0	0	0	0
High-frequency cetaceans																
Harbor porpoise	16.94	4.92	0.80	0.13	10.55	4.60	2.32	0.54	99.29	72.73	58.96	44.88	256.72	192.87	157.04	119.13
Pinnipeds in water																
Gray seal	2.56	0.51	0.06	0.06	0.13	0	0	0	56.43	38.03	27.70	20.71	34.86	22.14	16.64	11.40
Harbor seal	3.70	0.50	0.06	0	0.31	0.06	0	0	58.86	39.09	29.62	22.21	36.08	23.22	17.57	12.07

[a] Listed as Endangered under the ESA.

Table G-10. Construction schedule 2.1: the mean number of modeled marine mammals estimated to experience sound levels above exposure criteria for different sound attenuation levels. The schedule includes the installation of both WTG and OSS foundations (Table G-7).

Species	Level A								Level B							
	L_E (NMFS 2018)				**L_{pk} (NMFS 2018)**				**L_p (NMFS 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]	44.05	25.11	14.94	6.57	0.08	0.04	0	0	66.19	47.48	39.55	27.64	58.40	38.75	29.62	20.41
Minke whale	39.20	15.75	5.78	1.04	0.03	<0.01	0	0	88.71	63.72	51.89	34.61	63.53	44.50	36.08	25.55
Humpback whale	9.65	4.80	2.45	0.86	0.01	<0.01	0	0	15.67	10.40	8.09	5.14	12.30	8.17	6.37	4.31
North Atlantic right whale[a] (25% foraging)	2.23	0.91	0.44	0.10	<0.01	0	0	0	4.76	3.09	2.43	1.43	10.77	8.09	6.70	5.03
Sei whale[a]	0.43	0.24	0.14	0.06	<0.01	<0.01	0	0	0.65	0.46	0.39	0.27	0.57	0.38	0.29	0.20
Mid-frequency cetaceans																
Atlantic white sided dolphin	0.33	0.16	<0.01	0	0	0	0	0	641.43	440.09	364.66	237.68	355.67	248.02	178.95	110.87
Short-beaked dolphin	0	0	0	0	0	0	0	0	0	0	0	0	66.59	28.78	3.82	0
Bottlenose dolphin Northern Coastal	3.08	0.97	0.13	0	0	0	0	0	402.14	220.14	152.29	81.44	240.77	145.34	95.40	54.05
Bottlenose dolphin	19.99	4.60	0	0	0	0	0	0	3,814.10	2,133.26	1,417.27	750.51	2,236.12	1,319.48	876.67	495.60
Risso's dolphin	0.05	0.02	0.02	0	0.03	0	0	0	53.67	37.71	31.00	21.93	31.17	21.75	16.21	10.47
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	0	0	0	0	<0.01	0	0	0
High-frequency cetaceans																
Harbor porpoise	75.93	42.11	23.59	6.06	7.81	2.46	0.64	0.22	130.42	90.32	73.39	49.35	460.02	361.31	302.32	237.40
Pinnipeds in water																
Gray seal	14.43	4.12	0.77	<0.01	0.06	0	0	0	79.12	48.75	39.15	24.94	57.62	36.54	28.28	17.02
Harbor seal	15.42	4.34	1.24	0.12	0.12	<0.01	0	0	81.85	51.58	39.42	24.65	59.00	37.81	28.76	17.84

[a] Listed as Endangered under the ESA.

Table G-11. Construction schedule 2.2: the mean number of modeled marine mammals estimated to experience sound levels above exposure criteria for different sound attenuation levels. The schedule includes the installation of both WTG and OSS foundations (Table G-7).

Species	Level A								Level B							
	L_E (NMFS 2018)				L_{pk} (NMFS 2018)				L_p (NMFS 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]	39.20	21.98	12.94	5.54	0.06	0.03	0	0	58.89	42.25	35.46	24.23	51.97	34.30	26.34	18.02
Minke whale	33.84	13.38	4.81	0.84	0.03	0	0	0	77.30	55.48	45.23	29.91	55.31	38.71	31.45	22.16
Humpback whale	7.95	3.93	2.00	0.69	0.01	0	0	0	12.94	8.59	6.69	4.22	10.16	6.75	5.26	3.55
North Atlantic right whale[a] (25% foraging)	2.11	0.86	0.42	0.09	<0.01	0	0	0	4.51	2.93	2.31	1.35	10.23	7.68	6.36	4.77
Sei whale[a]	0.38	0.21	0.12	0.05	<0.01	<0.01	0	0	0.56	0.40	0.34	0.23	0.50	0.33	0.25	0.17
Mid-frequency cetaceans																
Atlantic white sided dolphin	0.29	0.15	0	0	0	0	0	0	564.52	386.91	321.31	208.15	312.69	218.16	157.01	97.12
Short-beaked dolphin	0	0	0	0	0	0	0	0	0	0	0	0	59.12	25.34	0	0
Bottlenose dolphin Northern Coastal	2.31	0.92	0	0	0	0	0	0	361.16	199.31	137.80	69.83	217.20	132.16	85.36	48.05
Bottlenose dolphin	13.13	4.38	0	0	0	0	0	0	3,423.42	1,921.84	1,300.20	639.16	2,018.16	1,193.82	780.12	438.22
Risso's dolphin	0.03	0.02	0.02	0	0.03	0	0	0	50.50	35.27	29.51	20.14	29.22	20.44	15.02	9.57
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	0	0	0	0	0	0	0
High-frequency cetaceans																
Harbor porpoise	70.99	39.24	21.75	5.36	7.25	2.23	0.55	0.21	122.39	84.70	69.00	46.01	432.95	339.87	284.24	223.13
Pinnipeds in water																
Gray seal	12.63	3.58	0.66	0	0.06	0	0	0	69.36	42.73	34.35	21.84	50.52	32.04	24.79	14.91
Harbor seal	13.49	3.78	1.08	0.11	0.11	0	0	0	71.76	45.21	34.59	21.58	51.73	33.15	25.22	15.64

[a] Listed as Endangered under the ESA.

G.2.3. Sea Turtle Exposure Range Estimates

Similar to the results presented for marine mammals (see Appendix G.2.1), Tables G-12 to G-13 contain the exposure ranges ($ER_{95\%}$) for sea turtles to injury and behavioral criteria thresholds for monopile and jacket foundations considering broadband mitigation of 0, 6, 10, and 15 dB attenuation. The tables in this section are for foundation types not included in the 2-year construction schedules described in Table 3.

Table G-12. Monopile foundation (12 m diameter, 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]	0.84	0.26	0.02	<0.01	0	0	0	0	2.91	1.89	1.24	0.49
Leatherback turtle[a]	0.93	0.28	0.02	0.02	0	0	0	0	2.57	1.67	0.92	0.47
Loggerhead turtle	0.45	<0.01	0	0	0	0	0	0	2.39	1.55	0.94	0.47
Green turtle	1.32	0.35	0.07	<0.01	0	0	0	0	2.97	1.88	1.34	0.67

[a] Listed as Endangered under the ESA.

Table G-13. Monopile foundation (12 m diameter, 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]	0.85	0.28	0.03	<0.01	0	0	0	0	2.80	1.90	1.23	0.63
Leatherback turtle[a]	0.88	0.13	0.03	0.02	0	0	0	0	2.66	1.71	1.14	0.43
Loggerhead turtle	0.30	0.02	0	0	0	0	0	0	2.46	1.50	1.01	0.65
Green turtle	1.32	0.35	0.09	<0.01	0	0	0	0	2.94	2.00	1.36	0.68

[a] Listed as Endangered under the ESA.

Table G-14. Monopile foundation (15 m diameter, 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]	1.10	0.41	0.04	0.03	<0.01	0	0	0	2.93	1.92	1.28	0.65
Leatherback turtle[a]	0.90	0.21	0.04	0.02	0	0	0	0	2.73	1.75	1.28	0.49
Loggerhead turtle	0.41	0.05	0	0	0	0	0	0	2.55	1.57	1.10	0.62
Green turtle	1.36	0.68	0.22	<0.01	0	0	0	0	2.94	1.97	1.34	0.64

[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-15 to G-16) are estimated for the yearly construction schedules described in Tables G-6 and G-7. Results include the WTG monopile and WTG jacket foundation schedules considering broadband mitigation of 0, 6, 10, and 15 dB attenuation, and are calculated in the same way as the marine mammals exposure estimates (see Appendix G.2.2).

Table G-15. Construction schedule 1.1: 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 OSS foundations (Table G-6).

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]	19.35	4.57	1.06	0.57	0	0	0	0	69.12	37.47	22.81	10.05
Leatherback turtle[a]	7.39	1.55	0.52	0.26	0	0	0	0	41.78	22.77	13.50	5.19
Loggerhead turtle	83.18	10.31	0	0	0	0	0	0	2,857.72	1,285.80	658.96	245.17
Green turtle	0.71	0.21	0.05	0.01	<0.01	0	0	0	2.03	1.06	0.62	0.29

[a] Listed as Endangered under the ESA.

Table G-16. Construction schedule 1.2: 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 OSS foundations (Table G-6).

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]	17.00	4.62	0.84	0.63	0	0	0	0	58.35	34.00	22.67	10.07
Leatherback turtle[a]	6.15	1.30	0.47	0.24	0	0	0	0	35.11	19.98	12.06	4.61
Loggerhead turtle	72.11	10.30	0	0	0	0	0	0	2,317.85	1,169.23	618.09	226.63
Green turtle	0.68	0.25	0.05	0.01	<0.01	0	0	0	1.83	1.06	0.64	0.32

[a] Listed as Endangered under the ESA.

Table G-17. Construction schedule 2.1: 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 OSS foundations (Table G-7).

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]	18.67	2.95	1.11	0.14	0	0	0	0	80.57	38.18	18.98	7.67
Leatherback turtle[a]	6.70	1.23	0.30	0.15	0	0	0	0	48.68	20.71	10.50	4.46
Loggerhead turtle	77.41	7.37	0	0	0	0	0	0	3,431.75	1,309.18	641.69	224.91
Green turtle	0.67	0.12	0.03	0.02	0	0	0	0	2.21	0.92	0.52	0.17

[a] Listed as Endangered under the ESA.

Table G-18. Construction schedule 2.2: 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 OSS foundations (Table G-7).

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]	15.22	2.17	0.87	0	0	0	0	0	71.09	33.26	16.31	6.30
Leatherback turtle[a]	5.34	0.95	0.24	0.12	0	0	0	0	41.78	17.56	8.78	3.80
Loggerhead turtle	59.15	5.38	0	0	0	0	0	0	3,006.10	1,129.31	553.90	182.84
Green turtle	0.57	0.10	0.02	0.02	0	0	0	0	1.98	0.78	0.44	0.13

[a] Listed as Endangered under the ESA.

G.2.5. Marine Mammal and Sea Turtle 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-19. Monopile foundation (12 m diameter, 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 (NMFS 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])	79.00	45.00	24.86	10.14	0.71	0.29	0	0	163.71	116.43	93.71	73.86	142.79	94.99	73.60	54.16
Minke whale	212.43	67.43	21.43	4.29	0.43	0	0	0	713.00	535.14	435.57	348.43	532.63	385.51	304.27	234.46
Humpback whale	82.00	42.57	22.71	6.29	0.57	0.14	0.14	0	184.00	130.43	100.00	76.29	146.66	102.37	78.23	57.44
North Atlantic right whale[a] (25% foraging)	82.57	29.43	11.71	2.57	0.29	0	0	0	269.00	192.71	151.57	112.00	537.30	417.50	347.01	271.83
Mid-frequency cetaceans																
Atlantic white sided dolphin	0	0	0	0	0	0	0	0	315.57	231.71	188.29	145.71	131.21	88.36	64.09	39.20
Short-beaked common dolphin	0	0	0	0	0	0	0	0	0	0	0	0	7.84	1.40	0	0
Bottlenose dolphin Northern coastal	0	0	0	0	0	0	0	0	82.14	49.43	36.29	23.14	35.16	20.10	13.29	7.06
Bottlenose dolphin	0	0	0	0	0	0	0	0	80.29	50.43	34.43	20.57	32.06	19.40	12.64	6.44
Risso's dolphin	0	0	0	0	0.14	0	0	0	266.71	193.86	156.57	118.71	114.73	76.74	56.81	36.24
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	0	0	0	0	0	0	0	0
High-frequency cetaceans																
Harbor porpoise	47.14	11.57	3.57	0.29	24.71	8.71	4.00	1.43	281.43	198.29	159.57	119.29	808.63	603.69	482.77	364.06
Pinnipeds in water																
Gray seal	4.57	0.57	0.29	0.14	0.29	0.14	0	0	115.14	75.71	56.71	42.71	72.76	46.61	34.47	22.57
Harbor seal	6.43	0.43	0.14	0	0.14	0.14	0	0	124.57	81.00	62.43	46.57	77.76	49.66	37.51	24.16

[a] Endangered species.
[b] Fin whale used as a surrogate for sei whale behavioral definition.

Table G-20. Monopile foundation (12 m diameter, 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 (NMFS 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])	147.57	85.00	49.57	17.00	1.43	0.14	0	0	292.71	214.71	175.43	141.43	245.73	167.40	132.84	99.01
Minke whale	420.14	134.00	36.29	8.43	2.57	0.14	0	0	1,324.00	1,019.14	842.86	673.00	973.04	714.20	574.59	442.31
Humpback whale	150.14	74.86	38.14	11.86	1.43	0	0	0	338.00	231.00	180.00	136.14	262.04	180.81	140.84	103.17
North Atlantic right whale[a] (25% foraging)	169.57	66.86	28.43	6.00	0.29	0	0	0	543.14	387.14	306.71	226.43	1,010.41	793.21	670.19	532.64
Mid-frequency cetaceans																
Atlantic white sided dolphin	0	0	0	0	0	0	0	0	574.71	422.43	346.86	270.14	236.53	162.36	117.40	72.60
Short-beaked common dolphin	0	0	0	0	0	0	0	0	0	0	0	0	14.27	2.99	0	0
Bottlenose dolphin Northern coastal	0	0	0	0	0	0	0	0	153.86	97.00	66.00	44.43	60.76	37.39	25.89	13.79
Bottlenose dolphin	0	0	0	0	0	0	0	0	151.57	97.14	65.71	40.43	59.17	35.63	23.89	13.19
Risso's dolphin	0	0	0	0	0	0	0	0	500.14	373.14	304.00	241.57	213.41	148.63	109.73	70.83
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	0	0	0	0	0	0	0
High-frequency cetaceans																
Harbor porpoise	98.43	22.00	5.14	1.00	46.00	16.57	6.00	2.00	529.00	393.00	313.14	240.71	1,273.84	977.83	812.01	632.59
Pinnipeds in water																
Gray seal	7.57	1.14	0	0	0.71	0	0	0	217.57	145.71	109.43	76.57	129.63	82.59	62.57	42.46
Harbor seal	11.14	1.57	0.29	0.14	1.29	0.43	0	0	225.86	152.43	115.14	83.00	134.21	88.31	66.83	43.59

[a] Endangered species.
[b] Fin whale used as a surrogate for sei whale behavioral definition.

Table G-21. Monopile foundation (15 m diameter, 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 (NMFS 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])	88.71	54.29	33.43	14.14	1.00	0	0	0	177.43	129.14	104.14	82.00	156.04	106.00	82.71	60.73
Minke whale	259.86	96.00	30.57	5.86	0.43	0	0	0	829.71	634.29	519.43	414.14	617.86	454.81	362.07	277.93
Humpback whale	92.29	52.00	27.43	9.29	0.71	0.14	0	0	203.29	144.57	111.71	83.14	160.30	113.21	86.90	63.51
North Atlantic right whale[a] (25% foraging)	101.71	40.29	18.43	4.00	0.57	0.14	0.14	0.14	320.86	232.29	179.29	138.29	597.27	469.20	389.93	311.09
Mid-frequency cetaceans																
Atlantic white sided dolphin	0	0	0	0	0	0	0	0	357.86	266.57	214.29	167.29	143.44	97.90	73.07	46.00
Short-beaked common dolphin	0	0	0	0	0	0	0	0	0	0	0	0	8.20	1.79	0	0
Bottlenose dolphin Northern coastal	0	0	0	0	0	0	0	0	87.29	52.29	37.86	24.86	34.80	20.50	13.77	7.53
Bottlenose dolphin	0.14	0	0	0	0	0	0	0	84.00	52.86	35.86	22.43	32.39	19.61	13.19	7.17
Risso's dolphin	0	0	0	0	0	0	0	0	302.43	222.71	179.86	138.00	125.07	85.73	64.67	41.06
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	0	0	0	0	0	0	0	0
High-frequency cetaceans																
Harbor porpoise	54.14	15.71	2.57	0.43	33.71	14.71	7.43	1.71	317.29	232.43	188.43	143.43	820.39	616.33	501.84	380.70
Pinnipeds in water																
Gray seal	5.71	1.14	0.14	0.14	0.29	0	0	0	125.71	84.71	61.71	46.14	77.66	49.33	37.07	25.40
Harbor seal	8.43	1.14	0.14	0	0.71	0.14	0	0	134.00	89.00	67.43	50.57	82.14	52.87	40.00	27.49

[a] Endangered species.
[b] Fin whale used as a surrogate for sei whale behavioral definition.

Table G-22. Monopile foundation (15 m diameter, 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 (NMFS 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])	172.86	100.00	59.43	24.86	1.57	0.29	0	0	318.86	242.43	200.86	159.71	271.21	187.14	149.50	112.44
Minke whale	502.71	181.86	54.71	12.29	3.57	0.14	0	0	1,507.00	1,181.86	979.43	786.14	1,105.13	827.36	665.01	512.80
Humpback whale	179.14	93.14	49.00	16.86	2.00	0.29	0.14	0.14	376.57	268.57	210.57	159.86	289.60	203.91	159.24	118.43
North Atlantic right whale[a] (25% foraging)	206.29	86.71	36.86	9.29	0.43	0	0	0	619.86	450.86	355.57	267.86	1,095.31	867.89	737.89	593.73
Mid-frequency cetaceans																
Atlantic white sided dolphin	0	0	0	0	0	0	0	0	638.57	489.57	401.71	316.00	262.54	182.23	136.29	85.69
Short-beaked common dolphin	0	0	0	0	0	0	0	0	0	0	0	0	15.07	3.21	0	0
Bottlenose dolphin Northern coastal	0	0	0	0	0	0	0	0	159.86	101.43	70.00	46.71	61.93	38.44	26.21	14.90
Bottlenose dolphin	0	0	0	0	0	0	0	0	157.43	101.57	69.29	42.86	59.47	36.99	24.67	14.31
Risso's dolphin	0.14	0	0	0	0	0	0	0	552.43	420.00	345.43	274.86	231.87	162.77	123.81	81.80
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	0	0	0	0	0	0	0
High-frequency cetaceans																
Harbor porpoise	103.00	18.57	3.86	0.29	55.86	19.43	7.14	2.71	592.29	446.86	360.29	280.14	1,283.34	998.43	831.89	664.17
Pinnipeds in water																
Gray seal	9.71	1.14	0	0	1.00	0.14	0	0	232.43	158.43	119.43	86.86	135.77	89.67	68.57	46.43
Harbor seal	15.14	2.29	0.29	0.14	1.57	0.29	0	0	245.29	166.43	125.43	90.86	143.70	94.91	71.74	48.91

[a] Endangered species.
[b] Fin whale used as a surrogate for sei whale behavioral definition.

Table G-23. Pre-piled jacket foundation (5 m diameter pin piles, 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 (NMFS 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])	174.00	97.57	57.43	24.57	0.29	0.14	0	0	261.43	187.57	157.43	107.57	230.71	152.27	116.94	79.97
Minke whale	579.86	229.29	82.43	14.43	0.43	0	0	0	1,324.71	950.71	775.14	512.57	947.81	663.46	539.01	379.77
Humpback whale	217.29	107.57	54.57	18.86	0.29	0	0	0	353.86	234.71	182.86	115.43	277.83	184.51	143.89	97.10
North Atlantic right whale[a] (25% foraging)	258.57	105.14	51.00	11.00	0.14	0	0	0	552.29	358.29	282.29	165.00	1,252.40	940.07	778.11	583.76
Mid-frequency cetaceans																
Atlantic white sided dolphin	0.29	0.14	0	0	0	0	0	0	554.43	380.00	315.57	204.43	307.10	214.26	154.20	95.39
Short-beaked common dolphin	0	0	0	0	0	0	0	0	0	0	0	0	20.53	8.80	0	0
Bottlenose dolphin Northern coastal	0.71	0.29	0	0	0	0	0	0	111.57	61.57	42.57	21.57	67.10	40.83	26.37	14.84
Bottlenose dolphin	0.43	0.14	0	0	0	0	0	0	111.71	62.71	42.43	20.86	65.86	38.96	25.46	14.30
Risso's dolphin	0.29	0.14	0.14	0	0.29	0	0	0	469.57	328.00	274.43	187.29	271.69	190.04	139.71	88.96
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	0	0	0	0	0	0	0
High-frequency cetaceans																
Harbor porpoise	295.14	163.14	90.43	22.29	30.14	9.29	2.29	0.86	508.86	352.14	286.86	191.29	1,800.00	1,413.03	1,181.74	927.67
Pinnipeds in water																
Gray seal	32.71	9.29	1.71	0	0.14	0	0	0	179.71	110.71	89.00	56.57	130.90	83.01	64.23	38.63
Harbor seal	35.71	10.00	2.86	0.29	0.29	0	0	0	190.00	119.71	91.57	57.14	136.97	87.77	66.77	41.40

[a] Endangered species.
[b] Fin whale used as a surrogate for sei whale behavioral definition.

Table G-24. Post-piled jacket foundation[a] (5 m diameter pin piles, 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 (NMFS 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])	197.86	121.57	75.57	36.86	0.57	0.14	0	0	297.57	213.29	171.14	133.00	262.34	178.51	133.36	95.29
Minke whale	721.86	338.14	145.14	30.71	1.29	0.14	0	0	1,470.29	1,066.71	855.29	628.29	1,063.21	751.30	593.84	445.59
Humpback whale	261.86	140.71	76.86	32.14	0.57	0.14	0	0	405.00	271.57	206.29	144.71	318.11	212.33	162.89	115.73
North Atlantic right whale[b] (25% foraging)	318.86	143.57	75.14	21.71	0.57	0	0	0	633.00	415.71	317.43	215.43	1,368.40	1,036.57	859.94	660.74
Mid-frequency cetaceans																
Atlantic white sided dolphin	0.29	0.14	0.14	0	0	0	0	0	622.29	435.00	346.43	250.86	351.57	243.01	183.19	116.47
Short-beaked common dolphin	0	0	0	0	0	0	0	0	0	0	0	0	22.39	10.00	6.46	0
Bottlenose dolphin Northern coastal	1.43	0.29	0.14	0	0	0	0	0	136.57	73.43	50.86	30.43	80.96	48.00	32.66	18.77
Bottlenose dolphin	1.14	0.14	0	0	0	0	0	0	137.00	76.00	48.43	30.00	79.34	46.56	32.09	18.39
Risso's dolphin	0.71	0.29	0.14	0	0.29	0	0	0	528.14	374.29	299.71	223.43	308.49	214.53	163.00	107.50
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	0	0	0	0.81	0	0	0
High-frequency cetaceans																
Harbor porpoise	349.29	201.43	126.57	45.57	39.14	15.00	5.57	0.86	572.43	400.43	314.86	234.29	1,946.39	1,539.13	1,296.10	1,022.13
Pinnipeds in water																
Gray seal	43.29	16.57	4.71	0.29	0.29	0	0	0	210.57	131.43	98.00	71.86	151.40	95.44	74.70	47.89
Harbor seal	48.71	17.29	5.71	0.43	0.29	0.14	0	0	221.14	141.14	100.86	73.14	159.10	101.34	77.39	49.97

[a] Post-piled 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-25. Monopile foundation (12 m diameter, 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]	8.71	1.71	0.57	0.14	0	0	0	0	35.43	19.29	11.57	5.14
Leatherback turtle[a]	5.86	1.57	0.29	0.14	0	0	0	0	39.71	20.71	11.29	5.29
Loggerhead turtle	1.29	0.14	0	0	0	0	0	0	57.00	25.71	12.14	4.86
Green turtle	9.29	2.57	1.00	0.14	0	0	0	0	33.86	16.86	9.57	4.71

[a] Listed as Endangered under the ESA.

Table G-26. Monopile foundation (12 m diameter, 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]	17.71	3.14	1.14	0.29	0	0	0	0	73.00	41.43	24.43	9.71
Leatherback turtle[a]	13.14	2.14	0.86	0.29	0	0	0	0	76.43	42.43	23.00	10.29
Loggerhead turtle	1.71	0.29	0	0	0	0	0	0	100.43	47.86	22.14	9.14
Green turtle	20.71	6.14	1.71	0.43	0	0	0	0	62.14	34.14	21.57	9.29

[a] Listed as Endangered under the ESA.

Table G-27. Monopile foundation (15 m diameter, 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]	11.57	3.14	0.57	0.43	0	0	0	0	39.71	23.14	15.43	6.86
Leatherback turtle[a]	7.43	1.57	0.57	0.29	0	0	0	0	42.43	24.14	14.57	5.57
Loggerhead turtle	2.00	0.29	0	0	0	0	0	0	64.29	32.43	17.14	6.29
Green turtle	13.43	4.86	1.00	0.29	0.14	0	0	0	36.14	21.00	12.57	6.43

[a] Listed as Endangered under the ESA.

Table G-28. Monopile foundation (15 m diameter, 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	5.86	1.43	0.43	0.14	0	0	0	81.29	49.43	32.00	15.00
Leatherback turtle[a]	16.14	3.29	1.57	0.29	0	0	0	0	86.71	47.86	28.57	12.43
Loggerhead turtle	3.71	0.29	0	0	0	0	0	0	125.57	63.29	34.86	14.00
Green turtle	26.57	9.43	2.86	0.43	0	0	0	0	67.43	41.00	26.29	12.00

[a] Listed as Endangered under the ESA.

Table G-29. Pre-piled jacket foundation (5 m diameter pin piles, 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]	10.00	1.43	0.57	0	0	0	0	0	46.71	21.86	10.71	4.14
Leatherback turtle[a]	6.43	1.14	0.29	0.14	0	0	0	0	50.29	21.14	10.57	4.57
Loggerhead turtle	1.57	0.14	0	0	0	0	0	0	79.86	30.00	14.71	4.86
Green turtle	10.86	1.86	0.29	0.29	0	0	0	0	37.43	14.86	8.43	2.43

[a] Listed as Endangered under the ESA.

Table G-30. Post-piled jacket foundation[a] (5 m diameter pin piles, 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[b]	15.86	2.86	1.00	0.29	0	0	0	0	60.14	29.14	14.86	6.43
Leatherback turtle[b]	11.86	2.43	0.57	0.29	0	0	0	0	64.29	28.86	15.57	6.14
Loggerhead turtle	2.86	0.29	0	0	0	0	0	0	106.14	41.43	20.29	7.71
Green turtle	15.43	3.00	1.14	0.29	0	0	0	0	47.43	21.14	11.86	4.43

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

G.3. Animat Seeding Area

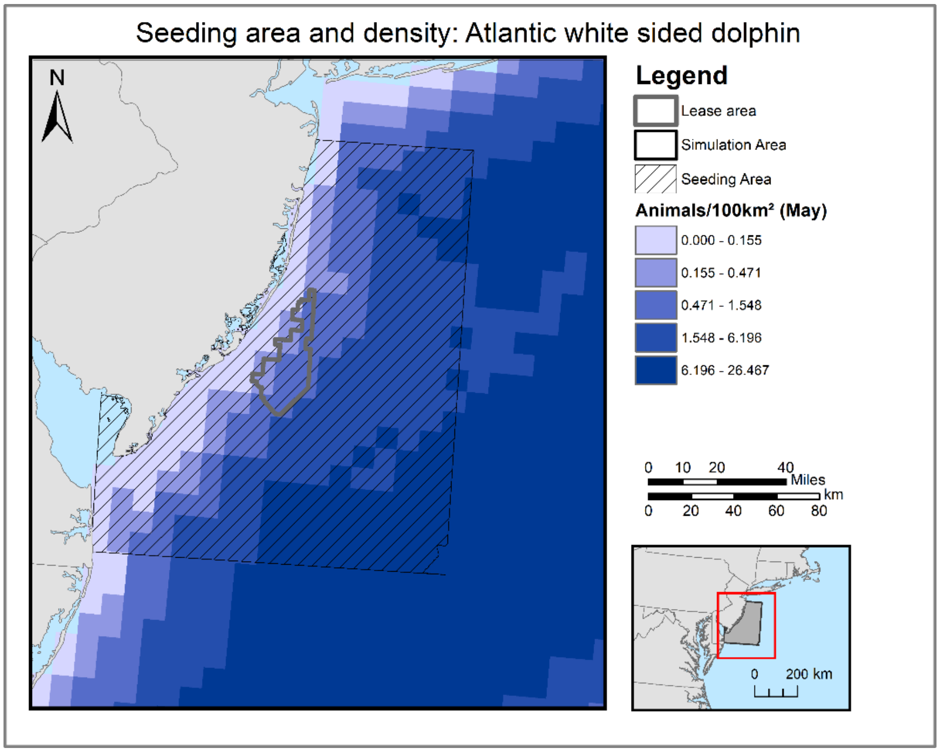

Figure G-1. Map of Atlantic white sided dolphin animat seeding range with density from Roberts et al. (2016) and (2018) for May, the month with the highest density in the simulation.

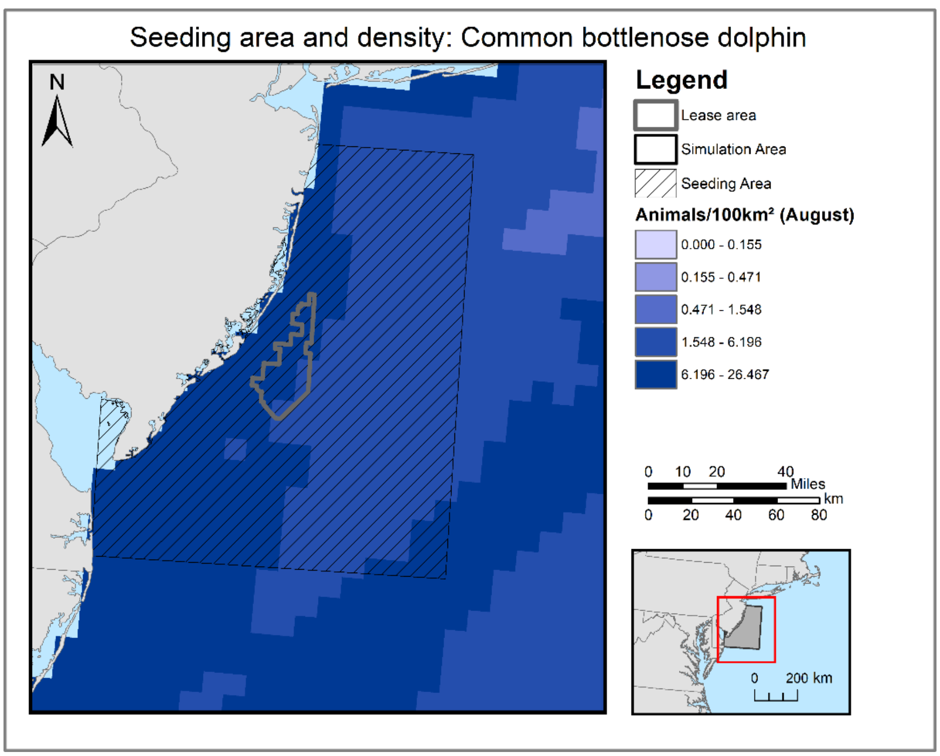

Figure G-2. Map of common bottlenose dolphin animat seeding range with density Roberts et al. (2016) and (2018) for August, the month with the highest density in the simulation.

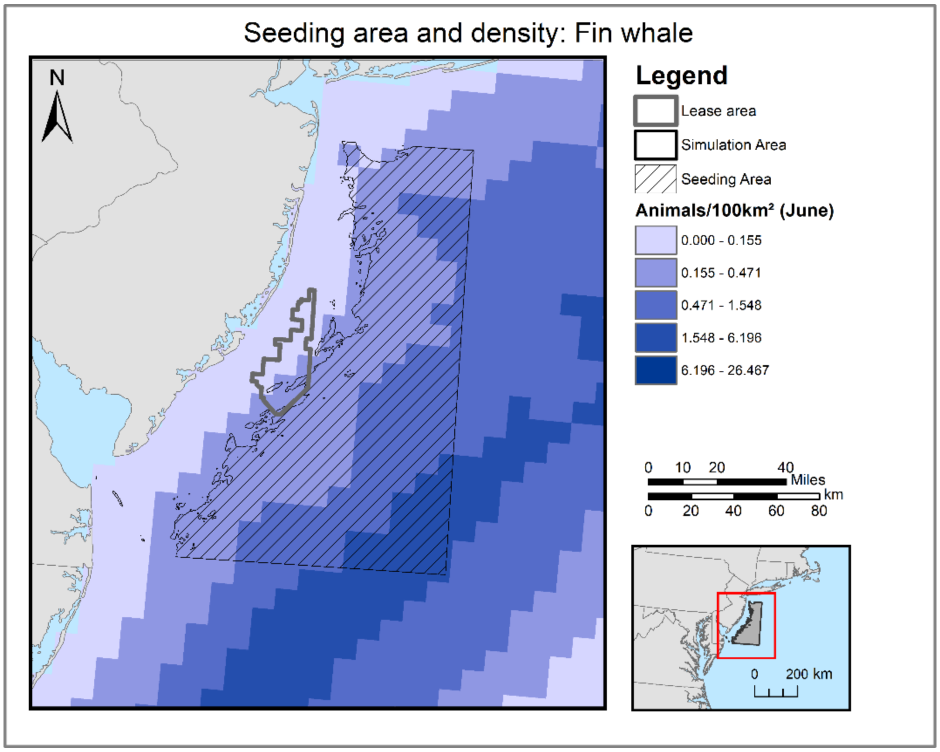

Figure G-3. Map of fin whale animat seeding range with density from Roberts et al. (2016) and (2018) for June, the month with the highest density in the simulation (also used as a surrogate for sei whale).

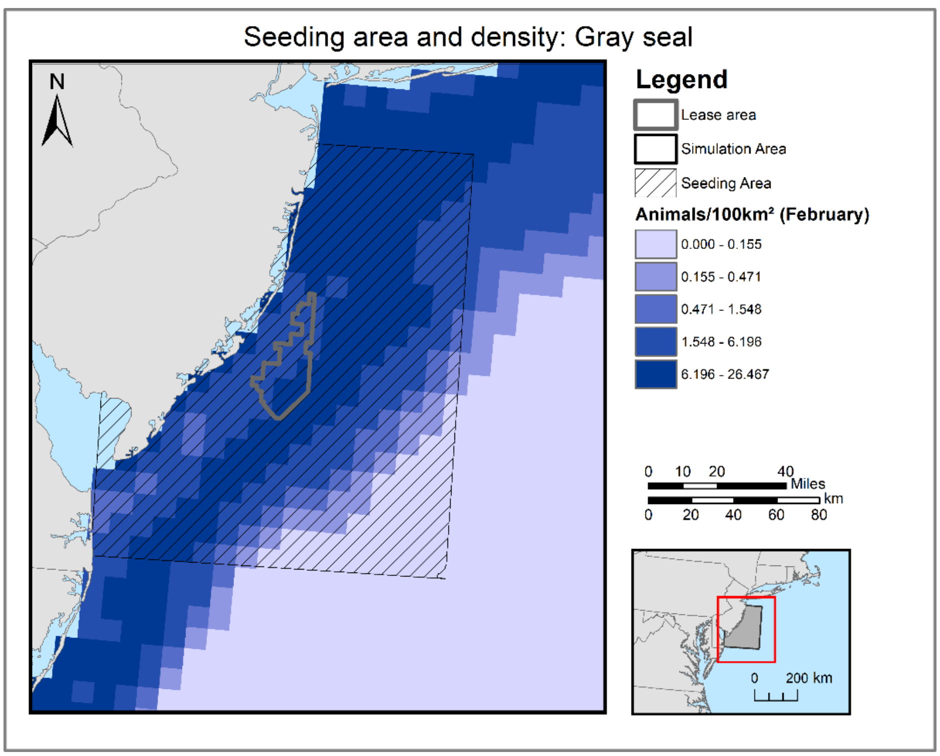

Figure G-4. Map of gray seal animat seeding range with density from Roberts et al. (2016) and (2018) for February, the month with the highest density in the simulation.

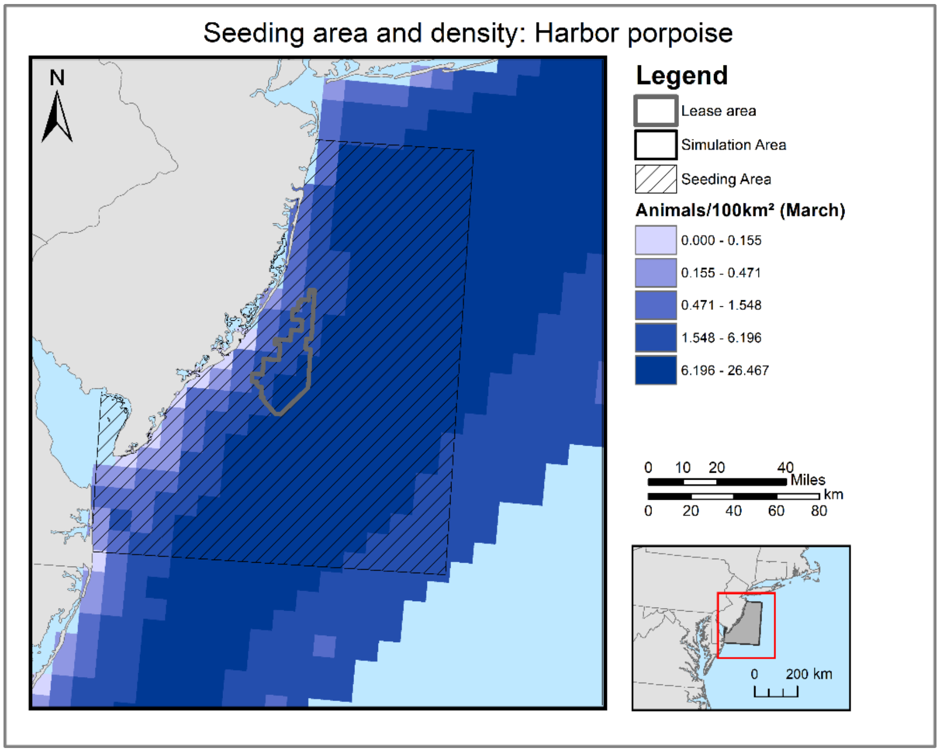

Figure G-5. Map of harbor porpoise animat seeding range with density from Roberts et al. (2016) and (2018) for March, the month with the highest density in the simulation.

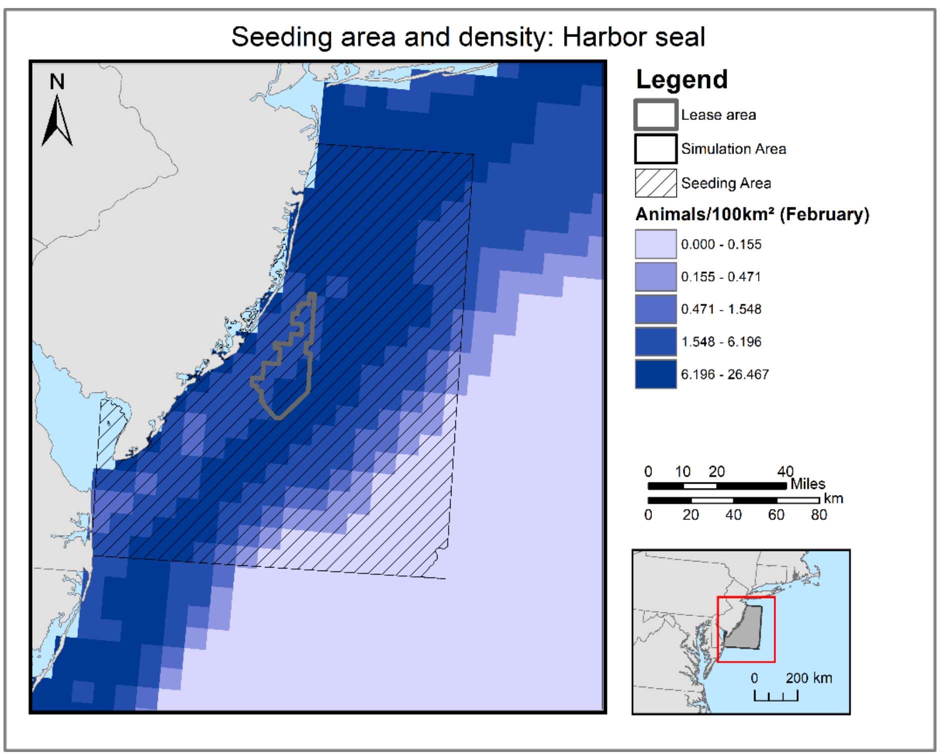

Figure G-6. Map of harbor seal animat seeding range with density from Roberts et al. (2016) and (2018) for February, the month with the highest density in the simulation.

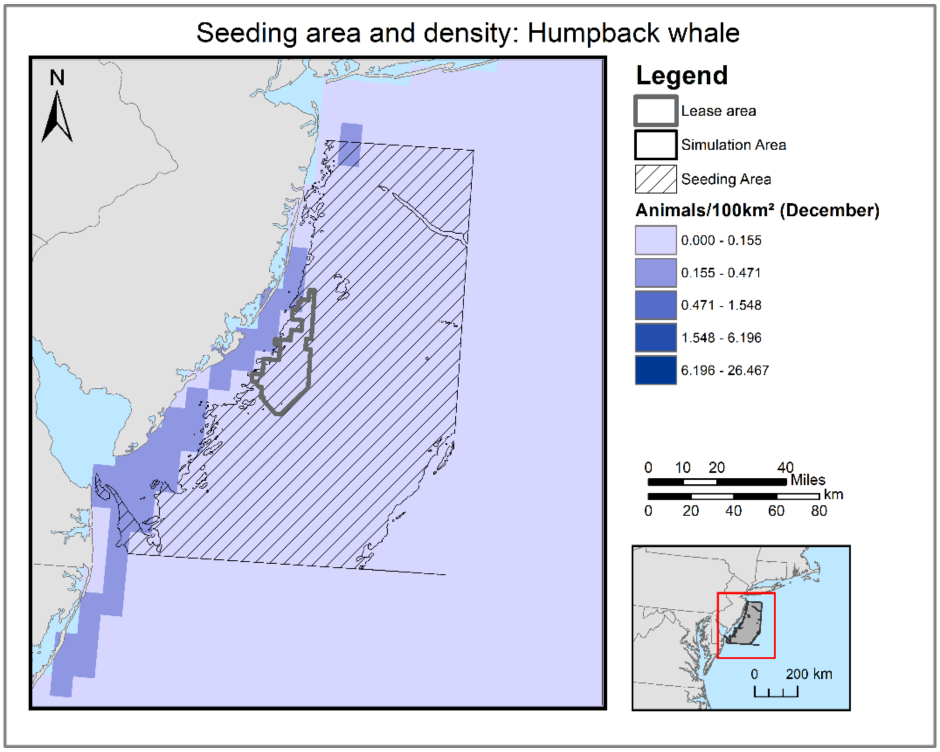

Figure G-7. Map of humpback whale animat seeding range with density from Roberts et al. (2016) and (2018) for December, the month with the highest density in the simulation.

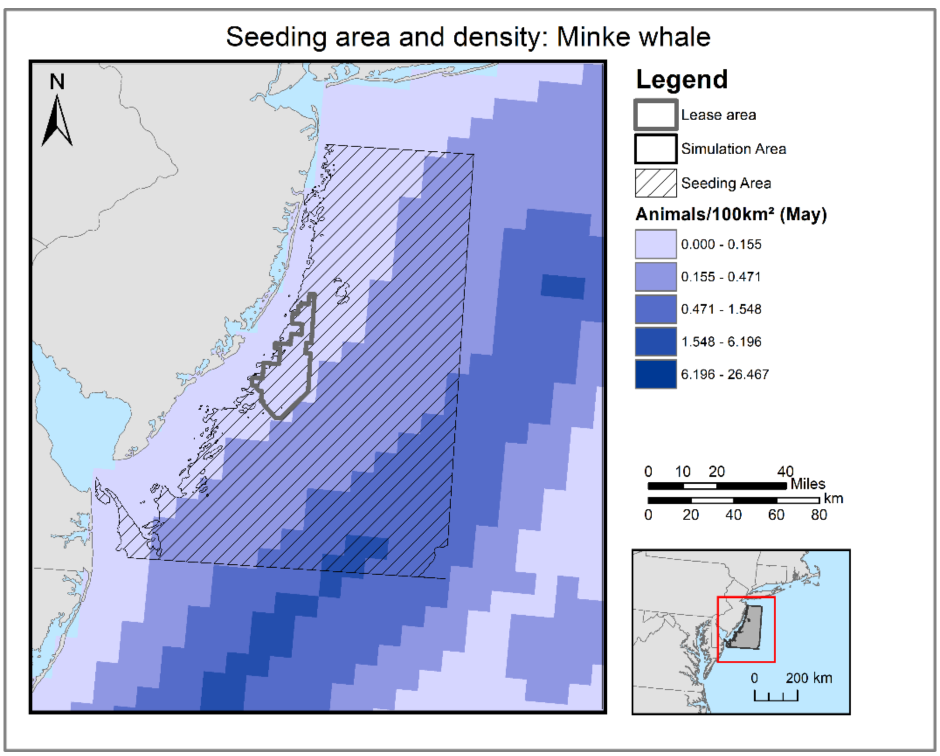

Figure G-8. Map. Map of minke whale animat seeding range with density from Roberts et al. (2016) and (2018) for May, the month with the highest density in the simulation.

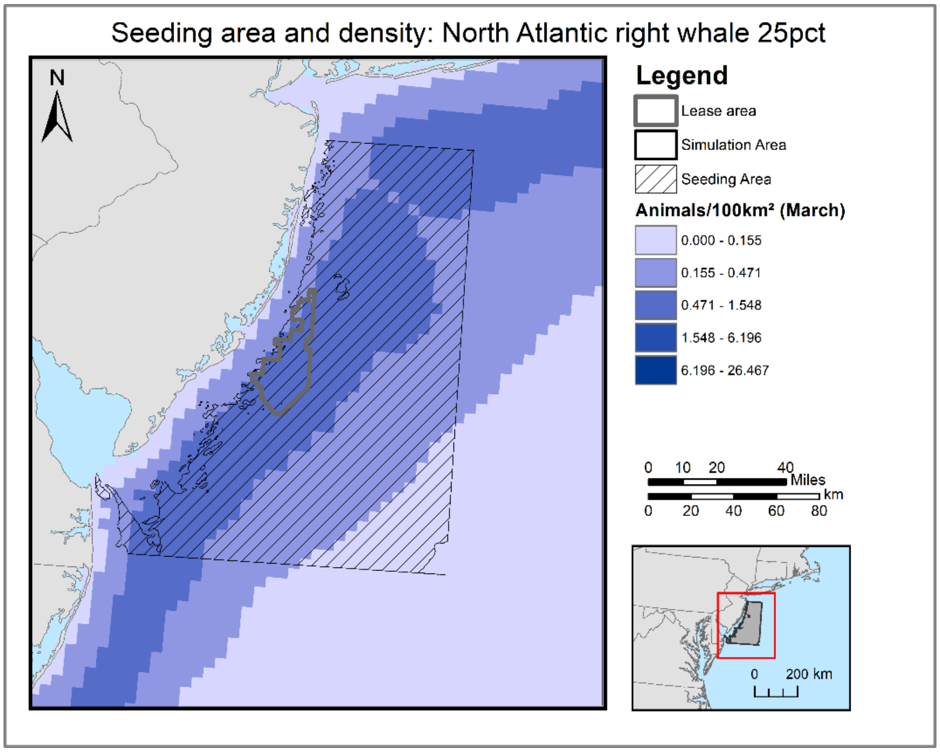

Figure G-9. Map of North Atlantic right whale seeding range with density from Roberts et al. (2020) for March, the month with the highest density in the simulation.

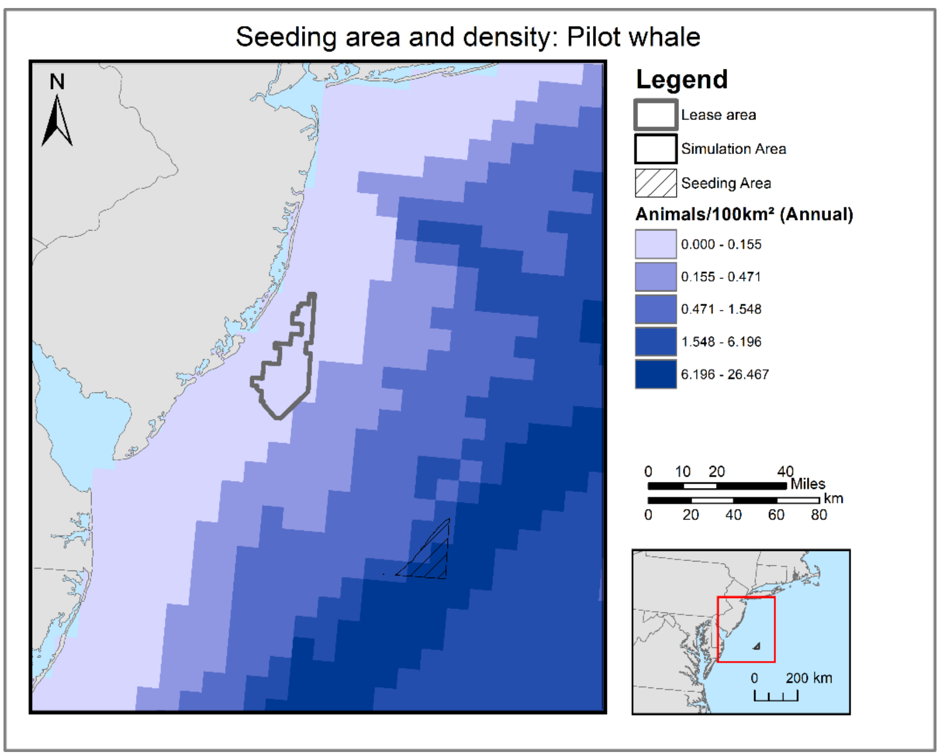

Figure G-10. Map of pilot whale seeding range with density from Roberts et al. (2016) and (2018) for the year.

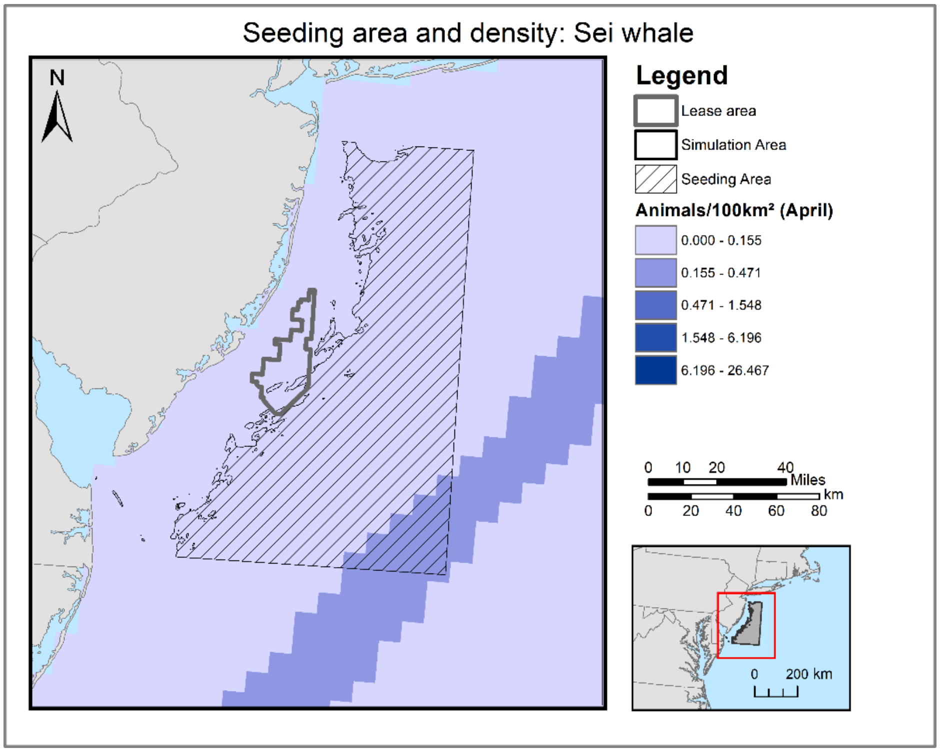

Figure G-11. Map of sei whale seeding range with density from Roberts et al. (2016) and (2018) for April, the month with the highest density in the simulation.

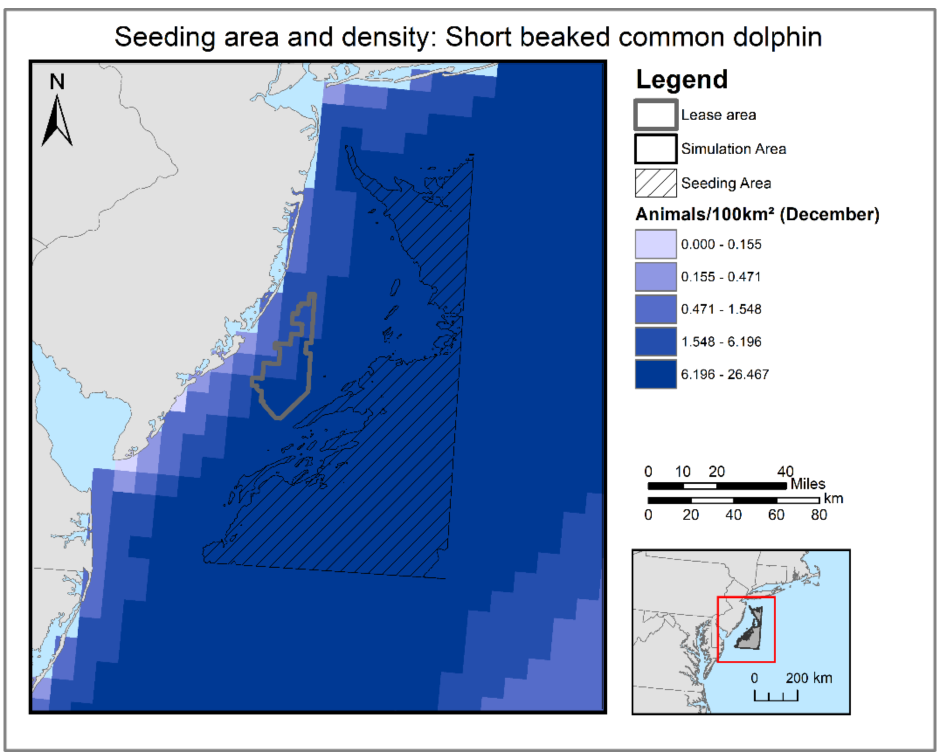

Figure G-12. Map of short beaked common dolphin seeding range with density from Roberts et al. (2016) and (2018) for December, the month with the highest density in the simulation.

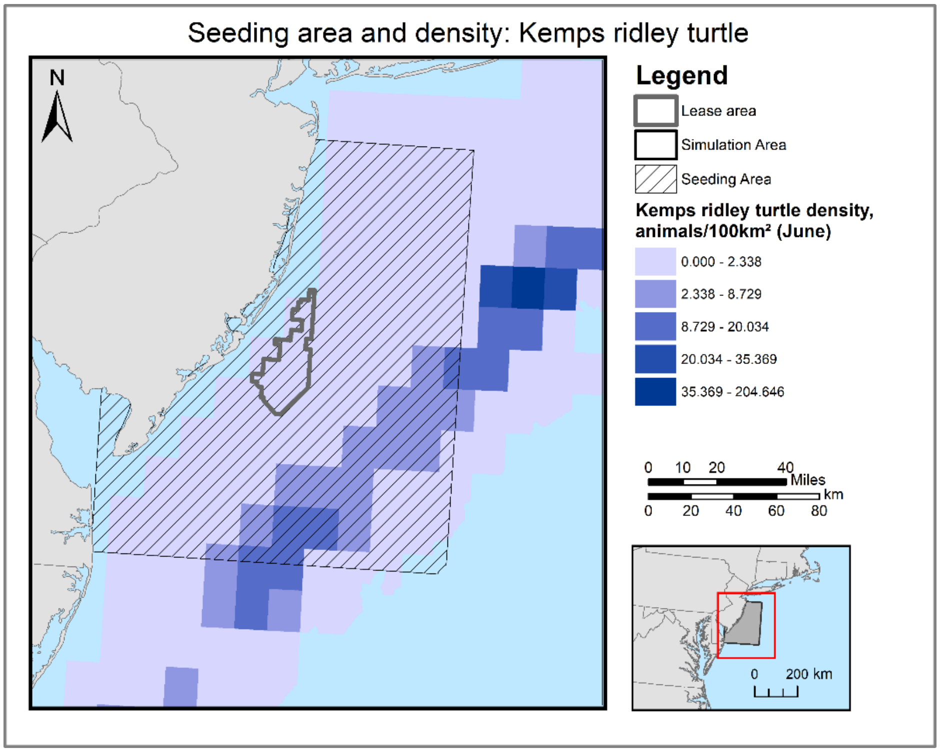

Figure G-13. Map of Kemps ridley turtle seeding range with density from DoN (2017) for summer, the season with the highest density. Densities used in exposure modeling were calculated from NYSERDA aerial survey reports (Normandeau Associates and APEM 2018, 2019a, 2019b, 2019, 2020).

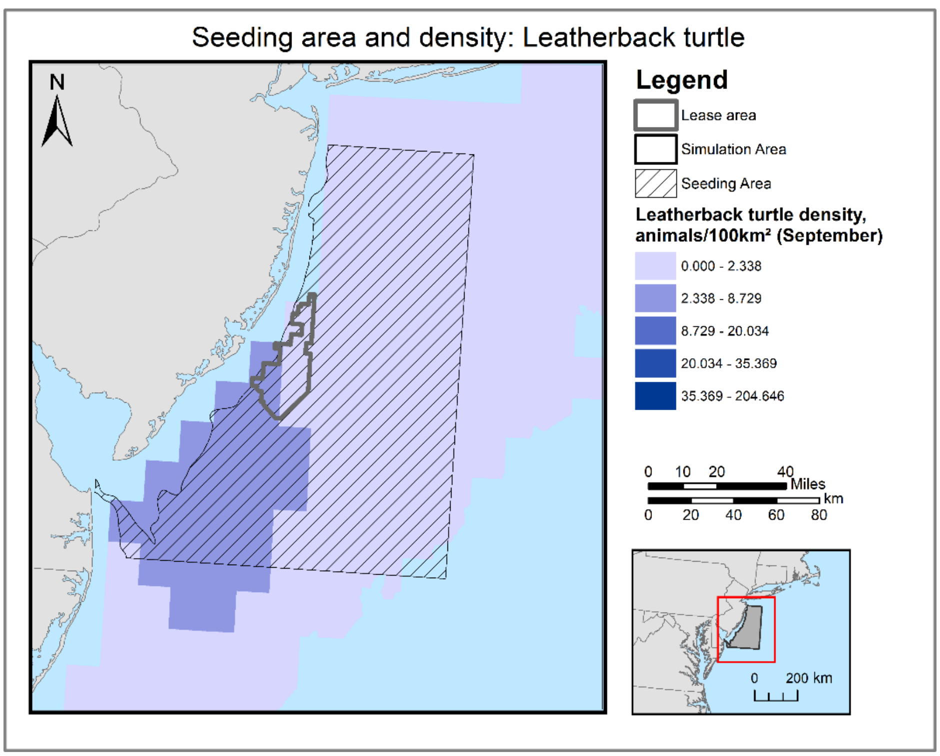

Figure G-14. Map of leatherback turtle seeding range with density from DoN (2017) for fall, the season with the highest density. Densities used in exposure modeling were calculated from NYSERDA aerial survey reports (Normandeau Associates and APEM 2018, 2019a, 2019b, 2019, 2020).

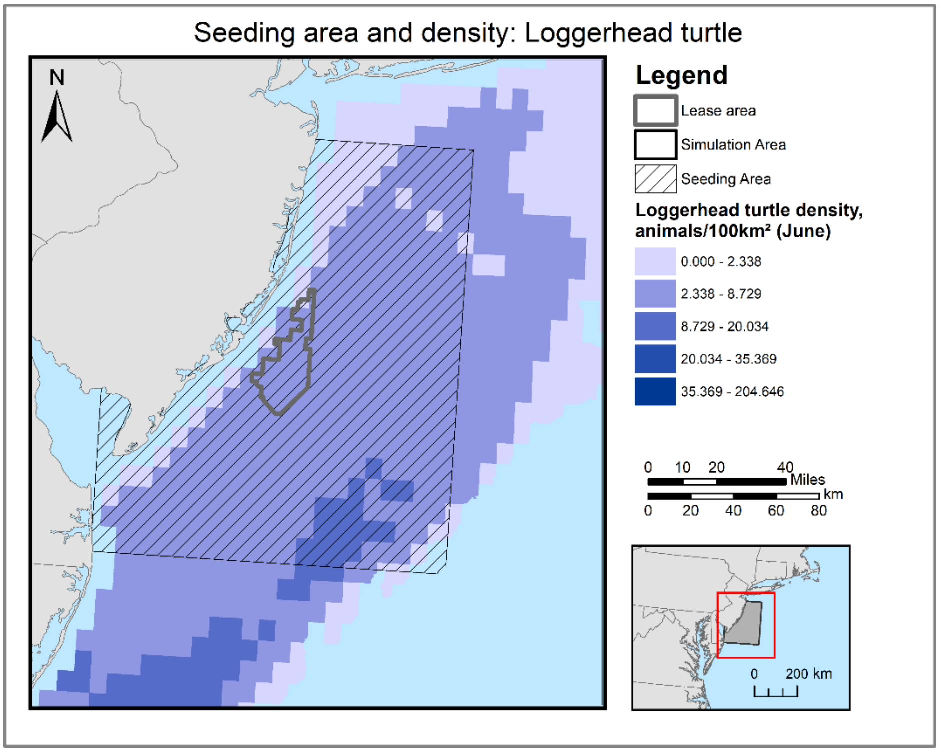

Figure G-15. Map of loggerhead turtle seeding range with density from DoN (2017) for summer, the season with the highest density. Densities used in exposure modeling were calculated from NYSERDA aerial survey reports (Normandeau Associates and APEM 2018, 2019a, 2019b, 2019, 2020).

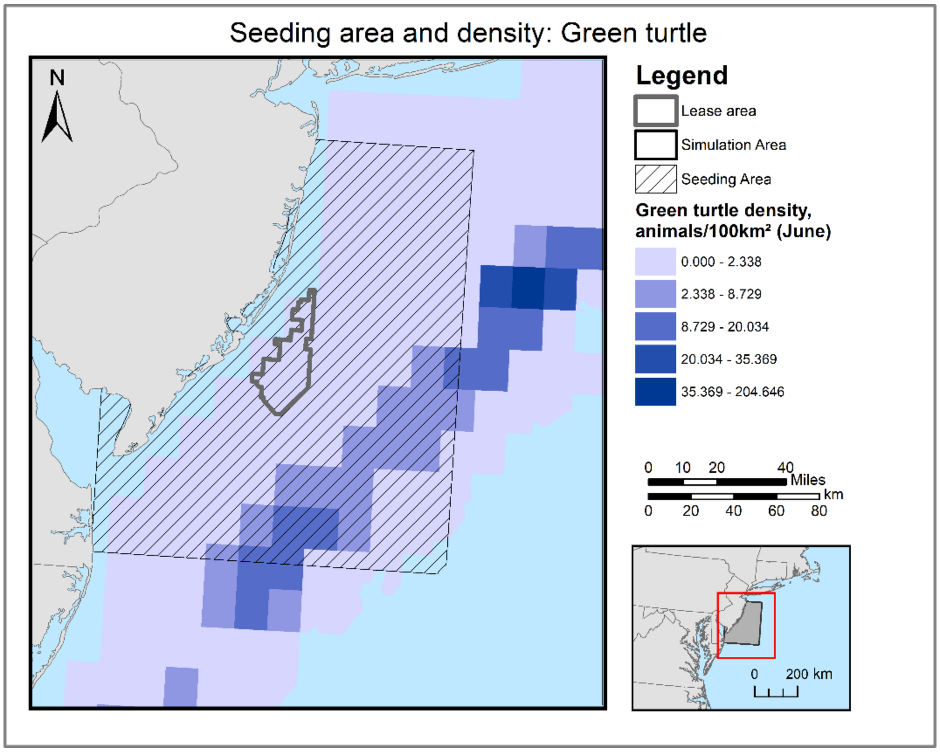

Figure G-16. Map of green turtle seeding range with density from DoN (2017) for summer, showing Kemps ridley sea turtle density as an example. Densities used in exposure modeling were calculated from NYSERDA aerial survey reports (Normandeau Associates and APEM 2018, 2019a, 2019b, 2019, 2020).