New England Wind

AVANGRID RENEWABLES

Construction and Operations Plan

Lease Area OCS-A 0534

Volume III Appendices

July 2022

Submitted by
Park City Wind LLC

Submitted to
Bureau of Ocean Energy Management
45600 Woodland Rd
Sterling, VA 20166

Prepared by
Epsilon Associates, Inc.

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In Association with:

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July 2022

Appendix III-M – Assessing the Potential Acoustic Impact on Marine Fauna during Construction of New England Wind

Assessing the Potential Acoustic Impact on Marine Fauna during Construction of New England Wind

JASCO Applied Sciences (USA) Inc.

22 June 2022

Submitted to:

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Amendment #2

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P001398-007
Document 01959
Version 9.0

Suggested citation:

Küsel, E.T., M.J. Weirathmueller, S.G. Dufault, K.E. Zammit, M.L. Reeve, M.E. Clapsaddle, K.E. Limpert, and D.G. Zeddies. 2022. *Assessing the Potential Acoustic Impact on Marine Fauna during Construction of New England Wind*. Document 01959, Version 9.0. Technical report by JASCO Applied Sciences for Epsilon Associates, Inc.

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Executive Summary

New England Wind is the proposal to develop offshore renewable wind energy facilities in Bureau of Ocean Energy Management (BOEM) Lease Area OCS-A 0534 along with associated offshore and onshore cabling, onshore substations, and onshore operations and maintenance (O&M) facilities. New England Wind will be developed in two Phases with a maximum of 130 wind turbine generator (WTG) and electrical service platform (ESP) positions. Two positions may potentially have co-located ESPs (i.e., two foundations installed at one grid position[1]), resulting in 132 foundations. Four or five offshore export cables will transmit electricity generated by the WTGs to onshore transmission systems in the Town of Barnstable, Massachusetts. Figure 1 provides an overview of New England Wind. Park City Wind LLC, a wholly owned subsidiary of Avangrid Renewables, LLC, is the Proponent and will be responsible for the construction, operation, and decommissioning of New England Wind.

New England Wind's offshore renewable wind energy facilities are located immediately southwest of Vineyard Wind 1, which is located in Lease Area OCS-A 0501. New England Wind will occupy all of Lease Area OCS-A 0534 and potentially a portion of Lease Area OCS-A 0501 in the event that Vineyard Wind 1 does not develop "spare" or extra positions included in Lease Area OCS-A 0501 and Vineyard Wind 1 assigns those positions to Lease Area OCS-A 0534. For the purposes of the COP, the Southern Wind Development Area (SWDA) is defined as all of Lease Area OCS-A 0534 and the southwest portion of Lease Area OCS-A 0501, as shown in Figure 1.

The SWDA may be approximately 411–453 square kilometers (km^2) (101,590–111,939 acres) in size depending upon the final footprint of Vineyard Wind 1. At this time, the Proponent does not intend to develop the two positions in the separate aliquots located along the northeastern boundary of Lease Area OCS-A 0501 as part of New England Wind (see Figure 1). The SWDA (excluding the two separate aliquots that are closer to shore) is just over 32 kilometers (km) (20 miles [mi]) from the southwest corner of Martha's Vineyard and approximately 38 km (24 mi) from Nantucket.[2] The WTGs and ESPs in the SWDA will be oriented in an east-west, north-south grid pattern with one nautical mile (NM) (1.85 km) spacing between positions.

Each Phase of New England Wind will be developed and permitted using a Project Design Envelope (the "Envelope"). This allows the Proponent to properly define and bracket the characteristics of each Phase for the purposes of environmental review while maintaining a reasonable degree of flexibility with respect to the selection of key components, such as the WTGs, foundations, offshore cables, and ESPs. To assess potential impacts and benefits to various resources, a "maximum design scenario," or the design scenario with the maximum impacts anticipated for that resource, is established considering the Envelope parameters for each Phase. Two impact piling construction schedules were established based on the characteristics described within the Envelope that have the potential to cause the greatest effect. For some resources, this approach overestimates potential environmental impacts as the maximum design scenario is not the scenario that the Proponent is likely to employ.

[1] If co-located ESPs are used, each ESP's monopile foundation would be located within 76 m (250 ft) of one of the potential ESP grid locations (i.e. the monopiles would be separated by up to 152 m [500 ft]).

[2] Within the SWDA, the closest WTG is approximately 34 km (21 mi) from Martha's Vineyard and 40 km (25 mi) from Nantucket.

Phase 1 of New England Wind (Park City Wind)

Phase 1, also known as Park City Wind, will be developed immediately southwest of the Vineyard Wind 1 Project. The Phase 1 Envelope allows for 41 to 62 WTGs and one or two ESP(s). Depending upon the capacity of the WTGs, Phase 1 will occupy 150–231 km^2 (37,066–57,081 acres) of the SWDA. The Phase 1 Envelope includes two WTG foundation types: monopiles and piled jackets. Strings of WTGs will connect with the ESP(s) via a submarine inter-array cable transmission system. The ESP(s) will include step-up transformers that increase the voltage of power generated by the WTGs prior to transmission and other electrical equipment. The ESP(s) will also be supported by a monopile or jacket foundation. Two high-voltage alternating current (HVAC) offshore export cables up to 101 km (54 NM) in length (per cable) installed within the SWDA and an Offshore Export Cable Corridor (OECC) will transmit electricity from the ESP(s) to a landfall site at the Craigville Public Beach or Covell’s Beach in the Town of Barnstable. Underground onshore export cables, located principally in roadway layouts, will connect the landfall site to a new Phase 1 onshore substation in Barnstable. Grid interconnection cables will then connect the Phase 1 onshore substation to the ISO New England (ISO-NE) electric grid at Eversource’s existing 345 kilovolt substation in West Barnstable.

Phase 2 of New England Wind (Commonwealth Wind)

Phase 2, also known as Commonwealth Wind, will be immediately southwest of Phase 1 and will occupy the remainder of the SWDA. Phase 2 may include one or more Projects, depending on market conditions. The footprint and total number of WTG and ESP positions in Phase 2 depends upon the final footprint of Phase 1; Phase 2 is expected to contain 64 to 88 WTG/ESP positions (up to three positions will be occupied by ESPs) within an area ranging from 222–303 km^2 (54,857– 74,873 acres). The Phase 2 Envelope includes three general WTG foundation types: monopiles, jackets (with piles or suction buckets), or bottom-frame foundations (with piles or suction buckets). Inter-array cables will transmit electricity from the WTGs to the ESP(s).

Two or three HVAC offshore export cables, each with a maximum length of 116–124 km (63–67 NM) per cable, will transmit power from the ESP(s) to shore. The Proponent intends to install all Phase 2 offshore export cables within the same OECC as the Phase 1 cables from the northwestern corner of the SWDA to within approximately 2–3 km (1–2 mi) of shore, at which point the OECC for each Phase will diverge to reach separate landfall sites in Barnstable. However, the Proponent has also identified two variations of the Phase 2 OECC in the event that technical, logistical, grid interconnection, or other unforeseen issues arise during the COP review and engineering processes that preclude one or more Phase 2 offshore export cables from being installed within all or a portion of the OECC. These variations of the Phase 2 OECC—the Western Muskeget Variant and the South Coast Variant—are shown on Figure 2.

Underground onshore export cables, located primarily within existing roadway layouts, will connect the landfall site(s) to one or two new onshore substations in the Town of Barnstable. Grid interconnection cables will then connect the onshore substation site(s) to the West Barnstable Substation. If the Phase 2 OECC South Coast Variant is employed and electricity generated by Phase 2 is delivered to a second grid interconnection point, Phase 2 could include one onshore transmission system in Barnstable and/or an onshore transmission system(s) in proximity to the second grid interconnection point.

For both Phases, to support construction and operation activities, the Proponent will use a combination of North Atlantic ports in Massachusetts, Rhode Island, Connecticut, New York, New Jersey, and/or Canada. During appropriate time periods, New England Wind-related vessels traveling to/from Salem Harbor will transit at 18.4 km per hour (10 knots) or less within NOAA-designated North Atlantic right whale critical habitat and outside critical habitat.

The primary sound source associated with New England Wind is impact (impulsive) pile driving during construction. Other sound sources include potential vibratory pile setting, which may be required during installation before impact hammering begins to ensure the pile is stable in the seabed and level for impact hammering; potential drilling, which may be required during pile installation to remove boulders and in cases of pile refusal; high-resolution geophysical (HRG) surveys to verify site conditions, ensure proper installation of components, and inspect depth of cable burial or foundations; and potential detonation of unexploded ordnance (UXO) if encountered and avoidance, physical removal, or alternative combustive removal techniques (e.g., deflagration) are not feasible. Other activities associated with cable-laying and construction vessels could contribute non-impulsive (dredging, dynamic positioning [DP] thrusters) and continuous (vessel propulsion) sound to the environment, but these sounds are considered secondary and are not expected to exceed typical background levels.

During Phase 1 of New England Wind, the Proponent is proposing to install monopile foundations with pile diameters up to 12 meters (m). In Phase 2 of New England Wind, an up to 13 m diameter monopile foundation pile is included in the Envelope. Although the maximum monopile diameter for Phase 2 is 13 m, it is expected that the average size of monopiles in Phase 2 will be close to 12 m. In both Phases, jacket foundations supported by 4 m diameter piles may also be installed. Therefore, for this acoustic analysis, JASCO Applied Sciences (JASCO) modeled the potential acoustic impact resulting from the installation of jacket foundations with 4 m diameter piles and 12 m and 13 m monopile foundations. The 12 m monopile was modeled at 5000 kJ and 6000 kJ hammer energy levels, and the 13 m monopile was modeled at 5000 kJ. Initial source modeling showed minimal difference between the 12 m and 13 m monopile. Given these similarities, the 13 m monopile was not modeled at 6000 kJ for this acoustic assessment and the 12 m monopile with 6000 kJ hammer energy was assumed to be a reasonable replacement in exposure calculations. Acoustic modeling was done at two locations representative of minimum and maximum water depths in the SWDA.

Forcing functions for pile driving were computed for each pile type using GRLWEAP, Pile Dynamics (2010). The resulting forcing functions were used as inputs to JASCO's 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 sound reduction resulting from noise attenuation systems such as bubble curtains, the modeling study included hypothetical broadband attenuation levels of 6, 12, and 18 dB for all impact pile driving.

Results of the acoustic modeling of piling activities are presented as single-strike ranges to a series of nominal sound pressure levels (SPL), sound exposure levels (SEL), and zero-to-peak pressure levels (PK). Range tables are provided for the modeled hammer energies for each pile diameter for an average summer sound speed profile and reported for different species' hearing group frequency weighting functions. These acoustic ranges to various sound isopleths were estimated for permitting and monitoring and mitigation purposes. JASCO's Animal Simulation Model Including Noise Exposure (JASMINE) was used to estimate the 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 near, or in the vicinity of, the proposed piling operations. JASMINE Exposure ranges ($ER_{95\%}$) are reported for each of the three pile diameters and for each species, using an average summer sound speed profile.

The potential 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 to marine mammal injury thresholds are based on relevant regulatory-defined thresholds (NMFS 2018). Injury (FHWG 2008, Andersson et al. 2007, Wysocki et al. 2007, Mueller-Blenkle et al. 2010, Purser and Radford 2011, Popper et al. 2014, Finneran et al. 2017) and behavioral (NOAA 2005, McCauley et al. 2000) thresholds for fish and sea turtles are derived from the best available science. The projected number of animals exposed to sound levels above threshold values was determined by scaling the number of animals exposed to a criterion in the model to reflect local populations using the Duke University Habitat-based Marine Mammal Density Model (Roberts et al. 2016a, 2016b, 2017, 2018, 2021) estimates for each species.

Animal aversion to sound and mechanism for recovery (or resetting) were included in JASMINE for comparison purposes only. Results for aversive versus non-aversive simulations are provided for two sensitive species: North Atlantic right whale (NARW, *Eubalaena glacialis*) and harbor porpoise (*Phocoena phocena*). Mitigation measures were not included in the aversion simulation modeling but are considered in the COP impact assessment.

The analysis for all pile types included noise mitigation and predicted the number of individual animals potentially exposed to sound levels above SEL and PK injury threshold criteria for Phases 1 and 2 of New England Wind. For NARW, a simulation with conservative assumptions and no mitigation other than 10 dB of noise attenuation resulted in fewer than four potential injurious exposures total combined for both Phases. Results from exposure simulations show that SEL threshold criteria may be exceeded at approximately 3.16 km.

Using the modeled sound fields in combination with behavioral thresholds and animal density data, sound levels were predicted to exceed behavioral threshold levels for a low number of individual animals for most species using mean animal densities. The model results predicted that fewer than 11 NARW might be exposed to levels of sound capable of eliciting behavioral response assuming 10 dB noise attenuation. The exposure range for NARW could range up to 6.0 km. In studies of mysticetes, received levels, distance from the source, and behavioral context are known to influence the probability of behavioral response (Dunlop et al. 2017).

All species of sea turtles that may be present in the SWDA are listed as threatened or endangered. Many species of sea turtle prefer coastal waters; however, both the loggerhead and leatherback are known to occupy deep water habitats. The SWDA falls within the critical habitat for loggerhead sea turtles. Impact pile driving produces low frequency sounds, with most energy below 1 kHz, which is within the hearing range of sea turtles. Sea turtle injury is evaluated using the dual criteria (PK and SEL) suggested by Finneran et al. (2017) and sea turtle behavior is evaluated using the 175 dB re 1 μPa SPL threshold (McCauley et al. 2000, Finneran et al. 2017). Using abundance numbers calculated from density data, less than one sea turtle was predicted to receive an acoustic exposure above injury threshold criteria with exposure ranges up to 200 m.

The Proponent will implement monitoring and mitigation measures including time of year restrictions, piling energy ramp up, use of Protected Species Observers (PSOs) and Passive Acoustic Monitoring (PAM), and species-specific protective zones. The Proponent plans to implement additional enhanced monitoring and mitigation measures identified through consultation with regulatory agencies to further reduce the potential for negative impacts from anthropogenic sound to marine fauna. After mitigative measures are implemented, the potential residual risk of impacts is expected to be significantly reduced.

Acronyms and Abbreviations

AMAPPS	Atlantic Marine Assessment Program for Protected Species
ANSI	American National Standards Institute
ASA	Acoustical Society of America
ASA	Acoustical Society of America
BIA	Biologically Important Area
BOEM	Bureau of Ocean Energy Management
CeTAP	Cetacean and Turtle Assessment Program
COP	Construction and Operations Plan
COSEWIC	Committee on the Status of Endangered Wildlife in Canada
CPA	closest point of approach
dB	decibel
DP	dynamic positioning
DPS	Distinct Population Segment
EEZ	Exclusive Economic Zone
$ER_{95\%}$	95% Exposure Range (defined in Section 2.7)
ER_{max}	maximum Exposure Range (defined in Section 2.7)
ESA	Endangered Species Act
ESP	electrical service platform
ft	feet
FWRAM	Full Wave Range Dependent Acoustic Model
G&G	Geophysical and geotechnical
GARFO	Greater Atlantic Regional Fisheries Office
h	hour
HESS	High Energy Seismic Survey
HF	high frequency (cetacean hearing group)
HVAC	high-voltage alternating current
Hz	hertz
IHA	Incidental Harassment Authorization
in	inch
ISO	International Standards Association
ISO-NE	ISO New England
IWC	International Whaling Commission
JASMINE	JASCO Animal Simulation Model Including Noise Exposure
kg	kilogram
kHz	kilohertz
kJ	kilojoule
km	kilometer
km^2	square kilometer
L_E	cumulative sound exposure level
$L_{E,24h}$	cumulative 24-hour sound exposure level
LF	low frequency (cetacean hearing group)
L_p	sound pressure level
L_{pk}	peak sound pressure level
m	meter
m/s	meter per second
MA	Massachusetts
MF	mid-frequency (cetacean hearing group)
mi	mile
μPa	micropascal
MMPA	Marine Mammal Protection Act
MN	meganewton
MONM	Marine Operations Noise Model
NARW	North Atlantic right whale
NAS	noise abatement system
NEFSC	Northeast Fisheries Science Center
NLPSC	Northeast Large Pelagic Survey Collaborative
NM	nautical mile
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NODE	US Navy Operating Area Density Estimate
NSF	National Science Foundation
O&M	operations and maintenance
OBIS-SEAMAP	Ocean Biogeographic Information System Spatial Ecological Analysis of Megavertebrate Populations
OCS	Outer Continental Shelf
OECC	Offshore Export Cable Corridor
OSP	Optimum Sustainable Population
PAM	passive acoustic monitoring
Park City Wind	Park City Wind, LLC
PDF	probability distribution function

PDSM	Pile Driving Source Model
PK	peak sound pressure level
PSO	Protected Species Observer
PTS	permanent threshold shift
PW	phocid in water (hearing group)
$R_{95\%}$	95% acoustic Range (defined in 5.3.F.5)
RCS	reactive compensation station
RI	Rhode Island
R_{max}	maximum acoustic Range (defined in 5.3.F.5)
rms	root mean square
RWSAS	Right Whale Sighting Advisory System
RWSAS	Right Whale Sightings Advisory System
SAR	stock assessment reports
SEFSC	Southeast Fisheries Science Center
SEL	sound exposure level
SELcum	cumulative sound exposure level
SERDP-SDSS	Strategic Environmental Research and Development Program Spatial Decision Support System
SPL	sound pressure level
SPUE	sightings per unit effort
SRTM	Shuttle Radar Topography Mission
SWDA	Southern Wind Development Area
TP	transition piece
TTS	temporary threshold shift
U.S.C.	United States Code
US	United States
USFWS	US Fish and Wildlife Service
WDA	Wind Development Area
WEA	Wind Energy Area
WTG	wind turbine generator

1. Overview of Assessed Activity

1.1. New England Wind Summary

New England Wind is the proposal to develop offshore renewable wind energy facilities in Bureau of Ocean Energy Management (BOEM) Lease Area OCS-A 0534 along with associated offshore and onshore cabling, onshore substations, and onshore operations and maintenance (O&M) facilities.

New England Wind will be developed in two Phases with a maximum of 130 wind turbine generator (WTG) and electrical service platform (ESP) positions. Two positions may potentially have co-located ESPs (i.e., two foundations installed at one grid position[3]), resulting in 132 foundations. Four or five offshore export cables will transmit electricity generated by the WTGs to onshore transmission systems in the Town of Barnstable, Massachusetts. Figure 1 provides an overview of New England Wind. Park City Wind LLC, a wholly owned subsidiary of Avangrid Renewables, LLC, is the Proponent and will be responsible for the construction, operation, and decommissioning of New England Wind.

Species that occur within the United States (US) Atlantic Exclusive Economic Zone (EEZ) are discussed generally with an evaluation of their likely occurrence in and near the SWDA, while species more likely to be present in the vicinity of New England Wind Project activities are described in detail. Potential impacts are assessed for the maximum Project envelope of New England Wind South assuming a full build-out of Phase 1 (also known as Park City Wind) and Phase 2 (also known as Commonwealth Wind) over multiple years, including up to 132 wind turbine generator (WTG)/electrical service platform (ESP) foundations.

New England Wind's offshore renewable wind energy facilities are located immediately southwest of the Vineyard Wind 1 Project in Lease Area OCS-A 0501. New England Wind will occupy all of Lease Area OCS-A 0534 and potentially a portion of Lease Area OCS-A 0501 in the event that Vineyard Wind 1 does not develop "spare" or extra positions included in Lease Area OCS-A 0501 and Vineyard Wind 1 assigns those positions to Lease Area OCS-A 0534. For the purposes of the Construction and Operations Plan (COP), the Southern Wind Development Area (SWDA) is defined as all of Lease Area OCS-A 0534 and the southwest portion of Lease Area OCS-A 0501, as shown in Figure 1.

The SWDA may be approximately 411–453 square kilometers (km^2) (101,590–111,939 acres) in size depending upon the final footprint of Vineyard Wind 1. At this time, the Proponent does not intend to develop the two positions in the separate aliquots located along the northeastern boundary of Lease Area OCS-A 0501 as part of New England Wind. The SWDA (excluding the two separate aliquots that are closer to shore) is just over 32 kilometers (km) (20 miles [mi]) from the southwest corner of Martha's Vineyard and approximately 38 km (24 mi) from Nantucket.[4] The WTGs and ESPs in the SWDA will be oriented in an east-west, north-south grid pattern with one nautical mile (NM) (1.85 km) spacing between positions.

[3] If co-located ESPs are used, each ESP's monopile foundation would be located within 76 m (250 ft) of one of the potential ESP grid locations (i.e. the monopiles would be separated by up to 152 m [500 ft]).

[4] Within the SWDA, the closest WTG is approximately 34 km (21 mi) from Martha's Vineyard and 40 km (25 mi) from Nantucket.

Each Phase of New England Wind will be developed and permitted using a Project Design Envelope (the "Envelope"). This allows the Proponent to properly define and bracket the characteristics of each Phase for the purposes of environmental review while maintaining a reasonable degree of flexibility with respect to the selection of key components, such as the WTGs, foundations, offshore cables, and ESPs. To assess potential impacts and benefits to various resources, a two impact piling construction schedules were established considering the Envelope parameters for each Phase that have the potential to cause the greatest effect. For some resources, this approach overestimates potential environmental impacts as the maximum design scenario is not the scenario the Proponent is likely to execute.

Phase 1 of New England Wind (Park City Wind)

Phase 1, also known as Park City Wind, will be developed immediately southwest of the Vineyard Wind 1 Project. The Phase 1 Envelope allows for 41 to 62 WTGs and one or two ESP(s). Depending upon the capacity of the WTGs, Phase 1 will occupy 150–231 km^2 (37,066–57,081 acres) of the SWDA. The Phase 1 Envelope includes two WTG foundation types: monopiles and piled jackets. Strings of WTGs will connect with the ESP(s) via a submarine inter-array cable transmission system. The ESP(s) will include step-up transformers that increase the voltage of power generated by the WTGs prior to transmission and other electrical equipment. The ESP(s) will also be supported by a monopile or jacket foundation. Two high-voltage alternating current (HVAC) offshore export cables up to 101 km (54 NM) in length (per cable) installed within the SWDA and an Offshore Export Cable Corridor (OECC) will transmit electricity from the ESP(s) to a landfall site at the Craigville Public Beach or Covell's Beach in the Town of Barnstable. Underground onshore export cables, located principally in roadway layouts, will connect the landfall site to a new Phase 1 onshore substation in Barnstable. Grid interconnection cables will then connect the Phase 1 onshore substation to the ISO New England (ISO-NE) electric grid at Eversource's existing 345 kilovolt substation in West Barnstable.

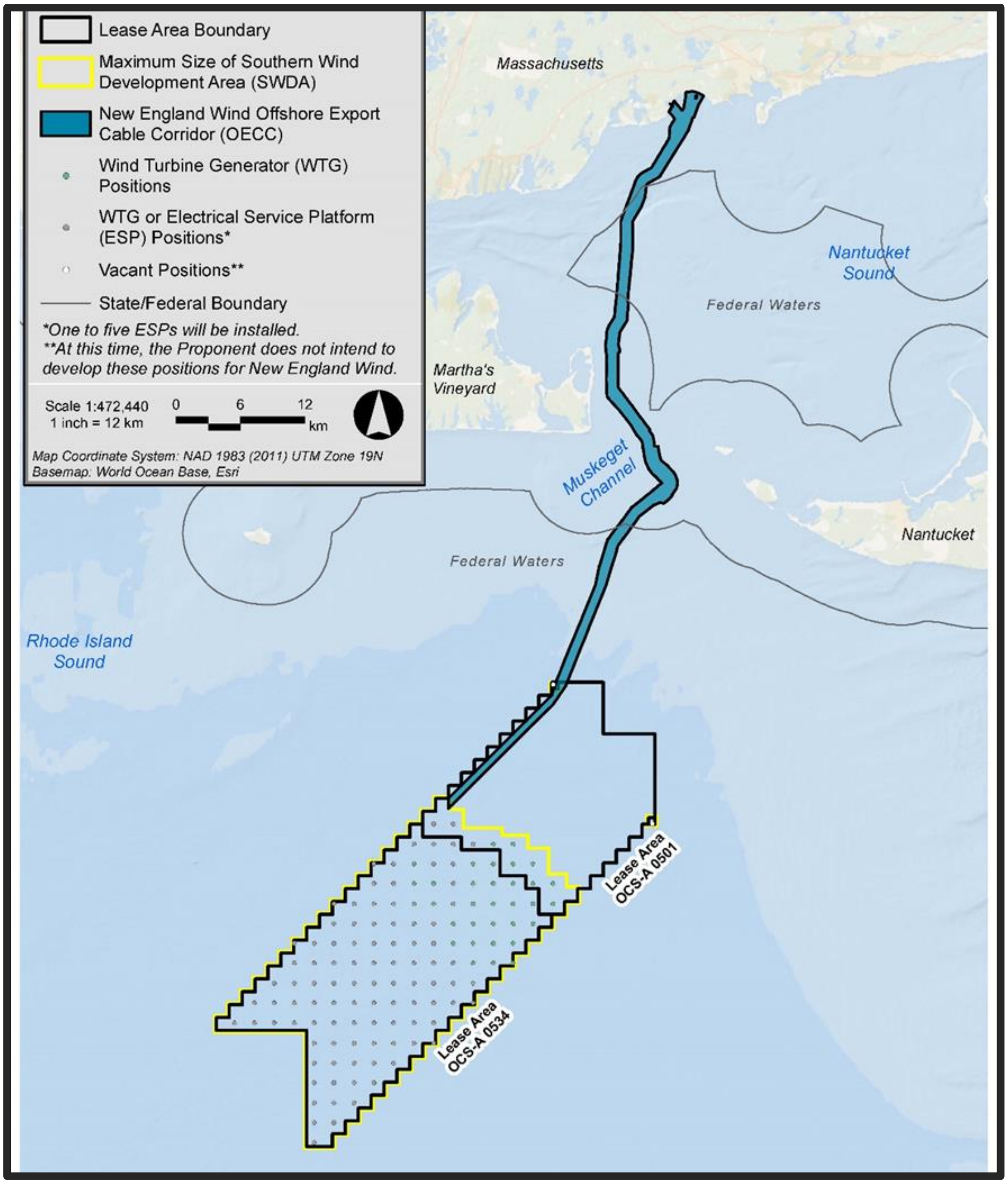

Figure 1. Site of the proposed New England Wind Project in Southern Wind Development Area (SWDA) (Lease Area OCS-A 0534).

Phase 2 of New England Wind (Commonwealth Wind)

Phase 2, also known as Commonwealth Wind, will occupy the remainder of the SWDA. Phase 2 may include one or more Projects, depending on market conditions. The footprint and total number of WTG and ESP positions in Phase 2 depends upon the final footprint of Phase 1; Phase 2 is expected to contain 64 to 88 WTG/ESP positions (up to three positions will be occupied by ESPs) within an area ranging from 222–303 km^2 (54,857–74,873 acres). The Phase 2 Envelope includes three general WTG foundation types: monopiles, jackets (with piles or suction buckets), or bottom-frame foundations (with piles or suction buckets). Inter-array cables will transmit electricity from the WTGs to the ESP(s). The ESP(s) will also be supported by a monopile or jacket foundation (with piles or suction buckets).

Two or three HVAC offshore export cables, each with a maximum length of 116–124 km (63–67 NM) per cable, will transmit power from the ESP(s) to shore. The Proponent intends to install all Phase 2 offshore export cables within the same OECC as the Phase 1 cables from the northwestern corner of the SWDA to within approximately 2–3 km (1–2 mi) of shore, at which point the OECC for Phase 2 will diverge to reach the Dowses Beach Landfall Site and/or Wianno Avenue Landfall Site in Barnstable. However, the Proponent has also identified two variations of the Phase 2 OECC in the event that technical, logistical, grid interconnection, or other unforeseen issues arise during the COP review and engineering processes that preclude one or more Phase 2 offshore export cables from being installed within all or a portion of the OECC. These variations of the Phase 2 OECC—the Western Muskeget Variant and the South Coast Variant—are shown on Figure 2.

Underground onshore export cables, located primarily within in roadway layouts, will connect the landfall site(s) to one or two new onshore substations in the Town of Barnstable. Grid interconnection cables will then connect the onshore substation site(s) to the West Barnstable Substation. If the Phase 2 OECC South Coast Variant is employed and electricity generated by Phase 2 is delivered to a second grid interconnection point, Phase 2 could include one onshore transmission system in Barnstable and/or an onshore transmission system(s) in proximity to the second grid interconnection point.

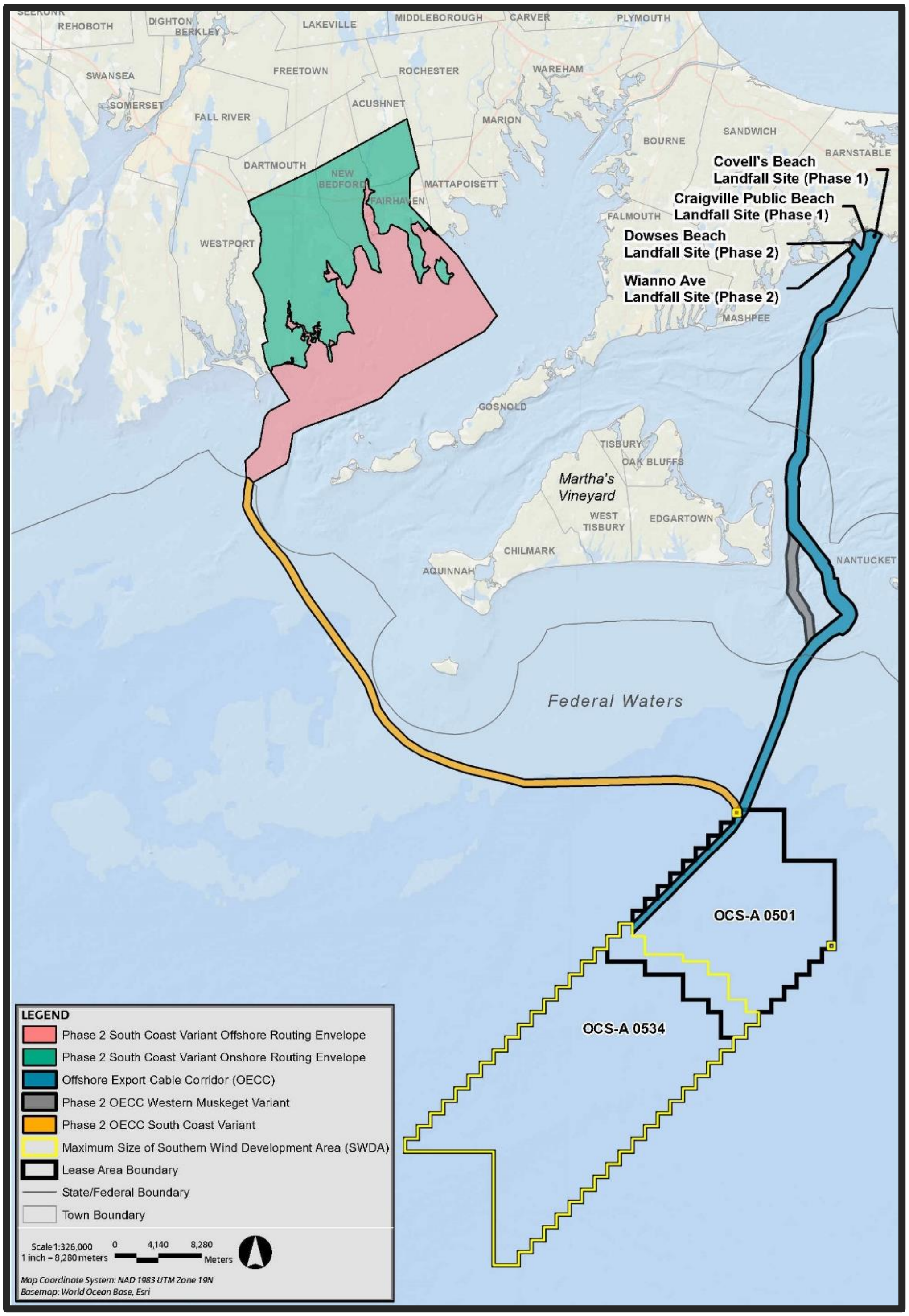

Figure 2. Phase 2 offshore export cable variants.

For both Phases, to support construction and operation activities, the Proponent will use a combination of North Atlantic ports in Massachusetts, Rhode Island, Connecticut, New York, New Jersey, and/or Canada. During appropriate time periods New England Wind-related vessels traveling to/from Salem Harbor will transit at 18.4 km per hour (10 knots) or less within NOAA-designated North Atlantic right whale critical habitat and outside critical habitat.

The primary sound source associated with the New England Wind Project is impact (impulsive) pile driving during foundation installation in the construction phase. Other sound sources include potential vibratory pile setting, which may be required during installation before impact hammering begins to ensure the pile is stable in the seabed and level for impact hammering; potential drilling, which may be required during pile installation to remove boulders and in cases of pile refusal; high-resolution geophysical (HRG) surveys to verify site conditions, ensure proper installation of components, and inspect depth of cable burial or foundations; and potential detonation of unexploded ordnance (UXO) if encountered and avoidance, physical removal, or alternative combustive removal techniques (e.g., deflagration) are not feasible. Other activities associated with cable-laying and construction vessels could contribute non-impulsive (dredging, dynamic positioning [DP] thrusters) and continuous (vessel propulsion, turbine operation) sound to the environment, but these sounds are considered secondary and are not expected to exceed typical background levels. Vessel noise will continue into the operations and maintenance, and decommissioning phases of the Project, but to a lesser extent 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).

During Phase 1 of New England Wind, the Proponent is proposing to install monopile foundations with pile diameters up to 12 m. In Phase 2 of New England Wind, a monopile foundation pile up to 13 m diameter is included in the Envelope. In both Phases, jacket foundations supported by 4 m diameter piles may also be installed.

Potential impacts are assessed for the maximum size of New England Wind assuming total build-out of Phases 1 and 2 over multiple years. Specifically, the assessment considers 132 foundations: 130 WTG/ESP grid positions, with two positions potentially having co-located ESPs (i.e., two monopile foundations installed at one grid position[5]).[6]

For this acoustic analysis, JASCO Applied Sciences (JASCO) modeled the potential acoustic impact resulting from monopile and jacket foundations. Following consultation with BOEM, 12 m monopiles were modeled for both Phases 1 and 2 with the majority of the piles being 12 m in diameter. The 13 m was modeled for Phase 2. A modeling comparison of the 12 and 13 m diameter monopile installed with the same maximum hammer energy had similar results. The maximum jacket foundation pile size included in both Phases (4 m [13 ft]) was also assessed.

[5] If co-located ESPs are used, each ESP's monopile foundation would be located within 76 m (250 ft) of one of the potential ESP grid locations (i.e. the monopiles would be separated by up to 152 m [500 ft]).

[6] A total of 132 foundations are presently proposed, which includes 130 WTG/ESP grid positions with two positions potentially having co-located ESPs (i.e., two foundations installed at one grid position). New England Wind previously also included one additional foundation for a potential reactive compensation station (RCS), bringing the total to 133 foundations. All hydroacoustic modeling was conducted for 133 foundations prior to the elimination of the potential RCS, which reduced the number of foundations to 132. The reduction to 132 foundations was determined to have a negligible effect on the predicted number of exposures, so the modeling was not redone.

1.2. Modeling Scope and Assumptions

The objectives of this modeling study were to predict the acoustic ranges to regulatory-defined acoustic thresholds associated with injury and behavioral disturbance for various marine fauna, including marine mammals, sea turtles, and fish that may occur near the SWDA during pile driving in the construction stage of the SWDA. JASCO also used the results of animal movement and exposure modeling to estimate potential exposure ranges ($ER_{95\%}$; see Section 2.7) and exposure numbers for marine mammals and sea turtles.

There are several potential anthropogenic sound sources associated with New England Wind; however, the primary sound source is impact (impulsive) pile driving during foundation installation in the construction stage. Foundation types proposed for the SWDA include monopiles, jacket, and bottom-frame foundations. Monopile foundations consist of a single pile (Figure 3), while jacket (Figure 5) and bottom-frame (Figure 6) foundations use three or four piles (pin piles) to secure the structure.

1.2.1. Monopile Foundation

A monopile is a single hollow cylinder fabricated from steel that is secured in the seabed. The monopiles modeled in the acoustic assessment are 12 m in diameter (an example monopile design for Phase 1 is shown on Figure 3), representing the maximum size monopile that may be installed in Phase 1 and an average size monopile in Phase 2. The maximum size monopile that may be installed in Phase 2 is a 13 m monopile (an example monopile design for Phase 1 is shown on Figure 4). The 12 m monopiles were modeled at 5000 kJ and 6000 kJ hammer energy levels, and the 13 m monopile was modeled at 5000 kJ. Initial source modeling showed minimal difference between the 12 m and 13 m monopiles. Given these similarities, the 13 m monopile was not modeled at 6000 kJ for this acoustic assessment, and the results for the 12 m monopiles for the 6000 kJ hammer are expected to be representative of the 13 m monopile at 6000 kJ. Monopiles are an equipment type that have been used successfully at many offshore wind energy locations. They currently account for more than 80% of the installed foundations in Europe, with more than 3350 units installed (Wind Europe 2017). Monopile foundations may be used for both WTGs and ESPs in both Phases of New England Wind.

1.2.2. Jacket Foundation

The jacket foundation design concept typically consists of a large lattice jacket structure and an integrated transition piece (TP) (Figure 5 shows an example piled jacket design for a Phase 2 ESP). The jacket structure is supported/secured by three to four pre-installed 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. The pile diameter modeled in the acoustic assessment was 4 m, which is the maximum size included in both the Phase 1 and Phase 2 Envelope.

1.2.3. Bottom-Frame Foundation

The bottom-frame foundation (for Phase 2 WTGs only) is similar to the jacket foundation, with the same maximum 4 m pile diameter (Figure 6) so was not modeled separately in the acoustic assessment. It is assumed that the potential acoustic impact of the bottom-frame foundation installation is equivalent to or less than that predicted for the jacket foundation.

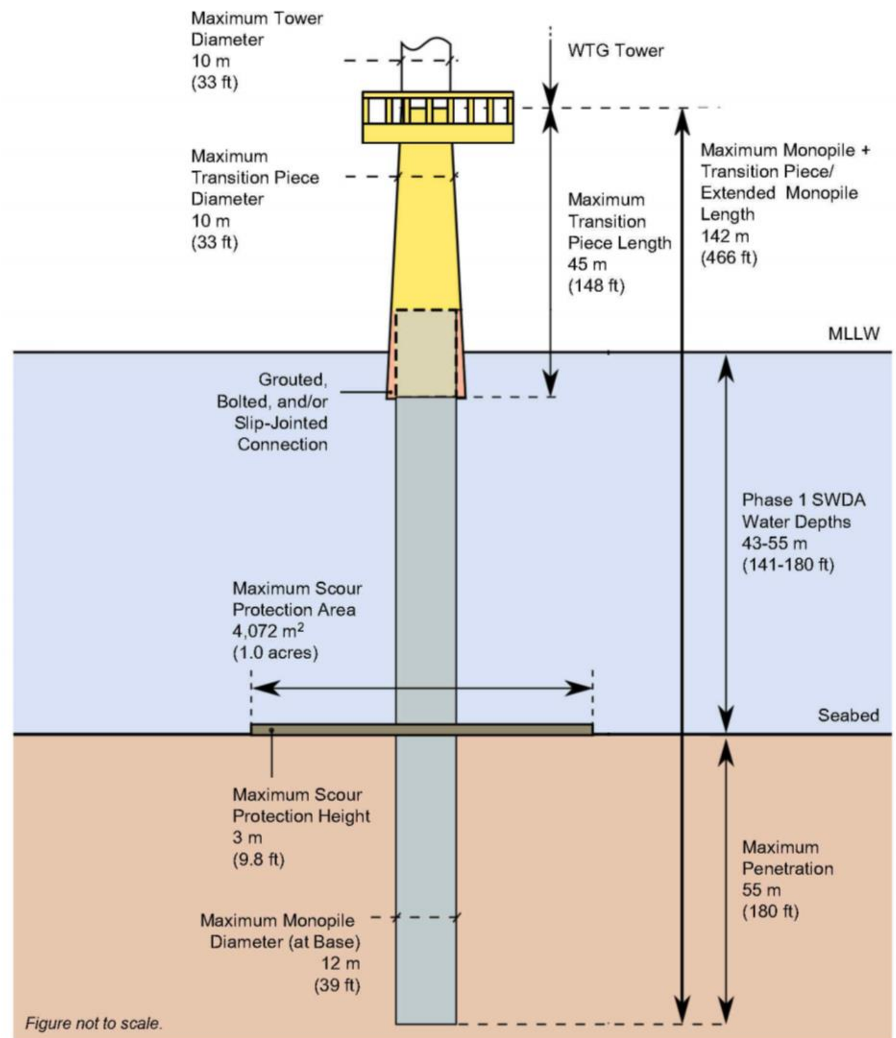

Figure 3. Schematic drawing of a 12 m monopile foundation for wind turbine generators (WTGs).

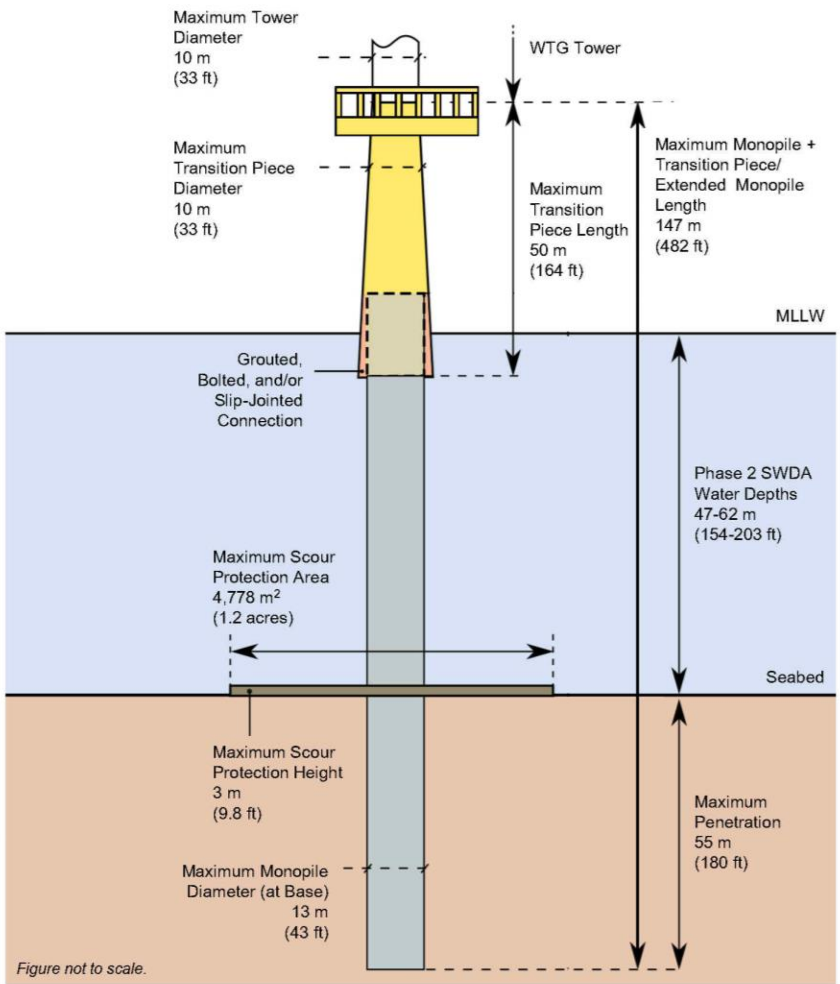

Figure 4. Schematic drawing of a 13 m monopile foundation for wind turbine generators (WTGs).

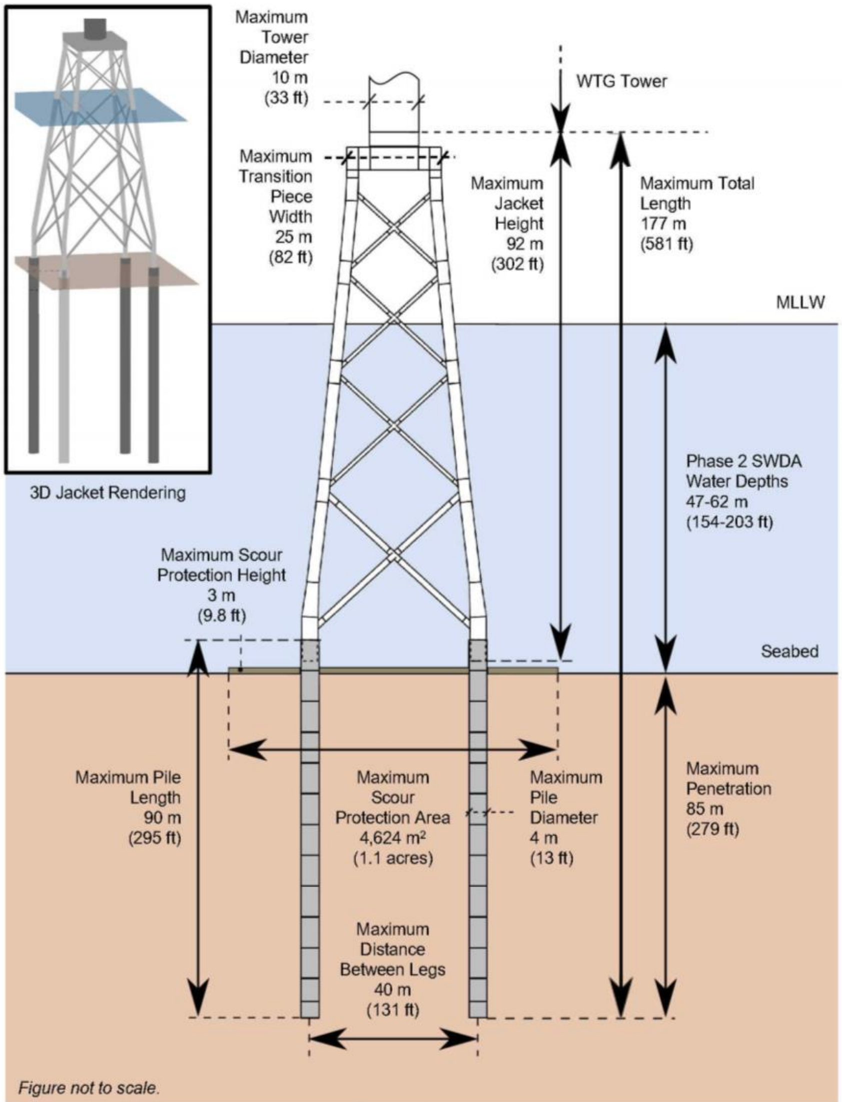

Figure 5. Schematic drawing of a jacket foundation.

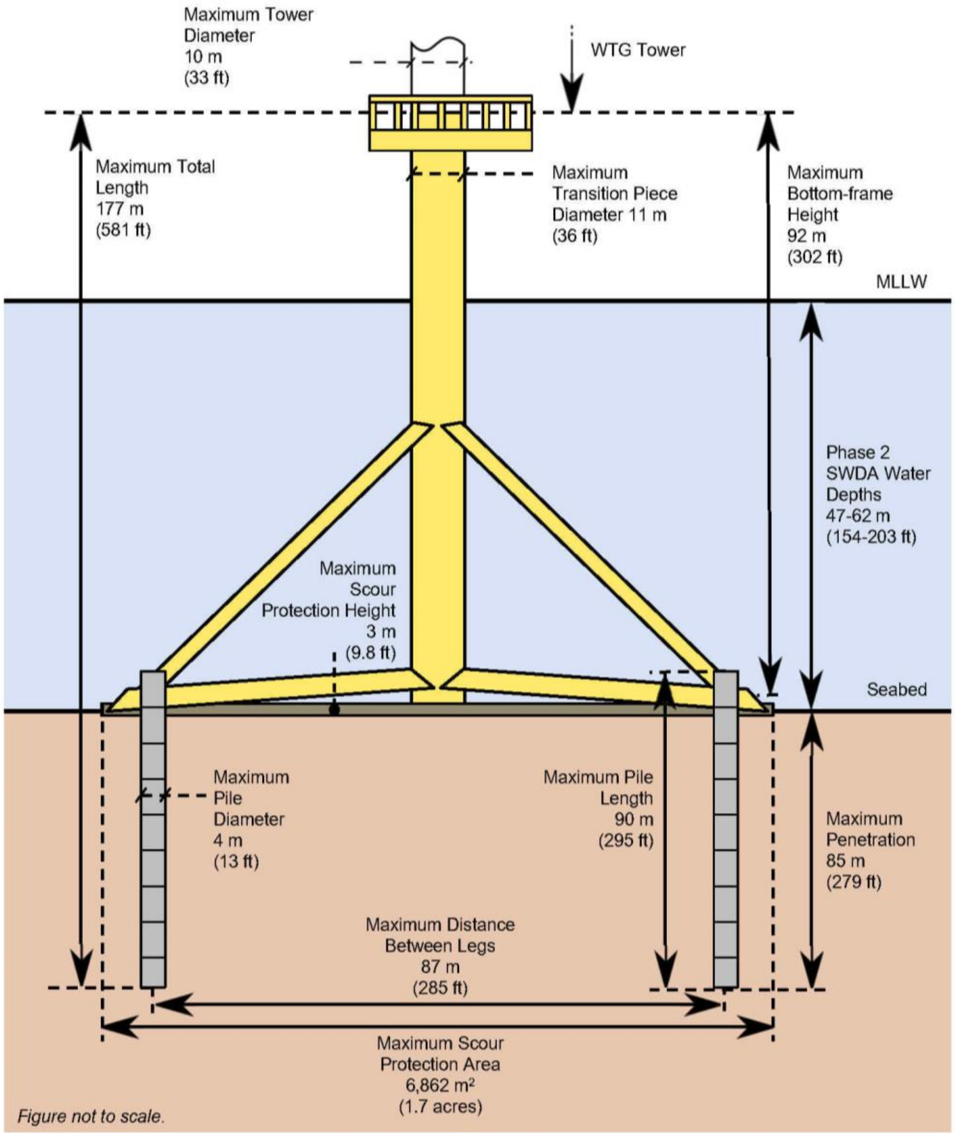

Figure 6. Schematic drawing of a bottom-frame foundation.

The amount of sound generated 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 an increased number of hammer strikes relative to installations in softer sediment. Maximum sound levels from foundation installation usually occur during the last stage of pile driving (Betke 2008). The representative make and model of impact hammers, and the representative hammering energy schedule used in the acoustic modeling effort were provided by the Proponent and two potential Project hammer suppliers. Key modeling assumptions for monopile and jacket foundations are provided in Appendix B. The representative hammer energy schedule is detailed in Table 1. Both monopile and jacket foundation piles are modeled with a vertical installation using a finite-difference structural model of pile vibration based on thin-shell theory. The acoustic assessment assumed no concurrent piling. Additional modeling details are provided in Appendix B of this report.

1.2.4. Modeled Foundation Parameters

The Proponent is proposing to install up to 132 WTG/ESP foundations in the SWDA. Due to the range of buildout scenarios for Phases 1 and 2 where certain parts of the SWDA could be included in either Phase, the total buildout of New England Wind was considered in the modeling effort (i.e., a total buildout of 132 WTG/ESP foundations). While a total of 132 foundations are presently proposed, New England Wind previously also included one additional foundation for a potential reactive compensation station (RCS), bringing the total to 133 foundations. All hydroacoustic modeling was conducted for 133 foundations prior to the elimination of the potential RCS. The reduction to 132 foundations was determined to have a negligible effect on the predicted number of exposures, so the modeling was not redone and the below analysis is based on 133 foundations.

The New England Wind envelope consisted of 12 and 13 m WTG monopile foundations and 4 m jacket foundations. Modeling for monopile foundations assumed one and two piles per day whereas jacket foundations assumed four pin piles per day for each jacket. It was also assumed that no concurrent pile driving will be performed. The estimated pile driving schedules used for animal movement modeling were provided by the Proponent's engineers and created based on the number of expected suitable weather days available per month in which pile driving may occur and potential construction vessel sequencing. The number of suitable weather days per month was obtained from historical weather data. See Table 1 for a summary of the modeled foundations.

Table 1. Hammer energy and modeled number of blows at each energy level for each modeled foundation.

12 m monopile 5000 kJ hammer			13 m monopile 5000 kJ hammer			12 m monopile 6000 kJ hammer			4 m pin pile 3500 kJ hammer			13 m monopile 6000 kJ hammer[a]		
Energy level (kJ)	Strike count	Pile penetration (%)	Energy level (kJ)	Strike count	Pile penetration (%)	Energy level (kJ)	Strike count	Pile penetration (%)	Energy level (kJ)	Strike count	Pile penetration (%)	Energy level (kJ)	Strike count	Pile penetration (%)
1000	690	25	**1000**	745	25	**1000**	750	25	**525**	875	25	**1000**	850	25
1000	1930	25	**1000**	2095	25	**2000**	1250	25	**525**	1925	25	**2000**	1375	25
2000	1910	20	**2000**	2100	20	**3000**	1000	20	**1000**	2165	14	**3000**	1100	20
3000	1502	20	**3000**	1475	20	**4500**	1000	20	**3500**	3445	26	**4500**	1100	20
5000	398	10	**5000**	555	10	**6000**	500	10	**3500**	1395	10	**6000**	550	10
Total	6430	100	**Total**	6970	100	**Total**	4500	100	**Total**	9805	100	**Total**	4975	100
Strike rate		30.0 bpm	**Strike rate**		30.0 bpm	**Strike rate**		25.0 bpm	**Strike rate**		30.0 bpm	**Strike rate**		27.6 bpm

[a] Although the project may install the 13 m monopiles at a maximum of 6000 kJ, this is not modeled beyond acoustic source modeling (see Section 4.1) and is not considered in the construction schedules (see Tables 3 and 4).

1.2.5. Acoustic Environment

New England Wind is located in a continental shelf environment characterized by predominantly sandy seabed sediments. Water depths in the Southern Wind Development Area vary between 42–62 m. From May through October, the average temperature of the upper 10–15 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 in November and December results in a sound speed profile that is more uniform with depth. The average summer sound speed profile was used in New England Wind acoustic propagation modeling. See Appendix F for more details on the environmental parameters used in acoustic propagation and exposure modeling.

1.2.6. Modeling Locations

Acoustic propagation modeling was conducted for 4 m diameter jacket foundation piles assuming a site (J1) in the central area of the SWDA in 53 m water depth. Two sites (M1 and M2) were chosen for modeling the 12 m diameter monopile foundations – M1 in the northwest section of the SWDA in 44 m water depth and M2 in the southeast section of the SWDA in 52 m water depth (Table 2; Figure 7). These locations were chosen based on the phasing plans of New England Wind, which involves the installation of 12 m diameter monopiles in Phase 1 and 13 m diameter monopiles in Phase 2, with jacket foundations planned for both phases. The 13 m diameter piles were only considered for modeling of the source functions for comparison with the 12 m diameter piles, which showed minimal difference in the forcing function and source spectra output for the two sizes. As the 12 m monopile represents the maximum size monopile for Phase 1 of New England Wind and the average size monopile for Phase 2, propagation modeling continued with the 12 m monopile. The water depth at the site locations were extracted from the bathymetry file provided by the Proponent and Shuttle Radar Topography Mission (SRTM), referred to as SRTM-TOPO15+ (Becker et al. 2009). Because of changes to the planned construction area which shifted the boundary of the SWDA farther south following completion of the modeling, one of the acoustic modeling locations and four of the animat modeling locations were located slightly north of the revised SWDA boundary. These modeling sites were not relocated since they remain representative of the average acoustic characteristics within the SWDA.

Table 2. Propagation modeling sampling locations used in the acoustic assessment.

Sound source	Site	Latitude (° N)	Longitude (° E)	Water depth (m)[a]
12 m monopile	M1	41.035501217	−70.571798180	44
13 m monopile	M2	40.834461320	−70.632933892	52
4 m pin pile	J1	40.934831948	−70.613405411	53

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

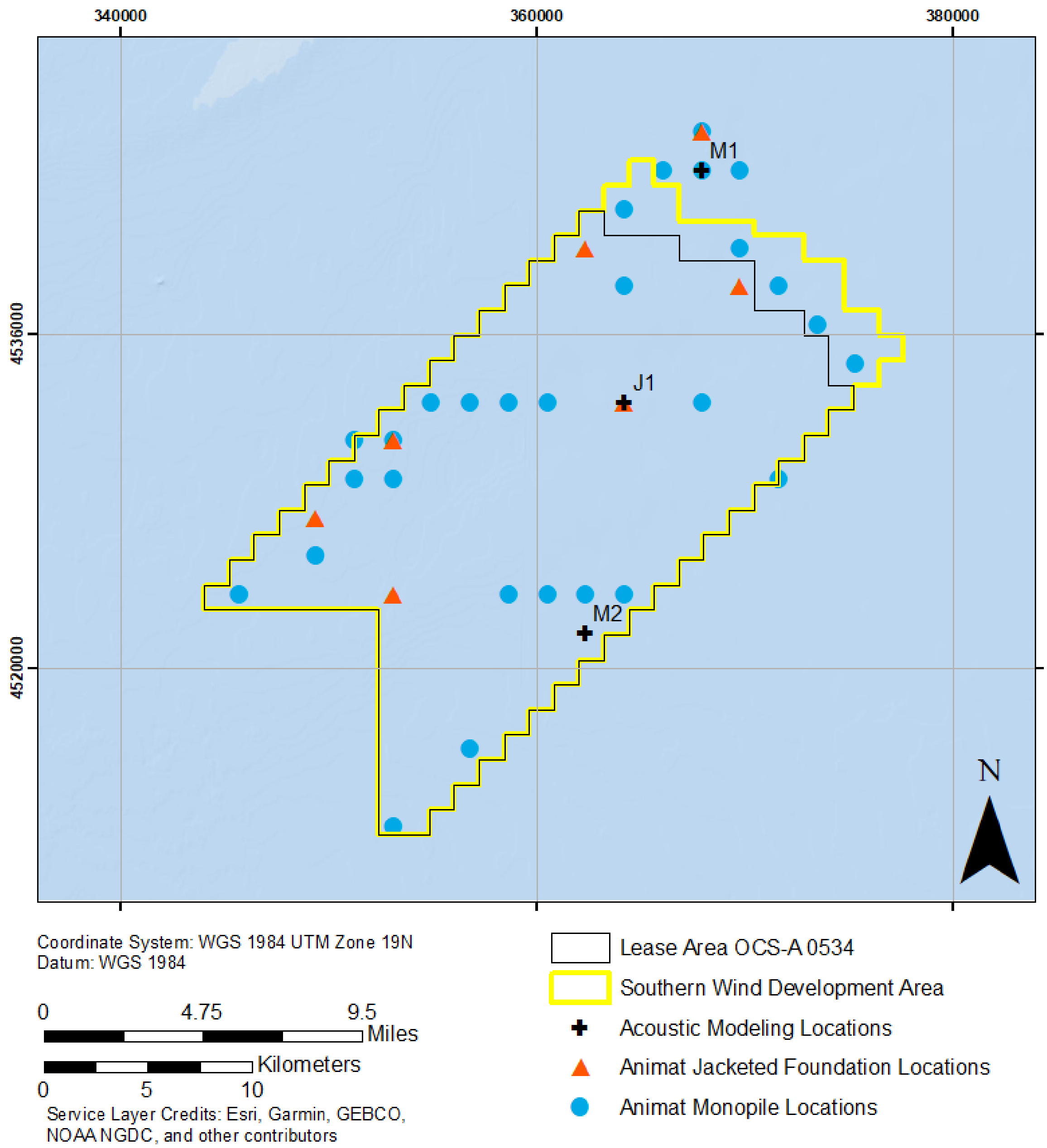

Figure 7. Project pile locations with acoustic propagation modeling and animal movement modeling locations (animat locations) highlighted in the Southern Wind Development Area (SWDA).

1.2.7. Assumed Piling Construction Schedule for Modeling

To allow some flexibility in the final design and during installation operations, two proposed construction schedules were used to evaluate potential impacts to marine mammals and sea turtles. Schedule A assumes that 89 monopile foundations and two jacket foundations are installed in Year 1 and up to 18 monopiles and 24 jacket foundations are installed in Year 2. The first year of Schedule A includes the potential installation of 13 m monopiles using a 6000 kJ hammer. This specific configuration was not modeled beyond acoustic source modeling because initial source modeling showed minimal difference between the 12 m and 13 m monopiles, and therefore the 12 m monopile with 6000 kJ hammer energy was assumed to be a reasonable replacement in exposure calculations. See Table 16 in Section 4.1 for a comparison of the broadband source levels between the 12 m and 13 m monopile.

Construction schedule A assumes that foundations for all of Phase 1 (Park City Wind) and a portion of Phase 2 (Commonwealth Wind) are installed in year 1, and that the remaining Phase 2 foundations are installed in year 2.

Schedule B is spread over 3 years where Year 1 includes 55 monopile and 3 jacket foundations and Years 2 and 3 include 53 and 22 jacket foundations, respectively. In years 2 and 3 of Schedule B, jacket foundations are assumed for all positions because they provide a conservative envelope for any of the assessed monopile foundations, up to and including a 13 m diameter monopile with a 6000 kJ hammer. Construction schedule B assumes that foundations for all of Phase 1 (Park City Wind) are installed in year 1 and that the Phase 2 (Commonwealth Wind) foundations are installed in years 2 and 3.

The construction schedules used to calculate exposures for the entire project duration are summarized in Tables 3 and 4. For construction schedules and animal movement modeling results separated by year, please reference Appendix H.2.

Table 3. Construction Schedule A, All Years Summed: The number of potential piling days per month under the maximum envelope used to estimate the total number of marine mammal and sea turtle acoustic exposures for New England Wind.

Construction month	12 m Monopile, 5000 kJ		12 m Monopile, 6000 kJ		13 m Monopile, 5000 kJ		4 m Pin Pile, 3500 kJ
	1 pile/day	2 piles/day	1 pile/day	2 piles/day	1 pile/day	2 piles/day	4 pin piles/day
May	4	0	4	0	0	0	0
June	2	5	0	3	0	0	0
July	0	9	0	4	0	0	0
August	0	9	0	0	0	0	8
September	0	1	0	0	1	6	9
October	0	0	0	0	0	6	6
November	0	0	0	0	0	3	2
December	0	0	0	0	4	0	1
Total	**6**	**24**	**4**	**7**	**5**	**15**	**26**

Table 4. Construction Schedule B, All Years Summed: The number of potential piling days per month under the maximum envelope used to estimate the total number of marine mammal and sea turtle acoustic exposures for New England Wind.

Construction month	12 m Monopile, 5000 kJ		4 m Pin Pile, 3500 kJ
	1 pile/day	2 piles/day	4 pin piles/day
May	4	0	2
June	6	4	13
July	0	7	19
August	1	5	20
September	0	3	14
October	1	1	6
November	2	0	3
December	1	0	1
Total	**15**	**20**	**78**

1.3. Other Sound Sources During Construction and Installation

The primary sources of underwater sound associated with New England Wind construction occur during the installation of monopile and jacket pile foundations. These include impact pile driving, potential vibratory setting of piles, and potential drilling used during pile installation to remove obstacles. Impact pile driving sounds are the focus of the modeling presented in the main text of this report. Vibratory setting of piles and drilling during pile installation were not modeled, but density-based exposure estimates of these two sound sources were calculated for marine mammals and are provided in Appendix K and Appendix L, respectively. Additionally, Appendix I provides exposure estimates of marine mammals for HRG survey sounds and Appendix J provides exposure estimates of marine mammals for potential UXO detonation.

1.3.1. Secondary Sound Sources

Secondary sound sources are anthropogenic sound sources that are only likely to cause behavioral responses and short-term stress in marine fauna. Secondary sound sources are expected to be of very low or low risk (see Table 5), and, because of their limited risk, a qualitative (instead of quantitative) evaluation of these sound sources was undertaken and is detailed for each source type below. For more information on the impacts of anthropogenic sounds to marine mammals and sea turtles during operations and maintenance of New England Wind, see Sections 6.7 and 6.8 of the COP.

Anthropogenic sounds from vessel traffic associated with New England Wind are likely to be similar in frequency characteristics and sound levels to existing commercial traffic in the region. Vessel sound may arise from cable laying operations, piling installation vessels, and transit into and out of the SWDA during construction. Potential sound impacts from cable installation are expected to derive primarily from the vessel(s) laying the cable. 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, sound radiated at less than 500 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 is 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 sound generated by using vibracores, CPTs, and drilling small boreholes diminishes below the NMFS Level B harassment thresholds (120 dB for continuous sound sources) relatively near to the sound source and is unlikely to cause harassment to marine mammals (NMFS 2009, Reiser et al. 2011, TetraTech 2014). Based on these studies, sounds from cable laying activities are anticipated to be comparable to potential vessel sound impacts expected in the SWDA for other general construction and installation vessel activities, and commercial fishing and shipping activities.

It is estimated that an average of approximately 30 vessels may operate in the SWDA or along the OECC at any given time during the construction of each Phase of New England Wind. Some of these vessels may remain in the SWDA, holding their positions 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 sound produced from the propellers is proportional to the number of blades, the propeller diameter, and the 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 sound pressure level (SPL) for numerous vessels with varying propulsion power under DP of up to 192 dB re 1 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 SWDA includes recreational vessels, fishing vessels, cargo vessels, tankers, passenger vessels, and others. Marine mammals in the region surrounding the SWDA are regularly subjected to commercial shipping activity and would potentially be habituated to vessel sound as a result of this exposure (BOEM 2014b). Because sound from vessel traffic associated with construction activities is likely to be similar to background vessel traffic sound, potential risk of impacts from vessel sound to marine mammals is expected to be low relative to the risk of impact from pile-driving sound.

Table 5. Definitions of impact risk, exposure, and vulnerability used in impact assessment.

Risk level	Exposure	Individual vulnerability
Very low	• No or limited observations of the species in or near the proposed Project infrastructure and acoustic exposure zones (low expected occurrence), and/or • Species tends to occur mainly in other habitat (e.g., deeper water or at lower/higher latitudes), and/or • No indication that the Lease Area has regional importance as it pertains to a particular species life history characteristics	• Literature and/or research suggest the affected species and timing of the stressor are not likely to overlap, and/or • Literature suggests limited sensitivity to the stressor, and/or • Little or no evidence of impacts from the stressor in the literature
Low	• Few observations of the species in or near the proposed Project infrastructure and noise exposure zones (occasional occurrence), and/or • Seasonal pattern of occurrence in or near the proposed Project infrastructure and acoustic exposure zones	• Literature and/or research suggest the affected species and timing of the stressor may overlap and/or • Literature suggests some low sensitivity to the stressor and/or • Literature suggests impacts are typically short-term (end within days or weeks of exposure) and/or • Literature describes mitigation/best management practices (BMPs) that reduce risk
Moderate	• Moderate year-round use of the areas associated with proposed Project infrastructure and acoustic exposure zones	• Literature and/or research suggest the affected species and timing of the stressor are likely to overlap, and/or • Literature and/or research suggest a moderate susceptibility to the stressor exists in the region and/or from similar activities elsewhere, and • Literature does not describe mitigation/BMPs that reduce risk
High	• Significant year-round use of the areas associated with proposed Project infrastructure and acoustic exposure zones	• Literature and/or research suggest the affected species and timing of the stressor will overlap, and • Literature suggests significant use of wind turbine areas, export cable corridor, and acoustic exposure zones for feeding, breeding, or migration, and • Literature does not describe mitigation/BMPs that reduce risk

2. Acoustic Modeling Methods Summary

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 8). Sound transmission depends on many environmental parameters, such as the sound speeds in water and substrates; sound production parameters of the pile and how it is driven, including the pile material, size (length, diameter, and thickness) and the type and energy of the hammer.

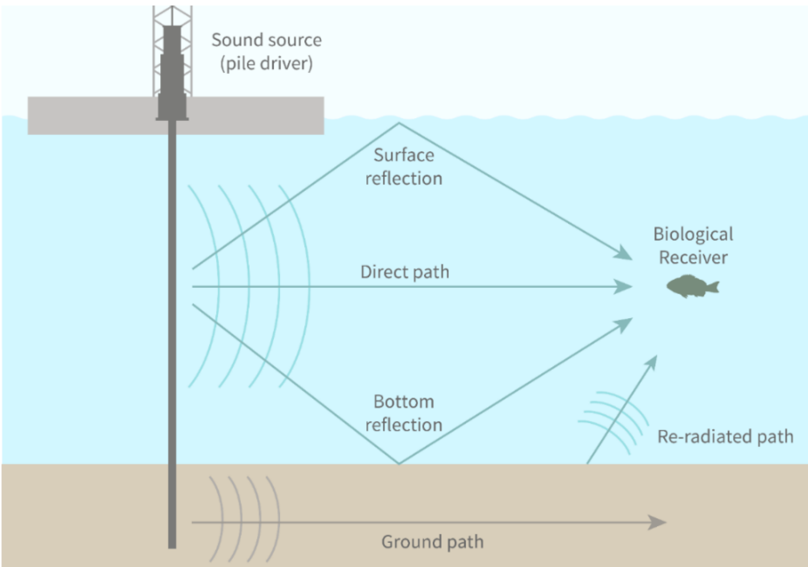

Figure 8. Sound propagation paths associated with pile driving (adapted from Buehler et al. 2015).

To estimate potential effects (e.g., injury, behavioral disturbance) to marine fauna from anthropogenic sound generated during New England Wind pile installation, JASCO performed the following modeling steps:

1. Modeled the spectral and temporal characteristics of the sound output from the proposed pile driving activities using the industry standard GRLWEAP (wave equation analysis of pile driving) model, and JASCO's Pile Driving Source Model (PDSM).
2. Acoustic propagation modeling using JASCO's Marine Operations Noise (MONM) and Full Wave Range Dependent Acoustic (FWRAM) Models that combined the outputs of the source model with the spatial and temporal environmental context (e.g., location, oceanographic conditions, seabed type) to estimate sound fields (converted to exposure radii for monitoring and mitigation). 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 transmission loss model.
3. Animal movement modeling integrated the computed sound fields with species-typical behavioral parameters (e.g., dive patterns, swim speed) in the JASCO Animal Simulation Model Including Noise Exposure (JASMINE) model to estimate received sound levels for the modeled animals (i.e., animats) that may occur in the operational area.
4. Estimated the number of potential injurious and behavioral level exposures based on pre-defined acoustic thresholds/criteria (e.g., NMFS 2018).

2.1. Source Modeling

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, and approximate pile penetration depth. See Appendix E for a more detailed description.

Forcing functions were computed for 4 m diameter jacket foundation piles and monopile foundations, with 12 m and 13 m diameter piles 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. Decidecade spectral source levels for each pile type, hammer energy and modeled location, using an average summer sound speed profile are provided in Appendix F.

2.2. Sound Propagation Modeling

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 transmission loss model. See Appendix F for a more detailed description.

2.3. Sound Level Attenuation Methods

The main goal for mitigating 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 impact, thus reducing the number of animals exposed and the sound levels to which they might 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 (bubble curtains positioned within a small radius around the pile) have been measured to reduce sound levels from ~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 NASs performance measured during impact driving for wind farm foundation installation provides expected performance for common NASs 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 ft (40 m) water depth. Increased air flow (0.5 m^3/min) may improve the attenuation levels up to 11 to 13 dB (M. Bellmann, personal communication, 2019). Double bubble curtains add another local impedance change and, for optimized systems, can achieve 15 to 16 dB of broadband attenuation (measured in up to 131.25 ft [40 m] water depth). The IHC-NMS can provide 15 to 17 dB of attenuation but is currently limited to piles <8 m diameter. Other NASs such as the AdBm NMS achieved 6 to 8 dB (M. Bellmann, personal communication, 2019), but HSDs were measured at 10 to 12 dB attenuation and are independent of depth (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 hypothetical broadband attenuation levels (0, 6, 10, and 12 dB) were included for comparison purposes, with 10 dB attenuation used to gauge the effects of noise reduction systems on the potential number of acoustic exposures and estimated exposure ranges, assuming this minimum achievable level of attenuation. The Proponent expects to implement noise attenuation mitigation technology to reduce sound levels by a target of approximately 12 dB or greater, which will significantly decrease the range over which pile driving sound will travel.

Potential mitigation measures that could be considered to achieve these sound reductions for New England Wind include equipment selection that is optimized for sound reduction such as an Integrated Pile Installer (i.e., a large metal tube through which a pile can guided and driven through), and underwater noise abatement systems (e.g., Hydro-sound Damper, AdBm encapsulated bubble sleeve), and/or bubble curtains, deployed near to the pile and farther from the source. For additional details on the potential impacts of varying levels of attenuation on sound propagation see Appendix G.

2.4. 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 New England Wind-associated sound sources, it is necessary to first establish the acoustic exposure criteria used by United States (US) regulators to estimate marine mammal takes. In 2016, NMFS issued a Technical Guidance document that provides acoustic thresholds for onset of PTS in marine mammal hearing for most sound sources, which was updated in 2018 (NMFS 2016, 2018). The Technical Guidance document also recognizes two main types of sound sources: impulsive and non-impulsive. Non-impulsive sources are further broken down into continuous or intermittent categories.

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

Sound levels thought to elicit disruptive behavioral response are described using the SPL metric. NMFS currently uses behavioral response thresholds of 160 dB re 1 µPa for intermittent sounds and 120 dB re 1 µPa for continuous sounds for all marine mammal species (NOAA 2005, 2019). Alternative thresholds used in this acoustic assessments include a graded probability of response approach and take into account the frequency-dependence of animal hearing sensitivity (Wood et al. 2012). The SPL 160 dB re 1 µPa threshold (NOAA 2005, 2019) for impulsive sounds and the Wood et al. (2012) are used in this acoustic assessment. The publication of ISO 18405 Underwater Acoustics–Terminology (ISO 2017) provided a dictionary of underwater bioacoustics (the previous standard was ANSI and ASA S1.1-2013). In the remainder of this report, we follow the definitions and conventions of ISO (2017) except where stated otherwise (Table 6).

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

Metric	NMFS (2018)	ISO (2017)	
		Main Text	Equations/Tables
Sound pressure level	n/a	SPL	L_p
Peak pressure level	PK	PK	L_{pk}
Cumulative sound exposure level	SELcum	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.

2.4.1. 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 7).

Southall et al. (2019) published an updated set of Level A sound exposure criteria (i.e., for onset of 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 7 are used in this analysis.

Table 7. Marine mammal hearing groups (Sills et al. 2014, NMFS 2018).

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

[a] The generalized hearing range is for all species within a group. Individual hearing will vary.

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

2.4.2. Marine Mammal Auditory Weighting Functions

The potential for anthropogenic sound to 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 7) published by Finneran (2016) are included in the NMFS (2018) Technical Guidance for use in conjunction with corresponding permanent threshold shift (PTS [Level A]) onset acoustic criteria (Table 8).

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

2.4.3. Marine Mammals 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 acoustic exposure injury risk. 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 temporary threshold shift (TTS) occurs, and PTS onset may be extrapolated from TTS onset level and an assumed growth function (Southall et al. 2007). The NMFS (2018) criteria incorporate the best available science to estimate PTS onset in marine mammals from sound energy accumulated over 24 h (SEL), or very loud, instantaneous peak sound pressure levels. These dual threshold criteria of SEL and PK are used to calculate marine mammal exposures (Table 8). If a non-impulsive sound has the potential to exceed the peak sound pressure level thresholds associated with impulsive sounds, these thresholds should also be considered.

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

Faunal group	Impulsive signals[a]		Non-impulsive signals
	Unweighted L_{pk} (dB re 1 µPa)	Frequency weighted $L_{E,24h}$ (dB re 1 µPa^{2}s)	Frequency weighted $L_{E,\,24hr}$ (dB re 1 µPa^{2}s)
Low-frequency (LF) cetaceans	219	183	199
Mid-frequency (MF) cetaceans	230	185	198
High-frequency (HF) cetaceans	202	155	173
Phocid seals in water (PW)	218	185	201

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

2.4.4. Marine Mammals 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 impact (NOAA 2005). A 50% probability of inducing behavioral responses at an SPL of 160 dB re 1 µPa was derived from the High Energy Seismic Survey (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. Southall et al. (2021) suggested new methodological developments for. studying behavioral responses however, no new behavioral exposure criteria were recommended. 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 (including harbor porpoises and beaked whales) and for migrating mysticetes. For this analysis, both the unweighted NOAA (2005) and the frequency-weighted Wood et al. (2012) criteria are used to estimate Level B exposures to impulsive pile-driving sounds (Table 9).

Table 9. Acoustic thresholds used in this assessment to evaluate potential behavioral impacts to marine mammals. Units are sound pressure level. 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 (NOAA 2005).

2.5. 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 thresholds 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 included in the tool are 206 dB re 1 µPa PK and either 187 dB re 1 $\mu Pa^2 \cdot s$ SEL (>2 grams [g] fish weight) or 183 dB SEL (<2 g fish weight) (FHWG 2008, Stadler and Woodbury 2009) (Table 10). The behavioral threshold for fish is ≥150 dB SPL (Andersson et al. 2007, Wysocki et al. 2007, Mueller-Blenkle et al. 2010, Purser and Radford 2011).

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. Their report includes thresholds for potential injury but does not define sound levels that may result in behavioral response, though it does indicate a high likelihood of response near impact pile driving (tens of meters), a moderate response at intermediate distances (hundreds of meters), and a low response far (thousands of meters) from the pile (Popper et al. 2014).

Injury, impairment, 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). Dual criteria (PK and SEL) have been suggested for PTS and TTS, along with auditory weighting functions published by Finneran et al. (2017) used in conjunction with SEL thresholds for PTS and TTS . 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 10).

Table 10. Acoustic metrics and thresholds for fish and sea turtles currently used by National Marine Fisheries Service (NMFS) Greater Atlantic Regional Fisheries Office (GARFO) and Bureau of Ocean Energy Management (BOEM) for impulsive pile driving.

Faunal group	Injury		Impairment		Behavior
	PTS		TTS		
	L_{pk}	$L_{E,\,24h}$	L_{pk}	$L_{E,\,24h}$	L_{p}
Fish equal to or greater than 2 g[a,b]	206	187	-	-	150
Fish less than 2 g[a,b]		183	-	-	
Fish without swim bladder[c]	213	216	-	-	-
Fish with swim bladder not involved in hearing[c]	207	203	-	-	-
Fish with swim bladder involved in hearing[c]	207	203	-	-	-
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).

PTS = permanent threshold shift; TTS = temporary threshold shift, which is a recoverable hearing effect.

[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).

2.6. Animal Movement Modeling and Exposure Estimation

The JASCO Animal Simulation Model Including Noise (JASMINE) was used to estimate the probability of exposure of animals to threshold levels of sound arising from pile driving operations during construction of New England Wind. 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) are determined and interpreted from marine species studies (e.g., tagging studies) where available, or reasonably extrapolated from related species (Appendix G.1). The predicted sound fields are 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 SWDA. The output of the simulation is the exposure history for each animat within the simulation. An individual animat's sound exposure level is summed over a specified duration, i.e., 24 h (Appendix H.1.1), 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 Section 2.4 within each analysis period. The number of animals 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 (Appendix H.1.3) 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.

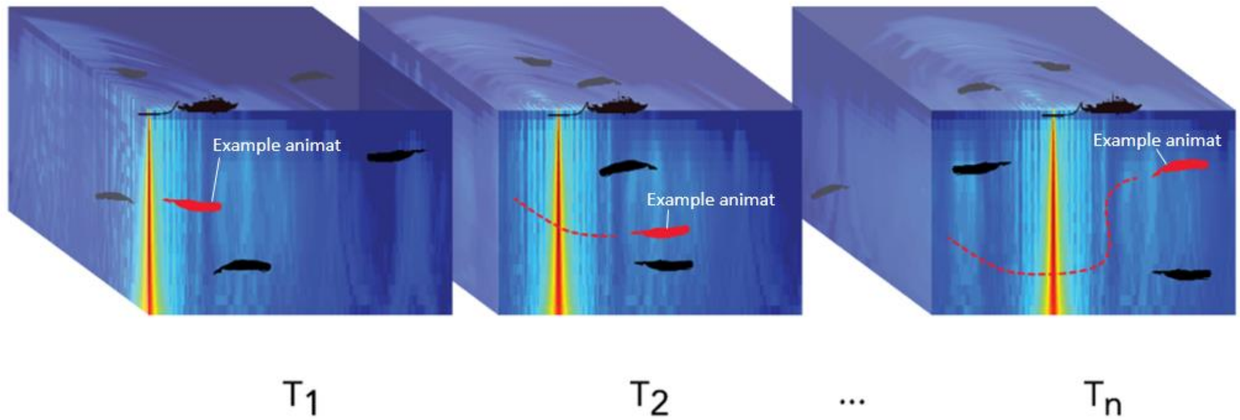

Figure 9. Depiction of animats in an environment with a moving sound field. Example animat (red) shown moving with each time step. The acoustic exposure of each animat is determined by where it is in the sound field, and its exposure history is accumulated as the simulation steps through time.

Figure 10 shows an example histogram of summary SEL exposures for each animat in a JASMINE simulation. The count above threshold is used to determine the predicted number of exposures above threshold for a given 24-hour scenario.

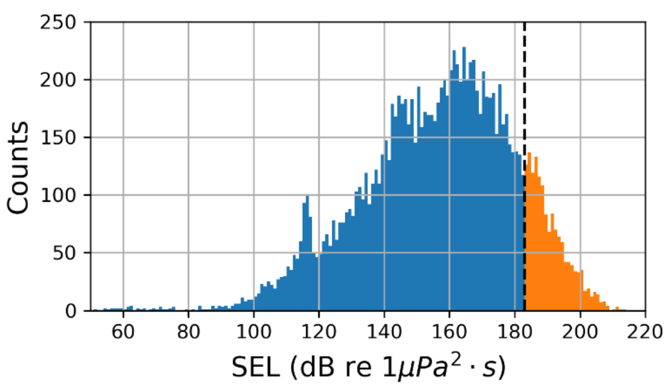

Figure 10. An example animat exposure histogram, showing the number of animats with sound exposure level (SEL) exposures at different levels for a single simulation. A vertical dashed line indicates an example sound level threshold, and the histogram bars above that threshold level are colored in orange.

Equation 1 describes how 24-h exposures x are calculated using the animat counts, the real-world density, and the sampling (seeding) density.

$$x = d_r \frac{x_{24h}}{d_s}, \quad (1)$$

where x_{24h} is the mean number of animats above threshold within a 24-hour period, d_r is the real-world animal density (e.g., from Roberts et al. 2016a), and d_s is the sampling density. As an example, consider the predicted 24-hour exposures x_A for NARW from an unattenuated 4-m jacket foundation assuming 2 piles are installed per day. The number of animats above threshold x_{24h} is 290.7, the real-world density d_r is 0.00276 animats/km^2, and the sampling density d_s is 0.597 animals/km^2:

$$x = 0.00276 \frac{290.7}{0.597} = 1.343\,. \quad (2)$$

In this case, the model predicts 1.343 animats will be exposed above threshold based on the installation of 2 unattenuated 4-m jacket foundations within a 24-hour period. To predict Project-level exposures, this calculation is repeated for each foundation type and for each month, assuming density estimates are available monthly. The total exposures x_{all} for the Project is calculated as a function of the 24-hour exposures for each month and foundation type (e.g., $x_{may,A}$), and the number of days of piling for each foundation type for each month (e.g., $n_{may,A}$). Note that that foundation type here refers to both the specific pile characteristics as well as the number of piles installed sequentially per 24-hour period. Construction schedules for the current Project are described in Tables 3 and 4. Equation 3 shows an example calculation where two foundation types, A and B, are installed over the period from May to August.

$$x_{all} = (n_{may,A} \cdot x_{may,A}) + (n_{jun,A} \cdot x_{jun,A}) + (n_{jul,A} \cdot x_{jul,A}) + (n_{aug,A} \cdot x_{aug,A}) + (n_{may,B} \cdot x_{may,B}) + (n_{jun,B} \cdot x_{jun,B}) + (n_{jul,B} \cdot x_{jul,B}) + (n_{aug,B} \cdot x_{aug,B}) \quad (3)$$

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.

2.6.1. Animal Aversion

While most results provided in this report do not include aversion or any mitigation measures other than sound attenuation, animal aversion to sound can be implemented in JASMINE and a subset of scenarios were run to provide a demonstration of the potential effect. Aversive results are included as a supplement and are presented for comparison purposes only (see Section 4.3.3).

Aversion is a common response of animals to sound, particularly at relatively high 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). 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 in to when a received level is exceeded. There are very few data on which modeling of 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 are assumed to avert by changing their headings by a fixed amount away from the source, with higher received levels associated with a greater deflection (Tables 11 and 12). 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 11 and 12). During this time, travel parameters are recalculated periodically as with normal behaviors. At the end of the aversion interval, the animat once again applies the parameters in Tables 11 and 12 and, depending on the current level of exposure, either begins another aversion interval or transitions to a non-aversive behavior; while aversion begins immediately, transition to a regular behavior occurs at the end of the next surface interval, consistent with regular behavior transitions.

Table 11. Aversion parameters for the animal movement simulation of North Atlantic right whales 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 12. Aversion parameters for the animal movement simulation of harbor porpoise 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

2.7. Exposure-based Range Estimation

Monitoring zones used for mitigation purposes have traditionally been estimated by determining the distance to injury and behavioral thresholds based only on acoustic information (see Appendix G). This traditional method tacitly assumes that all receivers (animals) in the area remain stationary for the duration of the sound event. Because both where an animal is in a sound field, and the pathway it takes through the sound field, determine the received level of the animal, treating animals as stationary may not produce realistic estimates for monitoring zones.

Animal movement modeling can be used to account for the movement of receivers when estimating distances for monitoring zones. The closest point of approach (CPA) for each of the species-specific animats (simulated animals) in a simulation is recorded and then the CPA distance that accounts for 95% of the animats that exceed an acoustic impact threshold is determined (Figure 11). The $ER_{95\%}$ (95% exposure range) is the horizontal distance that includes 95% of the CPAs of animats exceeding a given impact 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.

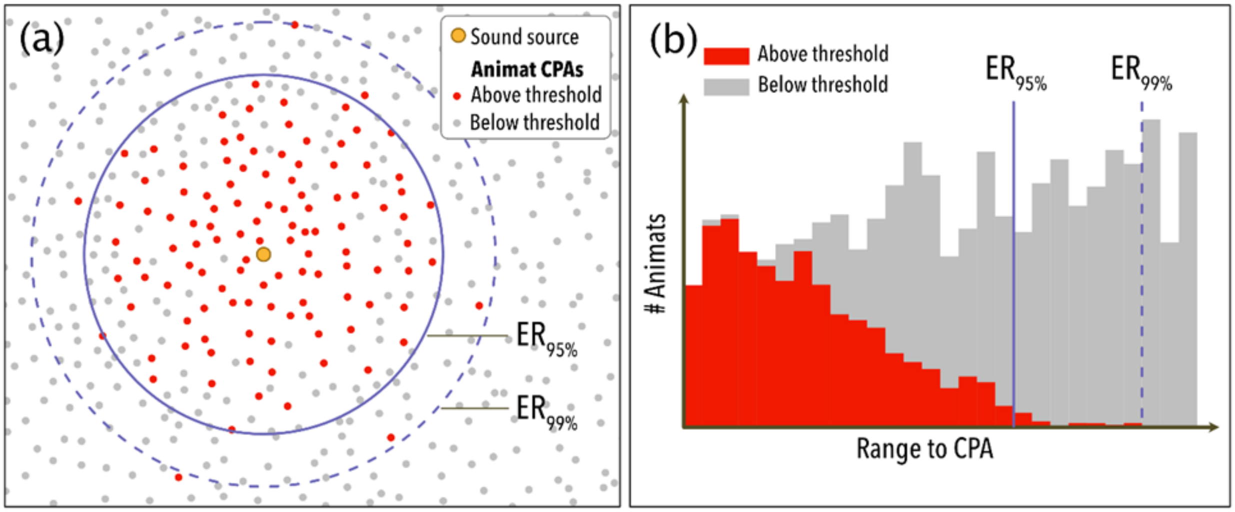

Figure 11. Example distribution of animat closest points of approach (CPAs). Panel (a) shows the horizontal distribution of animats near a sound source. Panel (b) shows the distribution of ranges to animat CPAs. The 95% and maximum Exposure Ranges ($ER_{95\%}$ and ER_{max}) are indicated in both panels.

3. Marine Fauna included in this Acoustic Assessment

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

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

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

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

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

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

3.1. Marine Mammals that may Occur in the Area

Thirty-nine marine mammal species (whales, dolphins, porpoise, seals, and manatees) comprising 39 stocks have been documented as present (some year–round, some seasonally, and some as occasional visitors) in the Northwest Atlantic Outer Continental Shelf (OCS) region (CeTAP 1982, USFWS 2014, Roberts et al. 2016a, Hayes et al. 2021). All 39 marine mammal species identified in Table 13 are protected by the MMPA and some are also listed under the ESA. The five ESA-listed marine mammal species known to be present year-round, seasonally, or occasionally in southern New England waters are the sperm whale (*Physeter macrocephalus*), NARW, 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.

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

Along with cetaceans, seals are protected under the MMPA. The four species of phocids (true seals) that have ranges overlapping the Project area, are harbor seals (*Phoca vitulina*), gray seals (*Halichoerus grypus*), harp seals (*Pagophilus groenlandicus*), and hooded seals (*Cystophora cristata*) (Hayes et al. 2019). One species of sirenian, the Florida manatee (*Trichechus manatus latirostris*), is an occasional visitor to the region during summer months (USFWS 2019). The manatee is listed as threatened under the ESA and is protected under the MMPA along with the other marine mammals.

The expected occurrence of each marine mammal species in the SWDA is listed in Table 13. 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 Offshore Development Area but due to habitat preferences and distribution information, species are generally not expected to occur in the SWDA, though rare sightings are a possibility.

Species that are identified as rare are not included in the animal movement and exposure modeling. The likelihood of incidental exposure for each species based on its presence, density, and overlap of proposed activities is described in Section 4.3.

Table 13. Marine mammals that may occur in the Southern Wind Development Area (SWDA).

Species	Scientific name	Stock	Regulatory status[a]	SWDA occurrence	Abundance[b]
Baleen whales (Mysticeti)					
Blue whale	*Balaenoptera musculus*	Western North Atlantic	ESA-Endangered	Rare	402
Fin whale	*Balaenoptera physalus*	Western North Atlantic	ESA-Endangered	Common	6802
Humpback whale	*Megaptera novaeangliae*	Gulf of Maine	MMPA	Common	1396
Minke whale	*Balaenoptera acutorostrata*	Canadian Eastern Coastal	MMPA	Common	21,968
North Atlantic right whale	*Eubalaena glacialis*	Western	ESA-Endangered	Common	368[c]
Sei whale	*Balaenoptera borealis*	Nova Scotia	ESA-Endangered	Common	6292
Toothed whales (Odontoceti)					
Sperm whales (Physeteroidae)					
Sperm whale	*Physeter macrocephalus*	North Atlantic	ESA-Endangered	Uncommon	4349
Dwarf sperm whale	*Kogia sima*	Western North Atlantic	MMPA	Rare	7750[d]
Pygmy sperm whale	*Kogia breviceps*	Western North Atlantic	MMPA	Rare	7750[d]
Dolphins (Delphinidae)					
Atlantic spotted dolphin	*Stenella frontalis*	Western North Atlantic	MMPA	Uncommon	39,921
Atlantic white-sided dolphin	*Lagenorhynchus acutus*	Western North Atlantic	MMPA	Common	93,233
Bottlenose dolphin	*Tursiops truncatus*	Western North Atlantic, offshore[e]	MMPA	Common	62,851
		Western North Atlantic, Northern Migratory Coastal	MMPA- Strategic	Rare	6639
Clymene dolphin	*Stenella clymene*	Western North Atlantic	MMPA	Rare	4237
False killer whale	*Pseudorca crassidens*	Western North Atlantic	MMPA	Rare	1791
Fraser's dolphin	*Lagenodelphis hosei*	Western North Atlantic	MMPA	Rare	Unknown
Killer whale	*Orcinus orca*	Western North Atlantic	MMPA	Rare	Unknown
Melon-headed whale	*Peponocephala electra*	Western North Atlantic	MMPA	Rare	Unknown
Pantropical spotted dolphin	*Stenella attenuata*	Western North Atlantic	MMPA	Rare	6593
Pilot whale, long-finned	*Globicephala melas*	Western North Atlantic	MMPA	Uncommon	39,215
Pilot whale, short-finned	*Globicephala macrorhynchus*	Western North Atlantic	MMPA	Uncommon	28,924
Pygmy killer whale	*Feresa attenuata*	Western North Atlantic	MMPA	Rare	Unknown
Risso's dolphin	*Grampus griseus*	Western North Atlantic	MMPA	Uncommon	35,215
Rough-toothed dolphin	*Steno bredanensis*	Western North Atlantic	MMPA	Rare	136
Short-beaked common dolphin	*Delphinus delphis*	Western North Atlantic	MMPA	Common	172,974
Spinner dolphin	*Stenella longirostris*	Western North Atlantic	MMPA	Rare	4102
Striped dolphin	*Stenella coeruleoalba*	Western North Atlantic	MMPA	Rare	67,036
White-beaked dolphin	*Lagenorhynchus albirostris*	Western North Atlantic	MMPA	Rare	536,016
Monodontid whales (Monodontidae)					
Beluga whale	*Delphinapterus leucas*	None defined for US Atlantic	MMPA	Rare	Unknown[f]

Species	Scientific name	Stock	Regulatory status[a]	SWDA occurrence	Abundance[b]
Beaked whales (Ziphiidae)					
Cuvier's beaked whale	*Ziphius cavirostris*	Western North Atlantic	MMPA	Rare	5744
Blainville's beaked whale	*Mesoplodon densirostris*	Western North Atlantic	MMPA	Rare	10,107[g]
Gervais' beaked whale	*Mesoplodon europaeus*	Western North Atlantic	MMPA		
Sowerby's beaked whale	*Mesoplodon bidens*	Western North Atlantic	MMPA		
True's beaked whale	*Mesoplodon mirus*	Western North Atlantic	MMPA		
Northern bottlenose whale	*Hyperoodon ampullatus*	Western North Atlantic	MMPA	Rare	Unknown
Porpoises (Phocoenidae)					
Harbor porpoise	*Phocoena phocoena*	Gulf of Maine/Bay of Fundy	MMPA	Common	95,543
Earless seals (Phocidae)					
Gray seal	*Halichoerus grypus*	Western North Atlantic	MMPA	Common	27,300[h]
Harbor seal	*Phoca vitulina*	Western North Atlantic	MMPA	Regular	61,336
Harp seal	*Pagophilus groenlandicus*	Western North Atlantic	MMPA	Uncommon	Unknown[i]
Hooded seal	*Cystophora cristata*	Western North Atlantic	MMPA	Rare	Unknown

[a] 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).

[b] Best available abundance estimate is from NOAA Fisheries Stock Assessment Reports (NOAA Fisheries 2021b).

[c] Best available abundance estimate is from NOAA Fisheries Stock Assessment (NOAA Fisheries 2021b). NARW consortium has released the 2021 report card results estimating a NARW population of 336 for 2020 (Pettis et al. 2022). However, the consortium "alters" the methods of Pace et al. (2017, 2021) to subtract additional mortality. This method is used in order to estimate all mortality, not just the observed mortality, therefore the NOAA Fisheries (2021b) stock assessment report (SAR) will be used to report an unaltered output of the Pace et al. (2017, 2021) model (DoC and NOAA 2020).

[d] This estimate includes both dwarf and pygmy sperm whales. Source: NOAA Fisheries (2021b).

[e] Bottlenose dolphins occurring in the Offshore Development Area likely belong to the Western North Atlantic Offshore stock (NOAA Fisheries 2021b).

[f] NMFS does not provide abundance estimates of beluga whales in US waters because there is no stock defined for the US Atlantic. Belugas occurring off the US Atlantic coast are likely vagrants from one of the Canadian populations (COSEWIC 2020).

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

[h] Estimate of gray seal population in US waters. Data are derived from pup production estimates; NOAA Fisheries (2021b) 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.

[i] NOAA Fisheries (2021b) report insufficient data to estimate the population size of harp seals in US waters; the best estimate for the entire western North Atlantic population is 7.6 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 modeled species are provided in Table 14. These were obtained using the Duke University Marine Geospatial Ecology Laboratory model (Roberts et al. 2016a, 2016b, 2017, 2018, 2021) and include recently updated model results for the NARW. The 2021 updated model includes new estimates for NARW abundance in Cape Cod Bay in December. Additionally, model predictions are summarized over three eras, 2003–2018, 2003–2009, and 2010–2018, to reflect the apparent shift in NARW distribution around 2010. The modeling conducted in support of this LOA application used the 2010–2018 density predictions.

Densities were calculated within a 6.2 km buffered polygon around the SWDA perimeter. The buffer size was selected as the largest 10 dB-attenuated exposure range over all species, scenarios, and threshold criteria, with the exception of the Wood et al. (2012) thresholds. Wood et al. (2012) exposure ranges were not considered in this estimate since they include a small subset of very long ranges for migrating mysticetes and harbor porpoise. 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 12). Densities were computed monthly, annually, and for the May–December period to coincide with proposed pile driving activities. For long- and short-finned pilot whales, monthly densities are unavailable from Roberts et al. (2016a, 2016b, 2017), so annual mean densities were used instead. Additionally, Roberts et al. (2016a, 2016b, 2017) provide density for pilot whales as a guild that includes both species. To obtain density estimates for long-finned and short-finned pilot whales, the guild density from Roberts et al. (2016a, 2016b, 2017) was scaled by the relative stock sizes based on the best available abundance estimate from NOAA Fisheries stock assessment reports (SARs) (NOAA Fisheries 2021b). Equation 4 shows an example of how abundance scaling is applied to compute density for short-finned pilot whales:

$$d_{short-finned} = d_{both}\left(\frac{a_{short-finned}}{a_{short-finned}+a_{long-finned}}\right), \qquad (4)$$

where a represents abundance and d represents density. Similarly, densities are provided for seals as a guild consisting primarily of harbor and gray seals (Roberts et al. 2016a, 2018). Gray and harbor seal densities were scaled by relative NOAA Fisheries SARs (NOAA Fisheries 2021b) abundance. However, density estimates are unavailable for the harp seal in the SWDA, so the lower gray density was used as a surrogate density for that species as a conservative measure. This is likely to overestimate impacts to harp seals because they are thought to be uncommon in the area and generally are only present in New England waters during January through May (Harris et al. 2002). Because of seasonal construction restrictions, pile driving is limited to May through December, meaning harp seals would only be exposed to pile driving during the month of May.

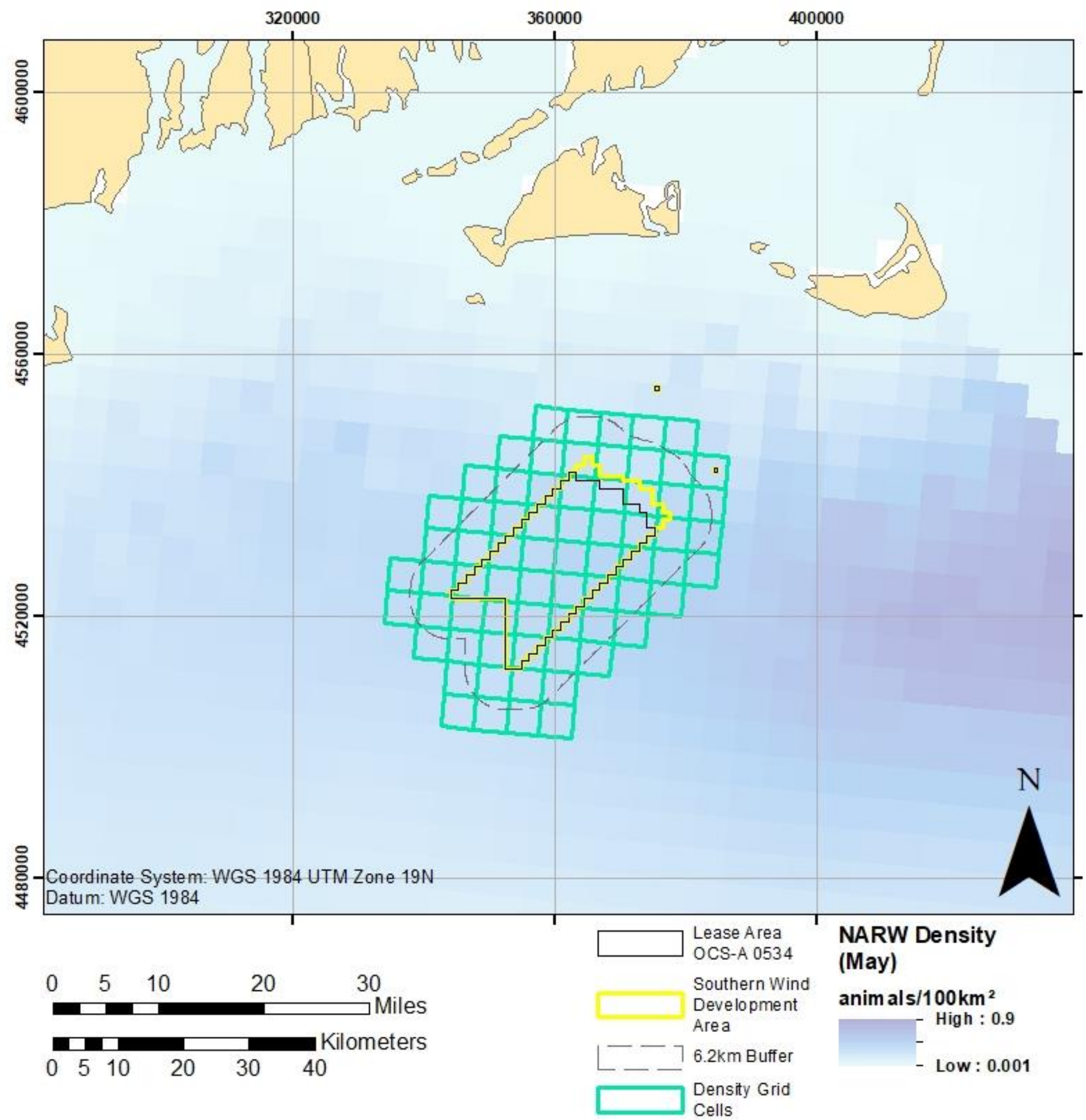

Figure 12. Marine mammal (e.g., North Atlantic right whale (NARW)) density map showing highlighted grid cells used to calculate mean monthly species estimates within a 6.2 km buffer around New England Wind (Roberts et al. 2016a, 2021). Note that the modeled densities are in units of animals/100 km^2, even when grid cells are 5 × 5 km.

Table 14. Mean monthly marine mammal density estimates for all species in a 6.2 km buffer around New England Wind.

Species of interest	Monthly densities (animals/100 km^2)												Annual mean	May to December mean
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec		
Fin whale[a]	0.214	0.184	0.178	0.325	0.368	0.369	0.390	0.352	0.280	0.157	0.152	0.159	0.261	0.278
Minke whale	0.065	0.081	0.083	0.181	0.263	0.243	0.087	0.061	0.063	0.074	0.033	0.047	0.107	0.109
Humpback whale	0.030	0.018	0.030	0.221	0.179	0.170	0.123	0.063	0.236	0.196	0.063	0.026	0.113	0.132
North Atlantic right whale[a]	0.660	0.780	0.811	0.904	0.362	0.023	0.004	0.003	0.004	0.010	0.051	0.264	0.323	0.090
Sei whale[a]	0.002	0.002	0.001	0.047	0.047	0.027	0.007	0.004	0.007	0.001	0.002	0.002	0.012	0.012
Atlantic white-sided dolphin	3.881	2.083	2.242	4.317	8.263	7.805	5.504	3.109	2.957	3.698	4.042	5.834	4.478	5.152
Atlantic spotted dolphin	0.002	0.002	0.003	0.013	0.025	0.034	0.070	0.124	0.137	0.124	0.075	0.009	0.052	0.075
Short beaked common dolphin	16.930	2.935	1.174	3.016	5.785	5.909	6.401	11.882	20.783	23.516	16.500	29.286	12.010	15.008
Common Bottlenose dolphin	0.678	0.042	0.013	0.485	0.556	0.650	1.336	1.338	2.671	3.296	1.497	0.768	1.111	1.514
Risso's dolphin	0.016	0.007	0.003	0.003	0.011	0.012	0.029	0.056	0.043	0.015	0.025	0.042	0.022	0.029
Long-finned pilot whale	0.625	0.625	0.625	0.625	0.625	0.625	0.625	0.625	0.625	0.625	0.625	0.000	0.625	0.625
Short-finned pilot whale	0.461	0.461	0.461	0.461	0.461	0.461	0.461	0.461	0.461	0.461	0.461	0.000	0.461	0.461
Sperm whale	0.002	0.003	0.002	0.002	0.003	0.008	0.036	0.038	0.008	0.008	0.008	0.002	0.010	0.014
Harbor porpoise	4.592	8.200	15.828	10.293	4.762	0.932	0.669	0.648	0.538	0.260	0.862	1.980	4.130	1.331
Gray seal	0.653	2.225	2.470	2.818	3.070	0.267	0.047	0.027	0.059	0.091	0.055	0.349	1.011	0.496
Harbor seal	1.466	4.999	5.549	6.331	6.897	0.599	0.106	0.061	0.132	0.205	0.124	0.784	2.271	1.114
Harp seal	0.653	2.225	2.470	2.818	3.070	0.267	0.047	0.027	0.059	0.091	0.055	0.349	1.011	0.496

[a] Listed as Endangered under the ESA.

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

Four species of sea turtles may occur in the SWDA, and all 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 SDWA. Kemp's Ridley sea turtles are thought to be regular visitors during those seasons. Green sea turtles are rare in the SWDA, generally preferring tropical and subtropical habitats, and are not considered further.

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 SWDA. Atlantic salmon is an anadromous species that historically ranged from northern Quebec southeast to Newfoundland and southwest to Long Island Sound. The Gulf of Maine distinct population segment (DPS) of the Atlantic salmon that spawns within eight coastal watersheds within Maine is federally listed as endangered. In 2009, the DPS was expanded to include all areas of the Gulf of Maine between the Androscoggin River and the Dennys River (NOAA Fisheries 2022). It is possible that adult Atlantic salmon may occur off the Massachusetts coast while migrating to rivers to spawn. However, 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, whereas those off the Yucatan peninsula and Indonesia are commonly found in waters between 25 to 30°C. 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 2021a).

3.4. Sea Turtle Density Estimates

There are limited density estimates for sea turtles in the lease area. For this analysis, sea turtle densities were obtained from the US Navy Operating Area Density Estimate (NODE) database on the Strategic Environmental Research and Development Program Spatial Decision Support System (SERDP-SDSS) portal (DoN, 2012, 2017) and from the Northeast Large Pelagic Survey Collaborative Aerial and Acoustic Surveys for Large Whales and Sea Turtles (Kraus et al. 2016). These data are summarized seasonally (winter, spring, summer, and fall). Since the results from Kraus et al. (2016) use data that were collected more recently, those were used preferentially where possible.

Sea turtles were most commonly observed in summer and fall, absent in winter, and nearly absent in spring during the Kraus et al. (2016) surveys of the MA WEA and RI/MA WEAs. Because of this, the more conservative winter and spring densities from SERDP-SDSS are used for all species. It should be noted that SERDP-SDSS densities are provided as a range, where the maximum density will always exceed zero, even though turtles are unlikely to be present in winter. As a result, winter and spring sea turtle densities in the lease area, while low, are likely still overestimated.

For summer and fall, the more recent leatherback and loggerhead densities extracted from Kraus et al. (2016) were used. These species were the most commonly observed sea turtle species during aerial surveys by Kraus et al. (2016) in the MA/RI and MA WEAs. However, Kraus et al. (2016) reported seasonal densities for leatherback sea turtles only, so the loggerhead densities were calculated for summer and fall by scaling the averaged leatherback densities from Kraus et al. (2016) by the ratio of the seasonal sighting rates of the two species during the surveys. The Kraus et al. (2016) estimates of loggerhead sea turtle density for summer and fall are slightly higher than the SERDP-SDSS densities, and thus more conservative.

Kraus et al. (2016) reported only six total Kemp's ridley sea turtle sightings, so the estimates from SERDP-SDSS were used for all seasons. Green sea turtles are rare in this area and there are no density data available for this species, so the Kemp's ridley sea turtle density is used as a surrogate to provide a conservative estimate.

Sea turtle densities used in exposure estimates are provided in Table 15.

Table 15. Sea turtle density estimates for all modeled species in the Southern Wind Development Area (SWDA).

Common name	Density (animals/100 km^2 [38.6 mi^2])[a]			
	Spring	Summer	Fall	Winter
Green sea turtle[b]	0.017	0.017	0.017	0.017
Leatherback sea turtle	0.022	0.630[c]	0.873[c]	0.022
Loggerhead sea turtle	0.103	0.206[d]	0.633[d]	0.103
Kemp's ridley sea turtle	0.017	0.017	0.017	0.017

[a] Density estimates are extracted from SERDP-SDSS NODE database within a 6.2 km buffer of the SWDA, unless otherwise noted.

[b] Kraus et al. (2016) did not observe any green sea turtles in the RI/MA WEA. Densities of Kemp's ridley sea turtles are used as a conservative estimate.

[c] Densities calculated as averaged seasonal densities from 2011 to 2015 (Kraus et al. 2016).

[d] Densities calculated as the averaged seasonal leatherback sea turtle densities scaled by the relative, seasonal sighting rates of loggerhead and leatherback sea turtles (Kraus et al. 2016).

4. Summary Results

Acoustic fields were modeled at one site for jacket foundations and two sites for monopiles, representing the range of water depths within the SWDA (Table 2; Figure 7). This section summarizes the source level modeling results (Section 4.1), both acoustic and exposure ($ER_{95\%}$) ranges (Sections 4.2 and 4.3). A summary of the number of marine mammals and sea turtles predicted to be exposed above regulatory acoustic sound level thresholds is provided in Section 4.3.

4.1. Modeled Acoustic Source Levels

Forcing functions (in meganewtons [MN]) were computed for each pile type at various hammer energies using GRLWEAP 2010 (GRLWEAP, Pile Dynamics 2010) and are shown in Figures 13–15. 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. The representative hammer parameters for a 5500 kJ and 3500 kJ hammer were provided as estimates from on-going hammer design work. As no hammer parameters were available for either a 5000 or 6000 kJ hammer, the modeled energies of the 5500 kJ hammer were scaled to represent the effect of the forcing functions for the two different hammers approximated. Decidecade spectral source levels for each pile type, hammer energy, and modeled location for summer sound speed profiles are shown in Figures 16 to 18. A broadband source level comparison between the 12 m and 13 m monopile is provided in Table 16.

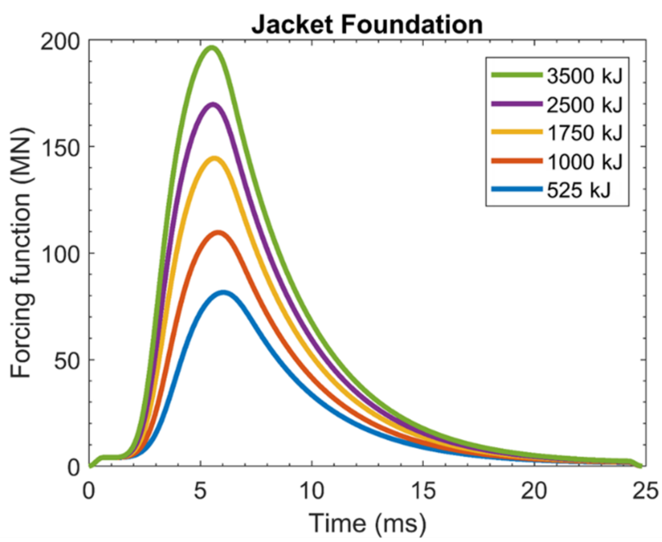

Figure 13. Modeled forcing functions versus time for a 4 m jacket foundation pile for each hammer energy using a 3500 kJ hammer.

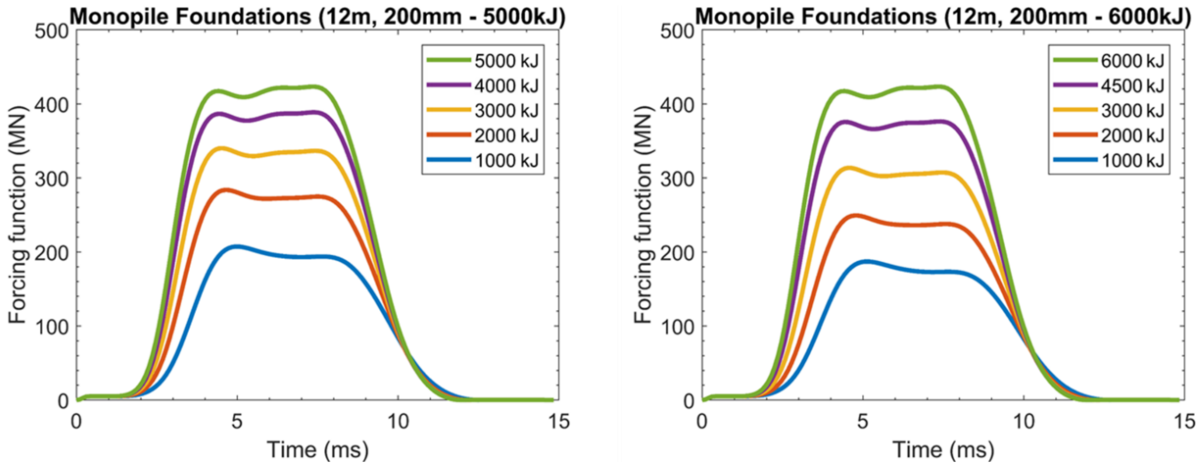

Figure 14. Modeled forcing functions versus time for a 12 m monopile at each hammer energy using a (left) 5000 kJ and (right) 6000 kJ hammer.

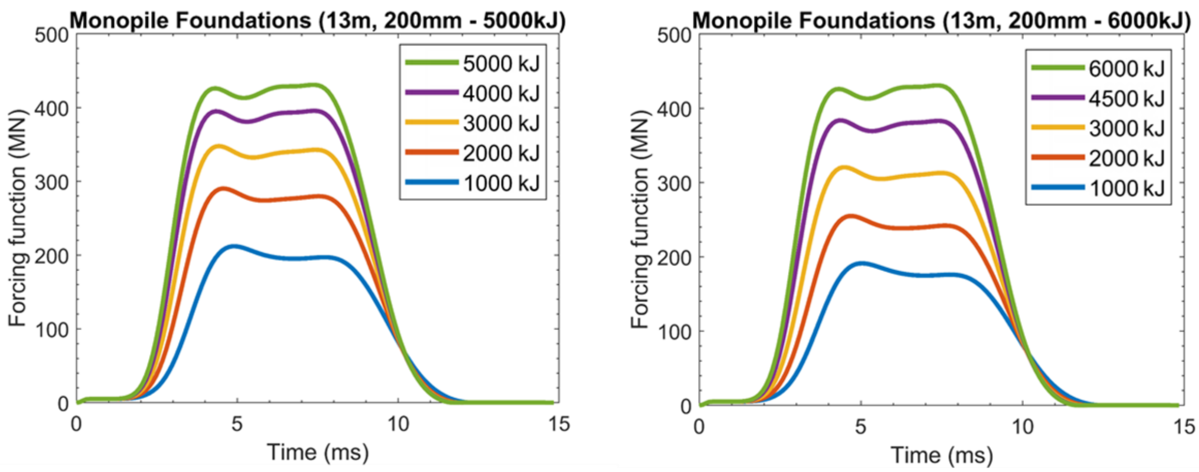

Figure 15. Modeled forcing functions versus time for a 13 m monopile at each hammer energy using a (left) 5000 kJ and (right) 6000 kJ hammer.

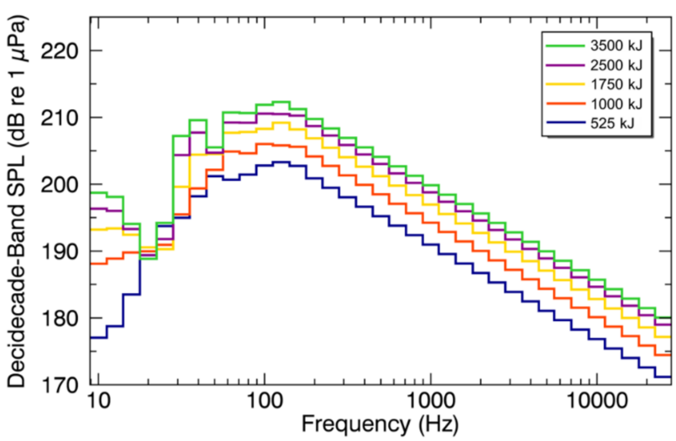

Figure 16. Decidecade band spectral source levels for 4 m jacket foundation pile installation at each hammer energy using a 3500 kJ hammer at site J1 (Figure 7) with an average summer sound speed profile at 1 m from the pile.

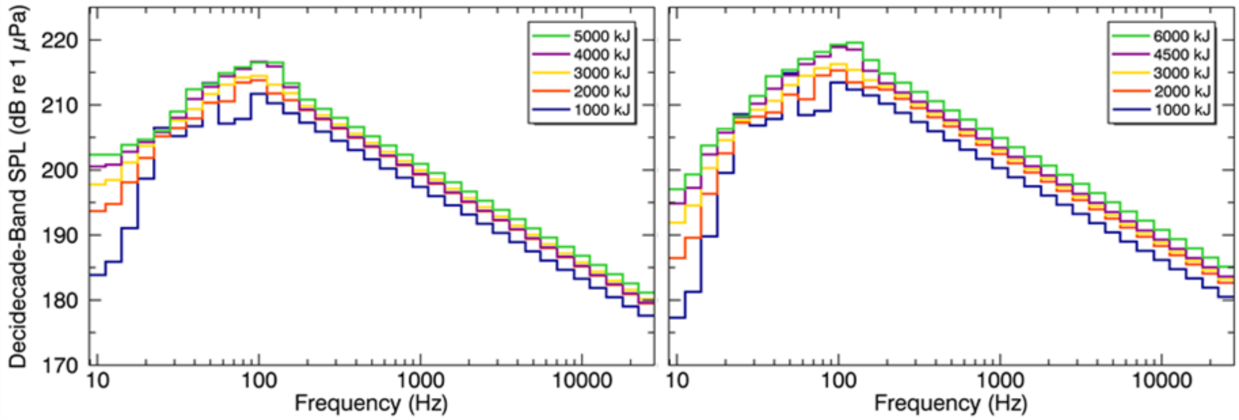

Figure 17. Decidecade band spectral source levels for 12 m monopile installation at each hammer energy using a (left) 5000 kJ and (right) 6000 kJ hammer at site M1 (Figure 7) with an average summer sound speed profile at 1 m from the pile.

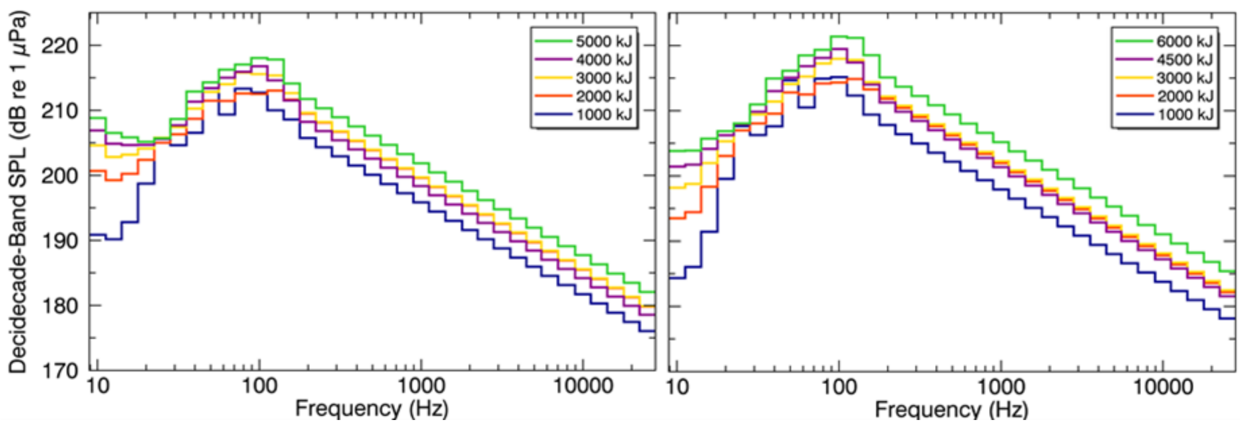

Figure 18. Decidecade band spectral source levels for 13 m monopile installation at each hammer energy using a (left) 5000 kJ and (right) 6000 kJ hammer at site M2 (Figure 7) with a summer sound speed profile at 1 m from the pile.

Table 16. Broadband source level comparison between the 12 m and 13 m monopile.

12 m Monopile		13 m Monopile		Broadband level difference (dB)[a]
Hammer energy level (kJ)	Broadband level (dB)[a]	Hammer energy level (kJ)	Broadband level (dB)[a]	
1000	221.94	1000	222.27	0.34
2000	223.30	2000	223.43	0.14
3000	224.56	3000	225.52	0.96
4500	226.31	4500	226.09	0.22
6000	227.32	6000	228.56	1.23

[a] Broadband levels are rounded to nearest 0.01 dB.

4.2. Modeled Ranges to Acoustic Thresholds Relevant for Impact Pile Driving

Though not used for exposure estimates in this assessment, acoustic ranges to exposure criteria thresholds are reported. For each sound level threshold, the maximum range (R_{max}) and the 95% range ($R_{95\%}$) were calculated. R_{max} is the distance to the farthest occurrence of the threshold level, at any depth. $R_{95\%}$ for a sound level is the radius of a circle, centered on the source, encompassing 95% of the sound at levels above threshold. Using $R_{95\%}$ reduces the sensitivity to extreme outlying values (the farthest 5% of ranges). A more detailed description of $R_{95\%}$ is found in Appendix F.5.

The following tables provide the ranges for marine fauna behavioral and auditory injury thresholds. The $R_{95\%}$ for SEL is inclusive of all the hammer energy levels, while the $R_{95\%}$ for PK is from the highest hammer energy level. The distances to SEL are calculated using the representative hammer energy schedules (Table 1) for driving one monopile or pin pile. The SEL ranges presented in Tables 17–20 are the distances from the foundation locations that would result in exposure above threshold if an animal remained stationary for the duration of one pile being driven into the bottom.

Table 17. PK ranges ($R_{95\%}$ in meters) to marine fauna auditory injury thresholds for the 5000 kJ, 12 m monopile foundation. Ranges to PK thresholds are for the highest hammer energy level. Ranges to SEL thresholds represent the cumulative sound level for one 12 m monopile foundation with varying levels of noise attenuation.

Faunal group	Metric, pile per day	Threshold	Attenuation level (dB)		
			0	10	12
Low-frequency (LF) cetaceans	L_{pk}	219	79	11	8
	L_E	183	17437	7036	5549
Mid-frequency (MF) cetaceans	L_{pk}	230	9	3	3
	L_E	185	644	89	63
High-frequency (HF) cetaceans	L_{pk}	202	720	230	191
	L_E	155	11686	5126	4159
Phocid seals in water (PW)	L_{pk}	218	94	14	9
	L_E	185	5024	1121	1075
Sea turtles	L_{pk}	232	7	3	3
	L_E	204	2860	612	439
Fish without swim bladder	L_{pk}	213	210	47	36
	L_E	216	616	100	63
Fish with swim bladder not involved in hearing	L_{pk}	207	540	105	79
	L_E	203	3900	1047	760
Fish with swim bladder involved in hearing	L_{pk}	207	540	105	79
	L_E	203	3900	1047	760
Fish greater than or equal to 2 g	L_{pk}	206	580	157	94
	L_E	187	16282	7204	5960
Fish less than 2 g	L_{pk}	206	580	157	94
	L_E	183	21542	10290	8648

L_{pk} = unweighted peak sound pressure (dB re 1 µPa); L_E = frequency-weighted sound exposure level (dB re 1 µPa^2·s).
Thresholds are taken from Tables 8 to 10.

Table 18. PK ranges ($R_{95\%}$ in meters) to marine fauna auditory injury thresholds for the 6000 kJ, 12 m monopile foundation. Ranges to PK thresholds are for the highest hammer energy level. Ranges to SEL thresholds represent the cumulative sound level for one 12 m monopile foundation with varying levels of noise attenuation.

Faunal group	Metric, pile per day	Threshold	Attenuation level (dB)		
			0	10	12
Low-frequency (LF) cetaceans	L_{pk}	219	79	11	8
	L_E	183	20770	8924	7140
Mid-frequency (MF) cetaceans	L_{pk}	230	9	3	3
	L_E	185	1101	113	89
High-frequency (HF) cetaceans	L_{pk}	202	720	230	191
	L_E	155	13769	6414	5272
Phocid seals in water (PW)	L_{pk}	218	94	14	9
	L_E	185	6320	2037	1128
Sea turtles	L_{pk}	232	7	3	3
	L_E	204	3620	930	611
Fish without swim bladder	L_{pk}	213	210	47	36
	L_E	216	900	128	89
Fish with swim bladder not involved in hearing	L_{pk}	207	540	105	79
	L_E	203	4825	1365	982
Fish with swim bladder involved in hearing	L_{pk}	207	540	105	79
	L_E	203	4825	1365	982
Fish greater than or equal to 2 g	L_{pk}	206	580	157	94
	L_E	187	19149	8756	7242
Fish less than 2 g	L_{pk}	206	580	157	94
	L_E	183	24623	12283	10395

L_{pk} = unweighted peak sound pressure (dB re 1 µPa); L_E = frequency-weighted sound exposure level (dB re 1 µPa^2·s)
Thresholds are taken from Tables 8 to 10.

Table 19. PK ranges ($R_{95\%}$ in meters) to marine fauna auditory injury thresholds for the 5000 kJ, 13 m monopile foundation. Ranges to PK thresholds are for the highest hammer energy level. Ranges to SEL thresholds represent the cumulative sound level for one 13 m monopile foundation with varying levels of noise attenuation.

Faunal group	Metric, pile per day	Threshold	Attenuation level (dB)		
			0	10	12
Low-frequency (LF) cetaceans	L_{pk}	219	93	14	10
	L_E	183	19473	7213	5716
Mid-frequency (MF) cetaceans	L_{pk}	230	13	5	5
	L_E	185	480	89	82
High-frequency (HF) cetaceans	L_{pk}	202	860	290	240
	L_E	155	11896	4955	3917
Phocid seals in water (PW)	L_{pk}	218	104	16	13
	L_E	185	4936	1246	656
Sea turtles	L_{pk}	232	8	5	4
	L_E	204	2987	560	412
Fish without swim bladder	L_{pk}	213	260	52	27
	L_E	216	560	108	80
Fish with swim bladder not involved in hearing	L_{pk}	207	580	114	93
	L_E	203	4198	1031	691
Fish with swim bladder involved in hearing	L_{pk}	207	580	114	93
	L_E	203	4198	1031	691
Fish greater than or equal to 2 g	L_{pk}	206	620	127	104
	L_E	187	19306	8133	6648
Fish less than 2 g	L_{pk}	206	620	127	104
	L_E	183	26101	11881	9815

L_{pk} = unweighted peak sound pressure (dB re 1 μPa); L_E = frequency-weighted sound exposure level (dB re 1 μPa^2·s)
Thresholds are taken from Tables 8 to 10.

Table 20. PK ranges ($R_{95\%}$ in meters) to marine fauna auditory injury thresholds for the 3500 kJ, 4 m jacket foundation. Ranges to PK thresholds are for the highest hammer energy level. Ranges to SEL thresholds represent the cumulative sound level for one and four, 4 m pin pile(s) with varying levels of noise attenuation.

Faunal hearing group	Metric	Threshold	Attenuation level (dB) (1 Pile)			Attenuation level (dB) (4 Piles)		
			0	10	12	0	10	12
Low-frequency (LF) cetaceans	L_{pk}	219	33	2	0	33	2	0
	L_E	183	18049	6885	5248	29350	12677	10482
Mid-frequency (MF) cetaceans	L_{pk}	230	2	-	-	2	-	-
	L_E	185	481	89	80	1577	268	146
High-frequency (HF) cetaceans	L_{pk}	202	580	139	123	580	139	123
	L_E	155	11908	5726	4651	17577	8847	7339
Phocid seals in water (PW)	L_{pk}	218	87	2	2	87	2	2
	L_E	185	5738	1234	1174	10051	3510	2377
Sea turtles	L_{pk}	232	0	-	-	0	-	-
	L_E	204	2426	422	306	5224	1230	945
Fish without swim bladder	L_{pk}	213	131	8	5	131	8	5
	L_E	216	408	85	45	1216	201	144
Fish with swim bladder not involved in hearing	L_{pk}	207	410	100	33	410	100	33
	L_E	203	3437	721	490	6822	1852	1471
Fish with swim bladder involved in hearing	L_{pk}	207	410	100	33	410	100	33
	L_E	203	3437	721	490	6822	1852	1471
Fish greater than or equal to 2 g	L_{pk}	206	440	108	87	440	108	87
	L_E	187	16714	6807	5342	26323	11998	10043
Fish less than 2 g	L_{pk}	206	440	108	87	440	108	87
	L_E	183	22684	10021	8265	34586	16738	14285

L_{pk} = unweighted peak sound pressure (dB re 1 µPa); L_E = frequency-weighted sound exposure level (dB re 1 µPa^2·s).
Thresholds are taken from Tables 8 to 10.
Dashes indicate that thresholds were not reached.

Table 21. SPL ranges ($R_{95\%}$ in meters) to marine fauna auditory behavioral thresholds for the 5000 kJ, 12 m monopile foundation. Ranges to SPL thresholds are for the highest hammer energy level.

Criteria source	L_p (dB re 1 µPa)	Frequency weighting	Faunal group	Attenuation level (dB)		
				0	10	12
NOAA (2005)	160	Unweighted	All species/behaviors	10867	4244	4026
Wood et al. (2012)	120	HF	Beaked whales and harbor porpoise	99797	57960	49856
	140	LF	Migrating mysticetes	38930	22062	19408
	160	LF	All other species/behaviors	10835	4235	4015
	160	MF		6181	3188	2896
	160	PW		7308	3716	3422
Finneran et al. (2017)	175	Unweighted	Sea turtles	3486	1365	984
McCauley et al. (2000)	166	Unweighted		6350	3349	3055
GARFO (2020)	150	Unweighted	Fish	22085	10867	9200

L_p = unweighted sound pressure level (dB re 1 µPa)
Thresholds are taken from Tables 8 to 10.

Table 22. SPL ranges ($R_{95\%}$ in meters) to marine fauna auditory behavioral thresholds for the 6000 kJ, 12 m monopile foundation. Ranges to SPL thresholds are for the highest hammer energy level.

Criteria source	L_p (dB re 1 µPa)	Frequency weighting	Faunal group	Attenuation level (dB)		
				0	10	12
NOAA (2005)	160	Unweighted	All species/behaviors	14103	5827	4702
Wood et al. (2012)	120	HF	Beaked whales and harbor porpoise	110217	87785	68471
	140	LF	Migrating mysticetes	48731	27061	24105
	160	LF	All other species/behaviors	14073	5795	4671
	160	MF		9225	3821	3389
	160	PW		12081	4257	4048
Finneran et al. (2017)	175	Unweighted	Sea turtles	4025	2068	1513
McCauley et al. (2000)	166	Unweighted		8568	3826	3488
GARFO (2020)	150	Unweighted	Fish	27084	14103	12041

L_p = unweighted sound pressure level (dB re 1 µPa)
Thresholds are taken from Tables 8 to 10.

Table 23. SPL ranges ($R_{95\%}$ in meters) to marine fauna auditory behavioral thresholds for the 5000 kJ, 13 m monopile foundation. Ranges to SPL thresholds are for the highest hammer energy level.

Criteria source	L_p (dB re 1 µPa)	Frequency weighting	Faunal group	Attenuation level (dB)		
				0	10	12
NOAA (2005)	160	Unweighted	All species/behaviors	12815	4636	4129
Wood et al. (2012)	120	HF	Beaked whales and harbor porpoise	117874	100049	88050
	140	LF	Migrating mysticetes	62209	27756	23899
	160	LF	All other species/behaviors	12759	4605	4121
	160	MF		6552	3112	2693
	160	PW		9754	3760	3347
Finneran et al. (2017)	175	Unweighted	Sea turtles	3441	1341	1000
GARFO (2020)	150	Unweighted	Fish	27802	12815	10708

L_p = unweighted sound pressure level (dB re 1 µPa)
Thresholds are taken from Tables 8 to 10.

Table 24. SPL Ranges ($R_{95\%}$ in meters) to marine fauna auditory behavioral thresholds for the 3500 kJ, 4 m jacket foundation. Ranges to SPL are for the highest hammer energy level.

Criteria source	L_p (dB re 1 µPa)	Frequency weighting	Faunal group	Attenuation level (dB)		
				0	10	12
NOAA (2005)	160	Unweighted	All species/behaviors	8424	3642	3414
Wood et al. (2012)	120	HF	Beaked whales and harbor porpoise	107076	79019	59400
	140	LF	Migrating mysticetes	40384	19704	16912
	160	LF	All other species/behaviors	8396	3638	3408
	160	MF		4696	2502	2193
	160	PW		6718	3224	2910
Finneran et al. (2017)	175	Unweighted	Sea turtles	2819	626	425
GARFO (2020)	150	Unweighted	Fish	19734	8424	6950

L_p = unweighted sound pressure level (dB re 1 µPa)
Thresholds are taken from Tables 8 to 10.

4.3. Sound Exposure Estimates

4.3.1. Marine Mammal Exposure Estimates

The mean number of marine mammals predicted to experience sound levels exceeding injury and behavior thresholds are provided in Tables 25–26 assuming 0, 10, and 12 dB broadband attenuation. These exposure estimates are calculated using the schedules described in Section 1.2.7, which combine the proposed years of construction. Appendix H contains supplemental results reported separately for each Project year. Exposure estimates utilize habitat-based models to derive species densities. These numbers may not be reflective of the current state of certain species' current populations, e.g., NARW, but are the best available data.

Table 25. Construction Schedule A, All Years Summed: The mean number of marine mammals predicted to receive sound levels above exposure criteria with sound attenuation. Construction schedule assumptions are summarized in Section 1.2.7.

Species	Injury						Behavior					
	L_E			L_{pk}			L_p [a]			L_p [b]		
	Attenuation (dB)						Attenuation (dB)					
	0	10	12	0	10	12	0	10	12	0	10	12
Low-frequency cetaceans												
Fin whale[c]	146.36	21.51	13.94	0.14	0.04	0.02	147.36	33.58	28.56	205.54	66.20	53.73
Minke whale	49.59	9.71	6.32	0.06	0.03	0.03	74.94	26.79	23.90	422.12	207.05	175.39
Humpback whale	81.08	13.69	9.09	0.13	0.05	0.05	68.89	16.46	14.11	97.99	31.83	25.69
North Atlantic right whale[c]	18.08	3.09	2.16	0.02	<0.01	<0.01	26.02	7.01	5.98	36.32	11.99	9.72
Sei whale[c]	3.60	0.53	0.36	0.01	<0.01	<0.01	5.44	1.29	1.09	42.29	20.13	16.86
Mid-frequency cetaceans												
Atlantic white-sided dolphin	0.62	0.21	0.21	1.56	1.56	1.56	3610.99	1334.89	1189.53	2722.32	1021.70	814.92
Atlantic spotted dolphin	0	0	0	0	0	0	14.74	3.92	3.38	17.04	4.18	3.03
Short-beaked common dolphin	4.05	1.28	0	6.96	5.09	5.09	16247.71	6999.42	6371.06	11666.25	4697.60	3805.18
Bottlenose dolphin	1.13	0.15	0	0.62	0.62	0.62	825.16	387.83	331.24	690.84	246.92	194.13
Risso's dolphin	0.04	0.02	<0.01	0.04	0.03	0.03	19.27	6.23	5.59	16.53	5.65	4.45
Long-finned pilot whale	0.06	0.06	0	0.15	0.15	0.15	447.66	165.24	147.76	324.89	126.66	100.70
Short-finned pilot whale	0.05	<0.01	<0.01	0.24	0.24	0.24	337.97	121.26	108.08	251.74	94.85	74.60
Sperm whale[c]	<0.01	<0.01	0	<0.01	<0.01	<0.01	8.93	2.64	2.34	7.71	2.52	1.92
High-frequency cetaceans												
Harbor porpoise	359.73	97.62	67.84	34.26	5.91	3.87	758.01	258.58	227.94	11092.63	5509.56	4618.70
Pinnipeds in water												
Gray seal	10.12	1.07	0.54	<0.01	<0.01	<0.01	170.45	32.11	24.86	199.28	60.51	47.44
Harbor seal	29.00	1.95	0.91	0.28	0.18	0.18	321.18	75.85	61.00	402.88	123.09	96.25
Harp seal	12.51	0.94	0.36	0.10	0	0	187.66	37.64	30.42	225.05	67.95	53.16

[a] NOAA (2005), [b] Wood et al. (2012), [c] Listed as Endangered under the ESA.

Table 26. Construction Schedule B, All Years Summed: The mean number of marine mammals predicted to receive sound levels above exposure criteria with sound attenuation. Construction schedule assumptions are summarized in Section 1.2.7.

Species	Injury						Behavior					
	L_E			L_{pk}			L_p [a]			L_p [b]		
	Attenuation (dB)						Attenuation (dB)					
	0	10	12	0	10	12	0	10	12	0	10	12
Low-frequency cetaceans												
Fin whale[c]	251.74	37.72	25.35	0.31	0.09	0.02	160.68	41.87	37.77	236.43	78.58	64.38
Minke whale	97.69	20.59	13.10	0.10	0.03	0.03	115.38	50.89	46.74	617.91	300.67	253.54
Humpback whale	117.67	20.47	13.67	0.15	0.02	0.02	69.43	19.53	17.64	101.72	34.17	27.70
North Atlantic right whale[c]	19.76	3.92	2.77	0.02	<0.01	<0.01	19.26	6.92	6.23	25.98	9.34	7.75
Sei whale[c]	6.78	1.14	0.83	0.02	<0.01	<0.01	6.12	1.88	1.73	54.33	24.66	20.41
Mid-frequency cetaceans												
Atlantic white-sided dolphin	2.60	0.87	0.87	1.17	1.17	1.17	5332.04	2385.18	2160.55	4060.10	1638.66	1327.44
Atlantic spotted dolphin	0	0	0	0	0	0	17.42	4.31	3.75	21.26	5.24	3.76
Short-beaked common dolphin	7.55	2.52	0	5.72	5.16	5.16	19012.51	9012.55	8248.25	13432.98	5737.60	4697.05
Bottlenose dolphin	2.02	0.31	0	0.41	0.41	0.41	998.97	526.97	447.68	830.86	315.02	248.12
Risso's dolphin	0.05	0.03	<0.01	0.03	0.02	0.01	23.89	8.98	8.23	20.92	7.52	5.97
Long-finned pilot whale	0.18	0.18	0	0.14	0.14	0.14	601.70	260.80	237.32	432.84	181.87	146.36
Short-finned pilot whale	0.08	0.01	0	0.14	0.14	0.14	447.99	194.21	175.55	334.52	135.57	107.62
Sperm whale[c]	<0.01	<0.01	0	<0.01	<0.01	<0.01	13.09	4.60	4.19	11.90	4.04	3.13
High-frequency cetaceans												
Harbor porpoise	611.86	173.78	117.38	56.46	8.82	6.32	932.60	400.40	363.83	12817.69	5868.55	4939.12
Pinnipeds in water												
Gray seal	13.69	1.55	0.92	<0.01	<0.01	<0.01	103.73	21.91	19.94	131.69	41.14	31.52
Harbor seal	48.24	3.85	1.64	0.77	0.10	0.10	236.43	77.88	67.72	300.72	99.42	78.24
Harp seal	20.33	1.42	0.52	0.19	0	0	129.91	36.14	32.17	159.01	52.37	41.11

[a] NOAA (2005), [b] Wood et al. (2012), [c] Listed as Endangered under the ESA.

4.3.2. Sea Turtle Exposure Estimates

The mean number of sea turtles predicted to experience sound levels exceeding injury and behavior thresholds are provided in Tables 27 and 28 assuming 0, 10, and 12 dB broadband attenuation. These exposure estimates are calculated using the schedules described in Section 1.2.7, which combine the proposed years of construction. Appendix H.2.1 contains supplemental results reported separately for each Project year.

Table 27. Construction Schedule A, All Years Summed: The mean number of sea turtles predicted to receive sound levels above exposure criteria with sound attenuation. Construction schedule assumptions are summarized in Section 1.2.7.

Species	Injury						Behavior		
	L_E			L_{pk}			L_p		
	Attenuation (dB)						Attenuation (dB)		
	0	10	12	0	10	12	0	10	12
Kemp's ridley turtle[a]	0.24	<0.01	<0.01	<0.01	<0.01	<0.01	1.15	0.25	0.18
Leatherback turtle[a]	5.57	0.23	0.02	0.23	0.23	0.23	40.48	8.57	5.69
Loggerhead turtle	2.18	0.04	<0.01	0.08	0.08	0.08	22.56	4.57	3.23
Green turtle	0.49	0.01	<0.01	<0.01	<0.01	<0.01	1.26	0.32	0.20

[a] Listed as Endangered under the ESA.

Table 28. Construction Schedule B, All Years Summed: The mean number of sea turtles predicted to receive sound levels above exposure criteriawith sound attenuation. Construction schedule assumptions are summarized in Section 1.2.7.

Species	Injury						Behavior		
	L_E			L_{pk}			L_p		
	Attenuation (dB)						Attenuation (dB)		
	0	10	12	0	10	12	0	10	12
Kemp's ridley turtle[a]	0.42	0.01	0	<0.01	<0.01	<0.01	1.64	0.35	0.27
Leatherback turtle[a]	8.07	0.18	0	0.17	0.17	0.17	55.79	10.09	6.82
Loggerhead turtle	2.64	0	0	0.09	0.09	0.09	27.72	5.24	3.88
Green turtle	0.77	0.02	<0.01	<0.01	<0.01	<0.01	1.69	0.42	0.23

[a] Listed as Endangered under the ESA.

4.3.3. Effect of Aversion

The exposure estimates tables above and in Appendices H.2.1 and H.2.2 do not account for aversion or the implementation of mitigation measures other than sound attenuation (e.g., pile driving shut-down or power down). However, to demonstrate the potential effect of aversion, a subset of the animat simulations (harbor porpoise and NARW) were run using the approach described in Section 2.6.1. For comparative purposes only, the results are shown with and without aversion (Table 29).

Table 29. Comparison of mean exposure estimates modeled for Construction Schedule A (all years summed) for harbor porpoises and North Atlantic right whales (NARWs) when aversion is included in animal movement models relative to models without aversion, assuming 10 dB attenuation.

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	3.09	<0.01	7.01	11.99	0.52	<0.01	3.14	9.50
Harbor porpoise	97.62	5.91	258.58	5509.56	0.39	0	14.13	4270.28

4.3.4. Potential Impacts Relative to Species' Abundance

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

Defining biologically significant impacts to a population of animals that result from injury or behavioral responses estimated from exposure models and acoustic thresholds remains somewhat subjective. The percent 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 provided in Section 4.3.1 are presented as a percent of total abundance for each species and each attenuation level in Tables 30 and 31. Abundance numbers used to calculate the percent of population estimated to receive threshold levels of sound are shown in Table 13.

Table 30. Construction Schedule A, All Years Summed: Marine mammal exposures as a percent of abundance with sound attenuation. Construction schedule assumptions are summarized in Section 1.2.7.

Species	Injury						Behavior					
	L_E			L_{pk}			L_p [a]			L_p [b]		
	Attenuation (dB)						Attenuation (dB)					
	0	10	12	0	10	12	0	10	12	0	10	12
Low-frequency cetaceans												
Fin whale[c]	2.15	0.32	0.20	<0.01	<0.01	<0.01	2.17	0.49	0.42	3.02	0.97	0.79
Minke whale	0.23	0.04	0.03	<0.01	<0.01	<0.01	0.34	0.12	0.11	1.92	0.94	0.80
Humpback whale	5.81	0.98	0.65	<0.01	<0.01	<0.01	4.94	1.18	1.01	7.02	2.28	1.84
North Atlantic right whale[c]	4.91	0.84	0.59	<0.01	<0.01	<0.01	7.07	1.91	1.62	9.87	3.26	2.64
Sei whale[c]	0.06	<0.01	<0.01	<0.01	<0.01	<0.01	0.09	0.02	0.02	0.67	0.32	0.27
Mid-frequency cetaceans												
Atlantic white-sided dolphin	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	3.87	1.43	1.28	2.92	1.10	0.87
Atlantic spotted dolphin	0	0	0	0	0	0	0.04	<0.01	<0.01	0.04	0.01	<0.01
Short-beaked common dolphin	<0.01	<0.01	0	<0.01	<0.01	<0.01	9.39	4.05	3.68	6.74	2.72	2.20
Bottlenose dolphin	<0.01	<0.01	0	<0.01	<0.01	<0.01	1.31	0.62	0.53	1.10	0.39	0.31
Risso's dolphin	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.05	0.02	0.02	0.05	0.02	0.01
Long-finned pilot whale	<0.01	<0.01	0	<0.01	<0.01	<0.01	1.14	0.42	0.38	0.83	0.32	0.26
Short-finned pilot whale	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	1.17	0.42	0.37	0.87	0.33	0.26
Sperm whale[c]	<0.01	<0.01	0	<0.01	<0.01	<0.01	0.21	0.06	0.05	0.18	0.06	0.04
High-frequency cetaceans												
Harbor porpoise	0.38	0.10	0.07	0.04	<0.01	<0.01	0.79	0.27	0.24	11.61	5.77	4.83
Pinnipeds in water												
Gray seal	0.04	<0.01	<0.01	<0.01	<0.01	<0.01	0.62	0.12	0.09	0.73	0.22	0.17
Harbor seal	0.05	<0.01	<0.01	<0.01	<0.01	<0.01	0.52	0.12	0.10	0.66	0.20	0.16
Harp seal	<0.01	<0.01	<0.01	<0.01	0	0	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

[a] NOAA (2005), [b] Wood et al. (2012), [c] Listed as Endangered under the ESA.

Table 31. Construction Schedule B, All Years Summed: Marine mammal exposures as a percent of abundance with sound attenuation. Construction schedule assumptions are summarized in Section 1.2.7.

Species	Injury						Behavior					
	L_E			L_{pk}			L_p [a]			L_p [b]		
	Attenuation (dB)						Attenuation (dB)					
	0	10	12	0	10	12	0	10	12	0	10	12
Low-frequency cetaceans												
Fin whale[c]	3.70	0.55	0.37	<0.01	<0.01	<0.01	2.36	0.62	0.56	3.48	1.16	0.95
Minke whale	0.44	0.09	0.06	<0.01	<0.01	<0.01	0.53	0.23	0.21	2.81	1.37	1.15
Humpback whale	8.43	1.47	0.98	0.01	<0.01	<0.01	4.97	1.40	1.26	7.29	2.45	1.98
North Atlantic right whale[c]	5.37	1.06	0.75	<0.01	<0.01	<0.01	5.23	1.88	1.69	7.06	2.54	2.11
Sei whale[c]	0.11	0.02	0.01	<0.01	<0.01	<0.01	0.10	0.03	0.03	0.86	0.39	0.32
Mid-frequency cetaceans												
Atlantic white-sided dolphin	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	5.72	2.56	2.32	4.35	1.76	1.42
Atlantic spotted dolphin	0	0	0	0	0	0	0.04	0.01	<0.01	0.05	0.01	<0.01
Short-beaked common dolphin	<0.01	<0.01	0	<0.01	<0.01	<0.01	10.99	5.21	4.77	7.77	3.32	2.72
Bottlenose dolphin	<0.01	<0.01	0	<0.01	<0.01	<0.01	1.59	0.84	0.71	1.32	0.50	0.39
Risso's dolphin	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.07	0.03	0.02	0.06	0.02	0.02
Long-finned pilot whale	<0.01	<0.01	0	<0.01	<0.01	<0.01	1.53	0.67	0.61	1.10	0.46	0.37
Short-finned pilot whale	<0.01	<0.01	0	<0.01	<0.01	<0.01	1.55	0.67	0.61	1.16	0.47	0.37
Sperm whale[c]	<0.01	<0.01	0	<0.01	<0.01	<0.01	0.30	0.11	0.10	0.27	0.09	0.07
High-frequency cetaceans												
Harbor porpoise	0.64	0.18	0.12	0.06	<0.01	<0.01	0.98	0.42	0.38	13.42	6.14	5.17
Pinnipeds in water												
Gray seal	0.05	<0.01	<0.01	<0.01	<0.01	<0.01	0.38	0.08	0.07	0.48	0.15	0.12
Harbor seal	0.08	<0.01	<0.01	<0.01	<0.01	<0.01	0.39	0.13	0.11	0.49	0.16	0.13
Harp seal	<0.01	<0.01	<0.01	<0.01	0	0	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

[a] NOAA (2005), [b] Wood et al. (2012), [c] Listed as Endangered under the ESA.

4.4. Exposure-based Ranges to Thresholds for Impact Pile Driving

The following subsections contain tables of exposure ranges (ER95%) calculated to both injury and behavioral sound exposure thresholds described in Sections 2.4 and 2.5 for the 12 and 13 m monopile, and 4 m jacket foundations. Exposure ranges are computed using the simulated movements of individual animats within each species group considered in the animal movement and exposure modeling, so ER95% results are reported by species rather than hearing group.

4.4.1. Marine Mammals

Exposure ranges ($ER_{95\%}$) to acoustic thresholds for injury and behavior are presented for jacket and monopile foundations, assuming 0, 10, and 12 dB broadband attenuation. This section includes only the subset of foundations and installation schedules included in Construction Schedules A and B (see Section 1.2.7). Additional configurations are provided in Appendix H.2.4.

Table 32. 12 m monopile, 5000 kJ hammer, one pile per day: Exposure ranges ($ER_{95\%}$) in km to marine mammal threshold criteria with sound attenuation.

Species	Injury						Behavior					
	L_E			L_{pk}			L_p [a]			L_p [b]		
	Attenuation (dB)						Attenuation (dB)					
	0	10	12	0	10	12	0	10	12	0	10	12
Low-frequency cetaceans												
Fin whale[c]	7.99	2.37	1.91	0.04	0.01	0.01	10.45	4.00	3.71	10.46	3.99	3.72
Minke whale	6.38	1.50	0.97	0.04	0.02	0.02	10.04	3.89	3.50	36.32	20.29	17.93
Humpback whale	9.08	2.76	2.12	0	0	0	10.45	3.99	3.74	10.47	3.99	3.74
North Atlantic right whale[c]	7.81	1.84	1.52	0	0	0	10.01	3.94	3.62	10.12	3.97	3.60
Sei whale[c]	7.20	1.95	1.26	<0.01	<0.01	<0.01	10.21	3.88	3.67	38.10	21.02	18.41
Mid-frequency cetaceans												
Atlantic white-sided dolphin	0	0	0	0.01	0.01	0.01	9.76	3.78	3.48	5.52	2.75	2.35
Atlantic spotted dolphin	0	0	0	0	0	0	10.11	4.15	2.98	5.69	2.57	1.93
Short-beaked common dolphin	0	0	0	0.01	0.01	0.01	9.79	3.79	3.51	5.61	2.86	2.42
Bottlenose dolphin	0	0	0	0.01	0.01	0.01	9.35	3.40	2.97	5.03	2.34	1.74
Risso's dolphin	0.02	0	0	0.02	<0.01	<0.01	10.20	3.85	3.62	6.07	2.94	2.65
Long-finned pilot whale	0	0	0	0.02	0.02	0.02	9.90	3.85	3.53	5.55	2.93	2.39
Short-finned pilot whale	<0.01	<0.01	0	<0.01	<0.01	<0.01	9.91	3.83	3.56	5.56	2.86	2.39
Sperm whale[c]	0	0	0	0.02	0.02	0.02	10.18	3.90	3.72	5.71	2.96	2.32
High-frequency cetaceans												
Harbor porpoise	5.17	1.55	1.07	0.56	0.13	0.11	9.97	3.94	3.66	97.57	53.67	46.82
Pinnipeds in water												
Gray seal	2.23	0.51	0.42	0	0	0	10.73	4.13	3.95	8.67	3.56	3.28
Harbor seal	2.03	0.21	0.02	0.02	0.02	0.02	10.28	3.75	3.56	8.33	3.33	3.09
Harp seal	1.80	0.15	0.06	0.05	0	0	10.43	4.00	3.54	8.50	3.48	3.16

[a] NOAA (2005), [b] Wood et al. (2012), [c] Listed as Endangered under the ESA.

Table 33. 12 m monopile, 5000 kJ hammer, two piles per day: Exposure ranges ($ER_{95\%}$) in km to marine mammal threshold criteria with sound attenuation.

Species	Injury						Behavior					
	L_E			L_{pk}			L_p [a]			L_p [b]		
	Attenuation (dB)						Attenuation (dB)					
	0	10	12	0	10	12	0	10	12	0	10	12
Low-frequency cetaceans												
Fin whale[c]	9.66	2.79	2.19	0.02	0	0	10.31	3.98	3.80	10.37	4.00	3.82
Minke whale	7.29	1.67	1.29	0.07	0.02	0.02	9.67	3.80	3.55	36.30	20.44	17.74
Humpback whale	10.91	3.44	2.46	0.03	0.01	0.01	10.44	3.98	3.66	10.50	3.98	3.66
North Atlantic right whale[c]	8.81	2.34	1.69	0.04	<0.01	<0.01	9.99	3.75	3.52	10.10	3.76	3.53
Sei whale[c]	8.50	2.04	1.50	0.03	0.02	0.02	10.17	3.85	3.54	38.42	20.94	18.42
Mid-frequency cetaceans												
Atlantic white-sided dolphin	0	0	0	0.02	0.02	0.02	9.47	3.74	3.35	5.48	2.77	2.32
Atlantic spotted dolphin	0	0	0	0	0	0	9.60	3.66	3.32	5.17	2.78	2.33
Short-beaked common dolphin	0	0	0	0.02	0.02	0.02	9.62	3.81	3.46	5.51	2.87	2.36
Bottlenose dolphin	<0.01	0	0	0.01	0.01	0.01	8.99	3.25	2.96	5.04	2.21	1.92
Risso’s dolphin	0.02	<0.01	<0.01	0.02	0.02	0.01	10.01	3.80	3.55	5.82	2.85	2.49
Long-finned pilot whale	0	0	0	0.01	0.01	0.01	9.70	3.74	3.46	5.56	2.89	2.34
Short-finned pilot whale	0	0	0	0.02	0.02	0.02	9.71	3.78	3.48	5.58	2.85	2.31
Sperm whale[c]	0.29	0	0	<0.01	<0.01	<0.01	9.75	3.79	3.55	5.54	2.82	2.39
High-frequency cetacean												
Harbor porpoise	5.50	1.60	1.28	0.56	0.15	0.09	9.91	3.86	3.63	97.41	53.14	46.68
Pinnipeds in water												
Gray seal	2.51	0.56	0.38	0.01	0.01	0.01	10.49	4.17	3.94	8.58	3.68	3.28
Harbor seal	2.43	0.21	0.16	<0.01	<0.01	<0.01	10.20	3.81	3.63	8.32	3.45	3.14
Harp seal	2.20	0.31	0.09	0.06	0	0	10.40	4.01	3.60	8.36	3.54	3.12

[a] NOAA (2005), [b] Wood et al. (2012), [c] Listed as Endangered under the ESA.

Table 34. 12 m monopile, 6000 kJ hammer, one pile per day: Exposure ranges ($ER_{95\%}$) in km to marine mammal threshold criteria with sound attenuation.

Species	Injury						Behavior					
	L_E			L_{pk}			L_p [a]			L_p [b]		
	Attenuation (dB)						Attenuation (dB)					
	0	10	12	0	10	12	0	10	12	0	10	12
Low-frequency cetaceans												
Fin whale[c]	10.14	3.31	2.45	0.04	0.01	0.01	15.62	6.19	4.63	15.63	6.21	4.66
Minke whale	8.15	2.40	1.68	0.02	0.02	0.02	14.49	5.66	4.27	60.34	28.63	25.77
Humpback whale	11.12	3.81	2.89	0.08	0	0	15.58	5.95	4.87	15.57	5.88	4.87
North Atlantic right whale[c]	9.84	2.93	2.03	0	0	0	14.50	5.46	4.51	14.58	5.48	4.52
Sei whale[c]	9.31	2.47	2.16	<0.01	<0.01	<0.01	15.08	5.79	4.69	73.70	31.08	26.82
Mid-frequency cetaceans												
Atlantic white-sided dolphin	0	0	0	0.01	0.01	0.01	14.21	5.35	4.34	8.81	3.31	2.93
Atlantic spotted dolphin	0	0	0	0	0	0	15.29	5.87	4.57	8.91	3.13	3.04
Short-beaked common dolphin	0	0	0	0.01	0.01	0.01	14.53	5.68	4.39	9.04	3.36	2.97
Bottlenose dolphin	0.11	0	0	0.01	0.01	0.01	14.04	4.77	3.94	8.13	3.02	2.72
Risso's dolphin	0.02	0.02	0	0.02	<0.01	<0.01	15.28	5.55	4.52	9.23	3.46	3.04
Long-finned pilot whale	0	0	0	0.02	0.02	0.02	14.61	5.55	4.44	8.81	3.37	3.00
Short-finned pilot whale	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	14.46	5.57	4.55	8.97	3.30	3.03
Sperm whale[c]	0.01	0	0	0.02	0.02	0.02	15.19	5.73	4.59	8.98	3.47	3.00
High-frequency cetaceans												
Harbor porpoise	6.53	2.26	1.69	0.60	0.21	0.18	14.64	5.76	4.45	105.70	84.55	80.55
Pinnipeds in water												
Gray seal	2.96	0.84	0.52	0	0	0	15.61	6.06	5.03	13.09	4.38	3.88
Harbor seal	2.86	0.43	0.22	0.02	0.02	0.02	15.39	6.01	4.48	12.58	4.09	3.70
Harp seal	2.39	0.25	0.09	0.05	0	0	15.38	5.93	4.89	12.83	4.22	3.89

[a] NOAA (2005), [b] Wood et al. (2012), [c] Listed as Endangered under the ESA.

Table 35. 12 m monopile, 6000 kJ hammer, two piles per day: Exposure ranges ($ER_{95\%}$) in km to marine mammal threshold criteria with sound attenuation.

Species	Injury						Behavior					
	L_E			L_{pk}			L_p [a]			L_p [b]		
	Attenuation (dB)						Attenuation (dB)					
	0	10	12	0	10	12	0	10	12	0	10	12
Low-frequency cetaceans												
Fin whale[c]	12.55	3.90	2.86	0.02	0	0	15.82	6.01	4.91	15.86	5.97	4.90
Minke whale	9.23	2.59	1.82	0.02	0.02	0.02	14.65	5.33	4.39	66.79	29.19	25.67
Humpback whale	13.59	4.62	3.60	0.03	0.01	0.01	15.78	5.92	4.72	15.81	5.93	4.72
North Atlantic right whale[c]	11.16	3.16	2.49	0.04	<0.01	<0.01	14.51	5.60	4.45	14.61	5.65	4.45
Sei whale[c]	11.07	3.08	2.25	0.02	0.02	0.02	15.40	5.79	4.79	76.41	32.38	27.74
Mid-frequency cetaceans												
Atlantic white-sided dolphin	0	0	0	0.02	0.02	0.02	14.09	5.40	4.29	8.54	3.22	2.83
Atlantic spotted dolphin	0	0	0	0	0	0	15.03	5.47	3.95	8.53	2.89	2.72
Short-beaked common dolphin	0.02	0	0	0.02	0.02	0.02	14.35	5.54	4.34	8.88	3.33	3.08
Bottlenose dolphin	0.19	0	0	0.01	0.01	0.01	14.12	4.93	3.77	8.39	2.92	2.57
Risso’s dolphin	0.03	<0.01	<0.01	0.02	0.02	0.02	15.39	5.89	4.54	9.27	3.33	3.09
Long-finned pilot whale	0	0	0	0.01	0.01	0.01	14.65	5.50	4.43	8.80	3.26	2.95
Short-finned pilot whale	0.02	0	0	0.02	0.02	0.02	14.60	5.62	4.43	8.85	3.27	2.99
Sperm whale[c]	0.29	0	0	<0.01	<0.01	<0.01	14.98	5.84	4.58	8.81	3.42	2.96
High-frequency cetaceans												
Harbor porpoise	7.01	2.30	1.69	0.66	0.17	0.15	14.63	5.48	4.53	107.40	86.45	82.28
Pinnipeds in water												
Gray seal	3.29	1.01	0.56	0.01	0.01	0.01	15.83	6.05	4.92	13.02	4.31	4.07
Harbor seal	3.31	0.63	0.19	0.07	<0.01	<0.01	15.37	6.03	4.78	12.97	4.15	3.63
Harp seal	3.07	0.41	0.20	0	0	0	15.69	5.97	4.86	12.86	4.23	3.83

[a] NOAA (2005), [b] Wood et al. (2012), [c] Listed as Endangered under the ESA.

Table 36. 13 m monopile, 5000 kJ hammer, one pile per day: Exposure ranges ($ER_{95\%}$) in km to marine mammal threshold criteria with sound attenuation.

Species	Injury						Behavior					
	L_E			L_{pk}			L_p [a]			L_p [b]		
	Attenuation (dB)						Attenuation (dB)					
	0	10	12	0	10	12	0	10	12	0	10	12
Low-frequency cetaceans												
Fin whale[c]	8.78	2.56	1.90	0.02	0	0	12.46	4.29	3.88	12.46	4.24	3.88
Minke whale	6.30	1.50	1.17	0	0	0	11.63	3.98	3.63	48.40	24.76	21.91
Humpback whale	9.40	2.87	2.27	0.03	<0.01	<0.01	12.35	4.26	3.74	12.37	4.25	3.74
North Atlantic right whale[c]	8.05	2.26	1.54	0.03	<0.01	<0.01	12.11	4.11	3.70	12.21	4.17	3.70
Sei whale[c]	7.73	1.66	1.25	0.03	<0.01	<0.01	11.98	4.21	3.69	61.51	25.73	22.45
Mid-frequency cetaceans												
Atlantic white-sided dolphin	0	0	0	0	0	0	11.47	3.95	3.58	5.68	2.55	2.27
Atlantic spotted dolphin	0	0	0	0	0	0	11.50	4.01	3.76	5.34	2.64	2.59
Short-beaked common dolphin	0	0	0	<0.01	0	0	11.57	3.99	3.48	6.15	2.64	2.31
Bottlenose dolphin	0	0	0	0	0	0	10.98	3.53	3.01	5.73	2.30	1.97
Risso's dolphin	0.01	<0.01	0	<0.01	0	0	12.15	4.26	3.77	6.28	2.62	2.39
Long-finned pilot whale	0	0	0	0	0	0	11.69	4.08	3.52	5.96	2.68	2.22
Short-finned pilot whale	0	0	0	<0.01	<0.01	<0.01	11.82	4.10	3.53	6.04	2.68	2.40
Sperm whale[c]	0	0	0	0	0	0	11.88	4.15	3.64	6.17	2.61	2.36
High-frequency cetacean												
Harbor porpoise	5.13	1.51	1.07	0.59	0.23	0.19	11.79	4.00	3.63	106.34	85.66	79.37
Pinnipeds in water												
Gray seal	2.16	0.59	0.12	0	0	0	12.56	4.53	4.08	9.67	3.73	3.30
Harbor seal	1.94	0.16	0	0	0	0	12.21	4.25	3.73	9.48	3.31	3.17
Harp seal	1.85	0.09	0	0	0	0	12.31	4.30	3.75	9.48	3.40	3.07

[a] NOAA (2005), [b] Wood et al. (2012), [c] Listed as Endangered under the ESA.

Table 37. 13 m monopile, 5000 kJ hammer, two piles per day: Exposure ranges ($ER_{95\%}$) in km to marine mammal threshold criteria with sound attenuation.

Species	Injury						Behavior					
	L_E			L_{pk}			L_p [a]			L_p [b]		
	Attenuation (dB)						Attenuation (dB)					
	0	10	12	0	10	12	0	10	12	0	10	12
Low-frequency cetaceans												
Fin whale[c]	10.98	3.14	2.24	0.02	0	0	12.35	4.20	3.84	12.35	4.20	3.84
Minke whale	7.37	1.65	1.20	0	0	0	11.51	3.82	3.55	49.23	24.59	21.59
Humpback whale	11.59	3.66	2.79	0.05	<0.01	<0.01	12.28	4.26	3.83	12.30	4.26	3.84
North Atlantic right whale[c]	9.52	2.53	1.79	0.02	<0.01	<0.01	11.65	4.03	3.51	11.76	4.07	3.55
Sei whale[c]	9.48	2.31	1.62	0.03	<0.01	<0.01	11.87	3.96	3.62	62.48	25.94	22.40
Mid-frequency cetaceans												
Atlantic white-sided dolphin	0	0	0	0	0	0	11.12	3.84	3.31	5.76	2.43	2.20
Atlantic spotted dolphin	0	0	0	0	0	0	11.23	3.85	3.28	5.28	2.55	2.14
Short-beaked common dolphin	0	0	0	<0.01	0	0	11.28	3.95	3.43	5.96	2.65	2.31
Bottlenose dolphin	0	0	0	<0.01	<0.01	<0.01	10.63	3.37	2.91	5.37	2.22	2.10
Risso's dolphin	0.02	<0.01	<0.01	<0.01	<0.01	<0.01	11.90	4.03	3.64	6.24	2.64	2.42
Long-finned pilot whale	0	0	0	0	0	0	11.51	3.90	3.51	5.80	2.63	2.23
Short-finned pilot whale	0	0	0	<0.01	<0.01	<0.01	11.58	3.95	3.50	5.95	2.64	2.31
Sperm whale[c]	0.30	0	0	<0.01	0	0	11.77	4.08	3.60	6.18	2.58	2.29
High-frequency cetaceans												
Harbor porpoise	5.48	1.50	1.20	0.61	0.21	0.19	11.46	3.95	3.58	107.93	85.98	79.39
Pinnipeds in water												
Gray seal	2.55	0.57	0.32	0	0	0	12.49	4.52	4.12	9.67	3.67	3.29
Harbor seal	2.69	0.19	0.08	0	0	0	12.02	4.25	3.70	9.31	3.34	3.20
Harp seal	2.22	0.32	0.05	0.06	0	0	12.11	4.29	3.73	9.40	3.49	3.16

[a] NOAA (2005), [b] Wood et al. (2012), [c] Listed as Endangered under the ESA.

Table 38. 4 m pin pile, 3500 kJ hammer, four pin piles per day: Exposure ranges ($ER_{95\%}$) in km to marine mammal threshold criteria with sound attenuation.

Species	Injury						Behavior					
	L_E			L_{pk}			L_p [a]			L_p [b]		
	Attenuation (dB)						Attenuation (dB)					
	0	10	12	0	10	12	0	10	12	0	10	12
Low-frequency cetaceans												
Fin whale[c]	13.29	4.07	3.14	0.02	<0.01	0	8.47	3.56	3.29	8.49	3.58	3.30
Minke whale	7.87	1.83	1.26	0.01	0	0	8.00	3.34	3.20	37.71	19.07	16.46
Humpback whale	13.83	4.49	3.25	0.02	0	0	8.44	3.56	3.28	8.44	3.57	3.28
North Atlantic right whale[c]	10.37	2.54	1.74	0.02	0	0	8.15	3.34	3.16	8.23	3.38	3.19
Sei whale[c]	10.90	2.84	1.89	<0.01	0	0	8.22	3.39	3.23	40.08	19.61	16.97
Mid-frequency cetaceans												
Atlantic white-sided dolphin	0.01	0.01	0.01	0	0	0	8.02	3.27	3.12	4.43	2.33	1.97
Atlantic spotted dolphin	0	0	0	0	0	0	8.40	3.26	3.17	4.39	2.27	2.01
Short-beaked common dolphin	<0.01	<0.01	0	0	0	0	7.98	3.34	3.15	4.49	2.41	2.07
Bottlenose dolphin	0.08	0.01	0	0	0	0	6.44	2.87	2.59	3.79	1.90	1.50
Risso's dolphin	0.01	0.01	0.01	<0.01	0	0	8.27	3.38	3.16	4.59	2.42	2.06
Long-finned pilot whale	<0.01	<0.01	0	0	0	0	7.96	3.30	3.10	4.49	2.32	1.91
Short-finned pilot whale	0.01	0	0	0	0	0	7.95	3.37	3.16	4.40	2.38	1.96
Sperm whale[c]	<0.01	<0.01	0	0	0	0	8.17	3.36	3.11	4.61	2.35	1.89
High-frequency cetaceans												
Harbor porpoise	5.90	1.77	1.29	0.53	0.10	0.10	8.15	3.38	3.21	96.13	65.51	54.74
Pinnipeds in water												
Gray seal	4.35	1.31	0.96	0	0	0	8.52	3.49	3.38	6.83	3.30	2.91
Harbor seal	3.33	0.32	0.12	0.06	0	0	8.33	3.44	3.12	6.68	3.08	2.70
Harp seal	2.85	0.28	0.15	0.07	0	0	8.44	3.49	3.24	6.77	3.21	2.81

[a] NOAA (2005), [b] Wood et al. (2012), [c] Listed as Endangered under the ESA.

4.4.2. Sea Turtles

Similar to the results presented for marine mammals (Section 4.4.1), exposure ranges ($ER_{95\%}$) to acoustic thresholds for injury and behavior are presented for jacket and monopile foundations, assuming 0, 10, and 12 dB broadband attenuation. This section includes only the subset of foundations and installation schedules included in Construction Schedules A and B (see Section 1.2.7). Additional configurations are provided in Appendix H.2.5.

Table 39. 12 m monopile, 5000 kJ hammer, one pile per day: Exposure ranges ($ER_{95\%}$) in km to sea turtle threshold criteria with sound attenuation.

Species	Injury						Behavior		
	L_E			L_{pk}			L_p		
	Attenuation (dB)						Attenuation (dB)		
	0	10	12	0	10	12	0	10	12
Kemp's ridley turtle[a]	0.72	0.02	0	0	0	0	2.91	0.82	0.69
Leatherback turtle[a]	0.98	0	0	<0.01	<0.01	<0.01	2.76	0.78	0.44
Loggerhead turtle	0.12	0	0	0.02	0.02	0.02	2.65	0.75	0.38
Green turtle	1.03	0.02	0.02	0.01	0.01	0.01	3.19	1.03	0.77

[a] Listed as Endangered under the ESA.

Table 40. 12 m monopile, 5000 kJ hammer, two piles per day: Exposure ranges ($ER_{95\%}$) in km to sea turtle threshold criteria with sound attenuation.

Species	Injury						Behavior		
	L_E			L_{pk}			L_p		
	Attenuation (dB)						Attenuation (dB)		
	0	10	12	0	10	12	0	10	12
Kemp's ridley turtle[a]	0.60	0.02	0	0.02	0.02	0.02	3.05	0.83	0.60
Leatherback turtle[a]	0.58	0.02	0	0.02	0.02	0.02	2.67	0.68	0.65
Loggerhead turtle	0.40	0	0	0.01	0.01	0.01	2.53	0.58	0.40
Green turtle	1.38	<0.01	<0.01	<0.01	<0.01	<0.01	3.21	1.17	0.72

[a] Listed as Endangered under the ESA.

Table 41. 12 m monopile, 6000 kJ hammer, one pile per day: Exposure ranges ($ER_{95\%}$) in km to sea turtle threshold criteria with sound attenuation.

Species	Injury						Behavior		
	L_E			L_{pk}			L_p		
	Attenuation (dB)						Attenuation (dB)		
	0	10	12	0	10	12	0	10	12
Kemp's ridley turtle[a]	0.97	0.07	0.02	0	0	0	3.53	1.66	0.88
Leatherback turtle[a]	1.21	0.03	0	<0.01	<0.01	<0.01	3.12	1.39	0.91
Loggerhead turtle	0.75	0.02	<0.01	0.02	0.02	0.02	3.42	1.13	1.06
Green turtle	1.87	0.16	0.07	0.01	0	0	3.78	1.97	1.44

[a] Listed as Endangered under the ESA.

Table 42. 12 m monopile, 6000 kJ hammer, two piles per day: Exposure ranges ($ER_{95\%}$) in km to sea turtle threshold criteria with sound attenuation.

Species	Injury						Behavior		
	L_E			L_{pk}			L_p		
	Attenuation (dB)						Attenuation (dB)		
	0	10	12	0	10	12	0	10	12
Kemp's ridley turtle[a]	1.12	0.02	0.02	0.02	0.02	0.02	3.57	1.77	1.31
Leatherback turtle[a]	1.27	0.17	0.02	0.02	0.02	0.02	3.24	1.35	1.12
Loggerhead turtle	0.63	<0.01	<0.01	0.01	0.01	0.01	3.05	1.20	0.85
Green turtle	2.24	0.15	0.03	<0.01	<0.01	<0.01	3.65	1.83	1.49

[a] Listed as Endangered under the ESA.

Table 43. 13 m monopile, 5000 kJ hammer, one pile per day: Exposure ranges ($ER_{95\%}$) in km to sea turtle threshold criteria with sound attenuation.

Species	Injury						Behavior		
	L_E			L_{pk}			L_p		
	Attenuation (dB)						Attenuation (dB)		
	0	10	12	0	10	12	0	10	12
Kemp's ridley turtle[a]	0.60	0	0	<0.01	<0.01	<0.01	2.83	1.19	0.69
Leatherback turtle[a]	0.58	0	0	0	0	0	2.78	0.69	0.51
Loggerhead turtle	0.29	<0.01	0	0	0	0	2.54	0.62	0.55
Green turtle	1.11	<0.01	<0.01	0	0	0	3.27	1.15	0.98

[a] Listed as Endangered under the ESA.

Table 44. 13 m monopile, 5000 kJ hammer, two piles per day: Exposure ranges ($ER_{95\%}$) in km to sea turtle threshold criteria with sound attenuation.

Species	Injury						Behavior		
	L_E			L_{pk}			L_p		
	Attenuation (dB)						Attenuation (dB)		
	0	10	12	0	10	12	0	10	12
Kemp's ridley turtle[a]	0.68	0.02	0	<0.01	<0.01	<0.01	2.87	1.12	0.87
Leatherback turtle[a]	0.56	0.02	0	0	0	0	2.77	0.98	0.51
Loggerhead turtle	0.37	<0.01	0	0	0	0	2.53	0.65	0.44
Green turtle	1.59	0.04	<0.01	0	0	0	3.20	1.23	0.96

[a] Listed as Endangered under the ESA.

Table 45. 4 m pin pile, 3500 kJ hammer, four pin piles per day: Exposure ranges ($ER_{95\%}$) in km to sea turtle threshold criteria with sound attenuation.

Species	Injury						Behavior		
	L_E			L_{pk}			L_p		
	Attenuation (dB)						Attenuation (dB)		
	0	10	12	0	10	12	0	10	12
Kemp's ridley turtle[a]	0.68	0.04	0	0	0	0	2.34	0.47	0.33
Leatherback turtle[a]	0.71	0.03	0	0	0	0	2.17	0.45	0.33
Loggerhead turtle	0.44	0	0	0	0	0	2.15	0.44	0.27
Green turtle	1.52	0.03	0.02	0	0	0	2.76	0.58	0.38

[a] Listed as Endangered under the ESA.

4.5. Acoustic Impacts to Fish

Applying the thresholds for potential injury (see Section 2.5) with 10 dB attenuation, the range to PK sound levels associated with 4 m jacket foundation piles, 12 m monopile foundation piles, and 13 m monopile foundations are 108 m, 157 m, and 127 m, respectively. Ranges from the piling source to regulatory-defined thresholds for SEL are 10 km for 4 m jacket foundation piles, 12 km for 12 m monopiles, and 12 km for 13 m monopiles all with 10 dB attenuation. These estimates do not account for any aversion that might occur as a result of the use of sound attenuation technologies (e.g., bubble curtains). Popper et al. 2014 does not define quantitative acoustic thresholds for behavioral response in fish. GARFO (2020) uses a 150 dB SPL threshold for all fish. When this criterion is used, distances to potential behavioral disturbance for fish are over 8 km from the 4 m jacket foundation piles, 14 km from the 12 m monopiles, and 12 km from the 13 m monopiles, respectively.

5. Discussion

Sounds fields produced during impact pile driving of monopile and jacket foundation piles for the maximum envelope of New England Wind, including Phases 1 and 2, were found by modeling the vibration of the pile when struck with a hammer, determining a far-field representation of the pile as a sound source, and then propagating the sound from the apparent source into the environment. The sound fields were then sampled by simulating animal movement within the sound fields and determining if simulated marine mammal and sea turtle animats (simulated animals) receive sound levels exceeding regulatory thresholds. The mean number of individuals of each species likely to receive sound levels exceeding the thresholds was determined by scaling the animat results using the real-world density of each species. For those animats that received sound levels exceeding threshold criteria, the closest point of approach to the source was found and the distance accounting for 95% of exceedances was reported as the exposure range, $ER_{95\%}$. The species-specific $ER_{95\%}$ (see tables in Section 4.4) were determined with different broadband attenuation levels (0, 6, 10, and 12 dB) to account for the use of noise reduction systems, such as bubble curtains. $ER_{95\%}$ can be used for mitigation purposes, like establishing monitoring or exclusion areas. Fish were considered as static receivers, so exposure ranges were not calculated. Instead, the acoustic distance to their regulatory thresholds were determined and reported with the different broadband attenuation levels (see tables in Section 4.5).

5.1. Exposure Estimates for Marine Mammals and Sea Turtles

The potential risk of exposure for marine mammals and sea turtles was estimated from the sound levels received by each animat over the course of the JASMINE simulation, comparing those levels with the relevant regulatory thresholds, scaling by the mean monthly densities for each species (Roberts et al. 2016a, 2016b, 2017, 2018, 2021), and then summing over the construction period to get the total number of individual animals that may experience sound levels exceeding regulatory thresholds. The thresholds for injurious exposures are based on cumulative SEL and maximum PK pressure level (NMFS 2018). Thresholds for behavioral disruption are based on maximum SPL (NOAA 2005, Wood et al. 2012, Finneran et al. 2017). Mean exposures above injury and behavior thresholds for Construction Schedules A and B assuming 10 dB of broadband attenuation are summarized in Table 46 (marine mammals) and Table 47 (sea turtles).

Table 46. Summary of impact pile driving exposures above injury and behavioral threshold for marine mammals for Construction Schedules A and B (all years summed), assuming 10 dB of broadband attenuation.

Species	Construction Schedule A				Construction Schedule B			
	L_E	L_{pk}	L_p [a]	L_p [b]	L_E	L_{pk}	L_p [a]	L_p [b]
Low-frequency cetaceans								
Fin whale[c]	21.51	0.04	33.58	66.20	37.72	0.09	41.87	78.58
Minke whale	9.71	0.03	26.79	207.05	20.59	0.03	50.89	300.67
Humpback whale	13.69	0.05	16.46	31.83	20.47	0.02	19.53	34.17
North Atlantic right whale[c]	3.09	<0.01	7.01	11.99	3.92	<0.01	6.92	9.34
Sei whale[c]	0.53	<0.01	1.29	20.13	1.14	<0.01	1.88	24.66
Mid-frequency cetaceans								
Atlantic white-sided dolphin	0.21	1.56	1334.89	1021.70	0.87	1.17	2385.18	1638.66
Atlantic spotted dolphin	0	0	3.92	4.18	0	0	4.31	5.24
Short-beaked common dolphin	1.28	5.09	6999.42	4697.60	2.52	5.16	9012.55	5737.60
Bottlenose dolphin	0.15	0.62	387.83	246.92	0.31	0.41	526.97	315.02
Risso's dolphin	0.02	0.03	6.23	5.65	0.03	0.02	8.98	7.52
Long-finned pilot whale	0.06	0.15	165.24	126.66	0.18	0.14	260.80	181.87
Short-finned pilot whale	<0.01	0.24	121.26	94.85	0.01	0.14	194.21	135.57
Sperm whale[c]	<0.01	<0.01	2.64	2.52	<0.01	<0.01	4.60	4.04
High-frequency cetaceans								
Harbor porpoise	97.62	5.91	258.58	5509.56	173.78	8.82	400.40	5868.55
Pinnipeds in water								
Gray seal	1.07	<0.01	32.11	60.51	1.55	<0.01	21.91	41.14
Harbor seal	1.95	0.18	75.85	123.09	3.85	0.10	77.88	99.42
Harp seal	0.94	0	37.64	67.95	1.42	0	36.14	52.37

[a] NOAA (2005), [b] Wood et al. (2012), [c] Listed as Endangered under the ESA.

Table 47. Summary of impact pile driving exposures above injury and behavioral threshold for sea turtles for Construction Schedules A and B (all years summed), assuming 10 dB of broadband attenuation.

Species	Construction Schedule A			Construction Schedule B		
	L_E	L_{pk}	L_p	L_E	L_{pk}	L_p
Kemp's ridley turtle[a]	<0.01	<0.01	0.25	0.01	<0.01	0.35
Leatherback turtle[a]	0.23	0.23	8.57	0.18	0.17	10.09
Loggerhead turtle	0.04	0.08	4.57	0	0.09	5.24
Green turtle	0.01	<0.01	0.32	0.02	<0.01	0.42

[a] Listed as Endangered under the ESA.

The endangered NARW is predicted to experience fewer than four injurious exposures during the combined installation of Phases 1 and 2. This corresponds to approximately 1% of the total species abundance (exposure estimates as a percent of abundance for all species are provided in Section 4.3.4). While NARW are migrating south during most of the proposed activity periods, they are also feeding. Rather than implementing a migrating behavioral state, we modeled foraging behaviors that result in more conservative exposure estimates as the animats have longer dwell times for feeding compared to the migratory assumption. The number of exposures above SEL injury threshold for all low-frequency cetaceans, assuming 10 dB attenuation, varies from approximately 1 to 38 individuals. Predicted injury-level acoustic exposures for mid-frequency cetacean species are low. Even the species with the highest number of predicted exposures, the common dolphin, has fewer than three exposures above the SEL threshold for injury, and fewer than six exposures above the PK threshold for injury (<0.01% of the population). Harbor porpoise, the only high frequency cetacean in the acoustic analysis, is predicted to experience up to 174 exposures above the SEL injury threshold, but this still only represents less than 0.2% of the population. For NARW, fewer than 10 animals are predicted to experience sound levels exceeding behavioral thresholds, which corresponds to 2.6% of the total population. Due to their relatively high local monthly densities, common dolphins have the highest predicted number of exposures above behavioral thresholds at approximately 9000 animals (approximately 5.2% of the population).

Even within a hearing group, the exposure modeling results vary substantially between species due to differences in estimated local species density, modeled monthly construction schedule, and modeled swimming and diving behavior. Injury exposure estimates for sei whales and NARWs are lower than for other low-frequency species (Table 46). The proposed schedules were developed considering a variety of factors including NARW temporal restrictions and anticipated weather days. The NARW restrictions are expected to preclude foundation installation in the periods with the greatest presence of NARW. Therefore, construction is modeled to occur only when NARW are expected not to be present, or present in only very low numbers. Furthermore, the construction schedule aligns with the predicted weather conditions resulting in greater construction activity over the summer months when NARW densities are at their lowest. Fewer weather delays and longer daylight will allow greater construction productivity. In some cases, particularly for low frequency cetaceans, the simulations predicted similar exposure estimates and ranges for injury and behavior criteria (Tables 46 and 47). This stems from the different threshold metrics that are used when assessing injury (SEL) and behavioral (SPL) thresholds. Behavioral criteria are based on the loudest single sound pressure level experienced by an animat and are similar across different species within a particular hearing group. In contrast, injury exposures for most of the species considered in this assessment are dominated by the cumulative sound exposure metric, which is more sensitive to the way animats move through and “sample” the sound field and also to the total number of strikes and hammer energy levels (see Tables 3 and 4). JASMINE species definitions are based on the most recent available literature on behavioral parameters such as speed, dive depth, dive reversals, surface intervals, and directionality.

Fewer than one sea turtle is predicted to be exposed to sound levels exceeding injury threshold. Up to 11 exposures above behavior threshold are predicted to occur.

5.2. Exposure Ranges for Marine Mammals and Sea Turtles

Tables 48 and 49, respectively, summarize the minimum and maximum exposure ranges across all foundation types and pile installation schedules (e.g., piles per day) for marine mammal and sea turtle injury and behavioral disruption. For the dual-criteria injury threshold the maximum of SEL or PK is reported, and, it is noted, that because different metrics and evaluation periods are used for injury and behavior the range to injury threshold may exceed the range to behavioral threshold. For example, the received level may be below the behavioral criteria threshold for a single strike but when the energy for many strikes is aggregated, the injury threshold may be exceeded.

The maximum $ER_{95\%}$ NARW exposure range across all foundation types to injury thresholds for any source with 10 dB attenuation is 3.16 km. The maximum $ER_{95\%}$ exposure range to injury thresholds for all low frequency cetaceans is approximately 4 km. For harbor porpoise, the exposure range to injury thresholds is up to 2.3 km. The maximum NARW exposure range for potential behavioral disruption is 5.6 km. The harbor porpoise has the largest $ER_{95\%}$ to behavioral threshold by a substantial margin, at approximately 86 km to the 50% threshold level as defined by (Wood et al. 2012). Harbor porpoises are designated as a sensitive species under these criteria, and the 50% threshold level for sensitive species is 120 dB SPL.

The maximum exposure range for sea turtle injury for any foundation type is 170 m. Sea turtle maximum exposure range for behavioral disruption is approximately 2 km.

Table 48. Summary of the predicted minimum and maximum marine mammal exposure ranges to injury and behavioral thresholds from impact pile driving assuming 10 dB of broadband attenuation.

Species	$max(L_E, L_{pk})$		L_p [a]		L_p [b]	
	Min	Max	Min	Max	Min	Max
Low-frequency cetaceans						
Fin whale[c]	2.37	4.07	3.56	6.19	3.58	6.21
Minke whale	1.50	2.59	3.34	5.66	19.07	29.19
Humpback whale	2.76	4.62	3.56	5.95	3.57	5.93
North Atlantic right whale[c]	1.84	3.16	3.34	5.60	3.38	5.65
Sei whale[c]	1.66	3.08	3.39	5.79	19.61	32.38
Mid-frequency cetaceans						
Atlantic white-sided dolphin	0	0.02	3.27	5.40	2.33	3.31
Atlantic spotted dolphin	0	0	3.26	5.87	2.27	3.13
Short-beaked common dolphin	0	0.02	3.34	5.68	2.41	3.36
Bottlenose dolphin	0	0.01	2.87	4.93	1.90	3.02
Risso's dolphin	<0.01	0.02	3.38	5.89	2.42	3.46
Long-finned pilot whale	0	0.02	3.30	5.55	2.32	3.37
Short-finned pilot whale	0	0.02	3.37	5.62	2.38	3.30
Sperm whale[c]	0	0.02	3.36	5.84	2.35	3.47
High-frequency cetaceans						
Harbor porpoise	1.50	2.30	3.38	5.76	53.14	86.45
Pinnipeds in water						
Gray seal	0.51	1.31	3.49	6.06	3.30	4.38
Harbor seal	0.16	0.63	3.44	6.03	3.08	4.15
Harp seal	0.09	0.41	3.49	5.97	3.21	4.23

[a] NOAA (2005), [b] Wood et al. (2012), [c] Listed as Endangered under the ESA.

Table 49. Summary of the predicted minimum and maximum sea turtle exposure ranges to injury and behavioral thresholds from impact pile driving assuming 10 dB of broadband attenuation.

Species	max(L_E, L_{pk})		L_p	
	Min	Max	Min	Max
Kemp's ridley turtle[a]	<0.01	0.07	0.47	1.77
Leatherback turtle[a]	0	0.17	0.45	1.39
Loggerhead turtle	0	0.02	0.44	1.20
Green turtle	<0.01	0.16	0.58	1.97

[a] Listed as Endangered under the ESA.

On average, there is a very slight increase in exposure range from 12 m to 13 m diameter monopiles at 5000 kJ, for both injury and behavior, but it is not as substantial as the increase from 1–2 piles per day or the increase from 5000 kJ to 6000 kJ max hammer energy. For both injury and behavior, the 2 pile per day cases were slightly longer than 1 per day for most species and foundation types.

5.3. Acoustic Ranges for Fish

Using exposure guidelines defined by Popper et al. (2014), acoustic results indicate that ranges to potential injury for fish with swim bladders not involved in hearing are small. Maximum range to the threshold defining potential injury across all foundation types is 2 km with 10 dB attenuation level. GARFO (2020) defines a broad behavioral criterion for all fish, which corresponds to a maximum range to threshold of 14 km.

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Appendix A. Glossary

Unless otherwise stated in an entry, these definitions are consistent with ISO 80000-3 (2017).

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.

acoustic noise

Sound that interferes with an acoustic process.

agent-based modelling

A simulation of autonomous agents acting in an environment used to assess the agents' experience of the environment and/or their effect on the environment. Also see **animal movement modelling**.

ambient sound

Sound that would be present in the absence of a specified activity, usually a composite of sound from many sources near and far, e.g., shipping vessels, seismic activity, precipitation, sea ice movement, wave action, and biological activity.

animal movement modelling

Simulation of animal movement based on behavioural rules for the purpose of predicting an animal's experience of an environment.

attenuation

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

auditory frequency weighting

The process of applying an auditory frequency weighting function. In human audiometry, C-weighting is the most commonly used function, an example for marine mammals are the auditory frequency weighting functions published by Southall et al. (2007).

auditory frequency weighting function

Frequency weighting function describing a compensatory approach accounting for a species' (or functional hearing group's) frequency-specific hearing sensitivity. Example hearing groups are low-, mid-, and high-frequency cetaceans, phocid and otariid pinnipeds.

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 S1.13-2005 (R2010)).

broadband level

The total level measured over a specified frequency range.

cetacean

Any animal in the order Cetacea. These are aquatic species and include whales, dolphins, and porpoises.

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.

decade

Logarithmic frequency interval whose upper bound is ten times larger than its lower bound (ISO 80000-3:2006).

decidecade

One tenth of a decade (ISO 2017). Note: An alternative name for decidecade (symbol ddec) is “one-tenth decade”. A decidecade is approximately equal to one third of an octave (1 ddec ≈ 0.3322 oct) and for this reason is sometimes referred to as a “one-third octave”.

decidecade band

Frequency band whose bandwidth is one decidecade. *Note*: The bandwidth of a decidecade band increases with increasing center frequency.

decibel (dB)

Unit of level used to express the ratio of one value of a power quantity to another on a logarithmic scale. Unit: dB.

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.

frequency weighting

The process of applying a frequency weighting function.

frequency-weighting function

The squared magnitude of the sound pressure transfer function. For sound of a given frequency, the frequency weighting function is the ratio of output power to input power of a specified filter, sometimes expressed in decibels. Examples include the following:

- *Auditory frequency weighting function*: compensatory frequency weighting function accounting for a species' (or functional hearing group's) frequency-specific hearing sensitivity.
- *System frequency weighting function*: frequency weighting function describing the sensitivity of an acoustic acquisition system, typically consisting of a hydrophone, one or more amplifiers, and an analogue to digital converter.

geoacoustic

Relating to the acoustic properties of the seabed.

hearing group

Category of animal species when classified according to their hearing sensitivity and to the susceptibility to sound. Examples for marine mammals include very low-frequency (VLF) cetaceans, low-frequency (LF) cetaceans, mid-frequency (MF) cetaceans, high-frequency (HF) cetaceans, very high-frequency (VHF) cetaceans, otariid pinnipeds in water (OPW), phocid pinnipeds in water (PPW), sirenians (SI), other marine carnivores in air (OCA), and other marine carnivores in water (OCW) (NMFS 2018, Southall et al. 2019). See **auditory frequency weighting functions**, which are often applied to these groups. Examples for fish include species for which the swim bladder is involved in hearing, species for which the swim bladder is not involved in hearing, and species without a swim bladder (Popper et al. 2014).

hertz (Hz)

A unit of frequency defined as one cycle per second.

impulsive sound

Qualitative term meaning sounds that are typically transient, brief (less than 1 second), broadband, with rapid rise time and rapid decay. They can occur in repetition or as a single event. Examples of impulsive sound sources include explosives, seismic airguns, and impact pile drivers.

level

A measure of a quantity expressed as the logarithm of the ratio of the quantity to a specified reference value of that quantity. Examples include sound pressure level, sound exposure level, and peak sound pressure level. For example, a value of sound exposure level with reference to 1 μPa^2 s can be written in the form *x* dB re 1 μPa^2 s.

low-frequency (LF) cetacean

See **hearing group**.

level

A measure of a quantity expressed as the logarithm of the ratio of the quantity to a specified reference value of that quantity. Examples include sound pressure level, sound exposure level, and peak sound pressure level. For example, a value of sound exposure level with reference to 1 μPa^2 s can be written in the form *x* dB re 1 μPa^2 s.

low-frequency (LF) cetacean

See **hearing group**.

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 propagation loss. The parabolic equation approximation omits effects of back-scattered sound, simplifying the computation of propagation loss. The effect of back-scattered sound is negligible for most ocean-acoustic propagation problems.

peak sound pressure level (zero-to-peak sound pressure level)

The level ($L_{p,pk}$ or L_{pk}) of the squared maximum magnitude of the sound pressure (p_{pk}^2). Unit: decibel (dB). Reference value (p_0^2) for sound in water: 1 μPa^2.

$$L_{p,\mathrm{pk}} := 10 \log_{10}\left(p_{\mathrm{pk}}^2/p_0^2\right) \mathrm{dB} \ = 20 \log_{10}\left(p_{\mathrm{pk}}/p_0\right) \mathrm{dB}$$

The frequency band and time window should be specified. Abbreviation: PK or Lpk.

permanent threshold shift (PTS)

An irreversible 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 pressure caused by a sound wave. Also called sound pressure.
Unit: pascal (Pa).

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 (PL)

Difference between a source level (SL) and the level at a specified location, PL(x) = SL − L(x). Also see **transmission loss**.

received level

The level measured (or that would be measured) at a defined location. The type of level should be specified.

reference values

standard underwater references values used for calculating sound **levels**, e.g., the reference value for expressing sound pressure level in decibels is 1 µPa.

Quantity	Reference value
Sound pressure	1 µPa
Sound exposure	1 μPa^2 s
Sound particle displacement	1 pm
Sound particle velocity	1 nm/s
Sound particle acceleration	1 $\mu m/s^2$

rms

abbreviation for 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 a 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 disturbance in the pressure, stress, or material displacement of a medium propagated by local compression and expansion of the medium.

sound exposure

Time integral of squared sound pressure over a stated time interval. The time interval can be a specified time duration (e.g., 24 hours) or from start to end of a specified event (e.g., a pile strike, an airgun pulse, a construction operation). Unit: Pa^2 s.

sound exposure level

The level (L_E) of the sound exposure (E). Unit: decibel (dB). Reference value (E_0) for sound in water: 1 μPa^2 s.

$$L_E := 10 \log_{10}(E/E_0) \text{ dB } = 20 \log_{10} \left(E^{1/2}/E_0^{1/2}\right) \text{ dB}$$

The frequency band and integration time should be specified. Abbreviation: SEL.

sound field

Region containing sound waves.

sound pressure

The contribution to total pressure caused by the action of sound.

sound pressure level (rms sound pressure level)

The level ($L_{p,\mathrm{rms}}$) of the time-mean-square sound pressure (p_{rms}^2). Unit: decibel (dB). Reference value (p_0^2) for sound in water: 1 μPa².

$$L_{p,\mathrm{rms}} := 10 \log_{10}(p_{\mathrm{rms}}^2/p_0^2)\ \mathrm{dB}\ = 20 \log_{10}(p_{\mathrm{rms}}/p_0)\ \mathrm{dB}$$

The frequency band and averaging time should be specified. Abbreviation: SPL or Lrms.

sound speed profile

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

source level (SL)

A property of a sound source obtained by adding to the sound pressure level measured in the far field the propagation loss from the acoustic centre of the source to the receiver position. Unit: decibel (dB). Reference value: 1 μPa²m².

temporary threshold shift (TTS)

Reversible loss of hearing sensitivity. TTS can be caused by noise exposure.

transmission loss (TL)

The difference between a specified level at one location and that at a different location, TL(x1,x2) = L(x1) − L(x2). Also see **propagation loss**.

Appendix B. Summary of Acoustic Assessment Assumptions

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 the Proponent.

Two different foundation types are being considered for New England Wind – foundations using 4 piles used to secure a jacket structure (see Figure 5) and monopile foundations consisting of single piles (monopiles, see Figure 3). For both jacket and monopile foundation models, the piles are assumed to be vertical and driven to a penetration depth of 50 m and 40 m, respectively. While pile penetrations across the SWDA will vary, these values were chosen as maximum penetration depths. The estimated number of strikes required to install piles to completion were obtained from the Proponent 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.

Additional modeling assumptions for the jacket foundation piles are as follows:

- 4 m diameter steel cylindrical pilings with a nominal wall thickness of 100 mm
- Impact pile driver hammer energy: 3500 kJ
- Helmet weight: 1830 kN
- Ram weight: 1719 kN
- Four piles installed per day

Additional modeling assumptions for the monopiles are as follows:

- One 12 m and one 13 m diameter steel cylindrical piling with a nominal wall thickness of 200 mm
- Impact pile driver hammer energy: Two estimated hammer energies (5000 and 6000 kJ) for the 12 m diameter pile and one hammer energy (5000 kJ) for the 13 m diameter pile modeled using a scaling factor of 2.556 dB per energy doubling
- Helmet weight: 2351 kN
- Ram weight: 2726 kN
- One or two piles installed per day

B.1. Detailed Modeling Technical Inputs

Table B-1. Details of model inputs, assumptions, and methods.

Parameter	Description
Jacket pile driving source model	
Modeling method	Finite-difference structural model of pile vibration based on thin-shell theory; Hammer forcing functions computed using GRLWEAP
Impact hammer energy	3500 kJ
Ram weight	1719 kN
Helmet weight	1830 kN
Expected penetration	50 m
Modeled seabed penetration	10.5 m @ 525 kJ, 23 m @ 1000 kJ, 33 m @ 1750 kJ, 43 m @ 2500 kJ, and 48 m @ 3500 kJ
Pile length	100 m
Pile diameter	4 m
Pile wall thickness	100 mm
L_E accumulation	Per-pulse sound exposures assumed to be equal for a given hammer energy, summed over expected number of strikes
Monopile pile driving source model	
12 m Monopile 5000 kJ	
Modeling method	Finite-difference structural model of pile vibration based on thin-shell theory; Hammer forcing functions computed using GRLWEAP
Impact hammer energy	5000 kJ
Ram weight	2726 kN
Helmet weight	2351 kN
Expected penetration	40 m
Modeled seabed penetration	8 m @ 1000 kJ, 18 m @ 2000 kJ, 26 m @ 3000 kJ, 34 m @ 4000 kJ, and 38 m @ 5000 kJ
Pile length	95 m
Pile diameter	12 m
Pile wall thickness	200 mm
L_E accumulation	Per-pulse sound exposures assumed to be equal for a given hammer energy, summed over expected number of strikes
12 m Monopile 6000 kJ	
Modeling method	Finite-difference structural model of pile vibration based on thin-shell theory; Hammer forcing functions computed using GRLWEAP
Impact hammer energy	6000 kJ
Ram weight	2726 kN
Helmet weight	2351 kN
Expected penetration	40 m
Modeled seabed penetration	8 m @ 1000 kJ, 18 m @ 2000 kJ, 26 m @ 3000 kJ, 34 m @ 4500 kJ, and 38 m @ 6000 kJ
Pile length	95 m
Pile diameter	12 m
Pile wall thickness	200 mm
L_E accumulation	Per-pulse sound exposures assumed to be equal for a given hammer energy, summed over expected number of strikes

13 m Monopile 5000 kJ	
Modeling method	Finite-difference structural model of pile vibration based on thin-shell theory; Hammer forcing functions computed using GRLWEAP
Impact hammer energy	5000 kJ
Ram weight	2726 kN
Helmet weight	2351 kN
Expected penetration	40 m
Modeled seabed penetration	8 m @ 1000 kJ, 18 m @ 2000 kJ, 26 m @ 3000 kJ, 34 m @ 4000 kJ, and 38 m @ 5000 kJ
Pile length	95 m
Pile diameter	13 m
Pile wall thickness	200 mm
L_E accumulation	Per-pulse sound exposures assumed to be equal for a given hammer energy, summed over expected number of strikes
Environmental parameters for all pile types	
Sound speed profile	GDEM data averaged over region
Bathymetry	SRTM data combined with bathymetry data provided by client
Geoacoustics	Elastic seabed properties based on client-supplied description of surficial sediment samples
Quake (shaft and toe)	2.54 mm (shaft) and 3.333 mm (toe)
Shaft damping	0.164 s/m
Toe damping	0.49 s/m
Shaft resistance	34%, 53%, 63%, 69%, 83% (for each energy level – Jackets) 28%, 30%, 40%, 46%, 66% (for each energy level – Monopiles)
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	10–25,000 Hz
Synthetic trace length	400 ms
Maximum modeled range	100 km

Appendix C. Underwater Acoustics Metrics

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

C.1. Acoustic Metrics

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

The zero-to-peak sound pressure, or peak sound pressure (PK or L_{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, $p(t)$:

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

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 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:

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

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):

$$L_E = 10\log_{10}\left(\int_T \mathrm{p}^2(\mathrm{t})\,\mathrm{dt} \Big/ \mathrm{T_0 p_0^2}\right)\ \mathrm{dB} \quad \text{(C-3)}$$

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

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

$$L_{E,\mathrm{N}} = 10\log_{10}\left(\sum_{\mathrm{i}=1}^{\mathrm{N}} 10^{\frac{\mathrm{L_{E,i}}}{10}}\right)\ \mathrm{dB} \quad \text{(C-4)}$$

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:

$$L_p = L_E - 10\log_{10}(T) \quad \text{(C-5)}$$

$$L_{p90} = L_E - 10\log_{10}(T_{90}) - 0.458 \quad \text{(C-6)}$$

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, $\mathrm{p(t)}$, over the same time period, T:

$$L_{eq} = 10\log_{10}\left(\frac{1}{T}\int_T \mathrm{p}^2(\mathrm{t})\,\mathrm{dt} \Big/ \mathrm{p_0^2}\right) \quad \text{(C-7)}$$

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 A) 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 Band 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 1/3-octave-bands, which are one tenth of a decade (approximately one-third of an octave) wide. Each decade represents a factor 10 in sound frequency. Each octave represents a factor 2 in sound frequency. The center frequency of the i^{th} 1/3-octave-band, $f_c(i)$, is defined as:

$$f_c(i) = 10^{\frac{i}{10}} \tag{C-8}$$

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

$$f_{lo,i} = 10^{\frac{-1}{20}} f_c(i) \quad \text{and} \quad f_{hi,i} = 10^{\frac{1}{20}} f_c(i)\,. \tag{C-9}$$

The decidecade bands become wider with increasing frequency, and on a logarithmic scale the bands appear equally spaced (Figure C-1). The acoustic modeling spans from band 10 (f_c (10) = 10 Hz) to band 44 ($f_c(44)$ = 25 kHz).

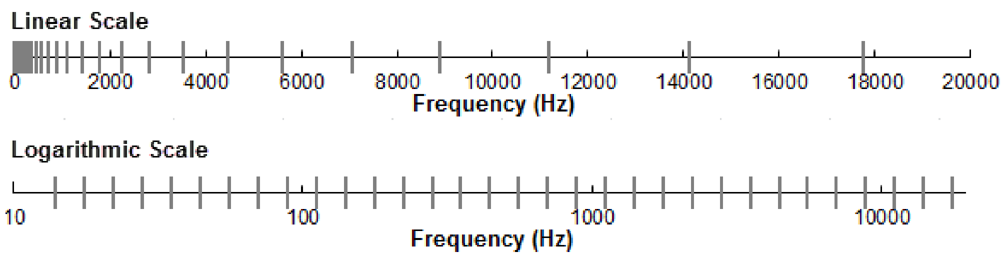

Figure C-1. Decidecade frequency bands (vertical lines) shown on a linear frequency scale and a logarithmic scale.

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

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

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

$$\text{Broadband Lp} = 10 \log_{10} \sum_i 10^{\frac{L_{p,i}}{10}}\,. \tag{C-11}$$

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, especially at higher frequencies. Acoustic modeling of decidecade bands requires less computation time than 1 Hz bands and still resolves the frequency-dependence of the sound source and the propagation environment.

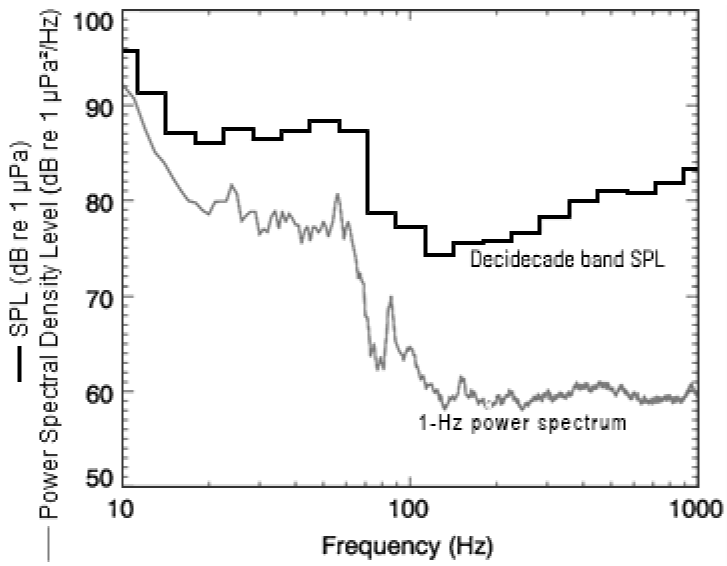

Figure C-2. Sound pressure spectral density levels and the corresponding decidecade band sound pressure levels of example ambient sound shown on a logarithmic frequency scale. Because the decidecade bands are wider with increasing frequency, the decidecade band SPL is higher than the power spectrum.

Appendix D. Auditory (Frequency) Weighting Functions

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

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

In 2015, a US Navy technical report by Finneran (2015) recommended new auditory weighting functions.

The auditory weighting functions for marine mammals are applied in a similar way as A-weighting for noise level assessments for humans. The new frequency-weighting functions are expressed as:

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

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

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).

Hearing group	a	b	f_{lo} (Hz)	f_{hi} (kHz)	K* (dB)
Low-frequency cetaceans	1.0	2	200	19,000	0.13
Mid-frequency cetaceans	1.6	2	8800	110,000	1.20
High-frequency cetaceans	1.8	2	12,000	140,000	1.36
Phocid pinnipeds in water	1.0	2	1900	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

* In NMFS (2018), this variable is labelled C.

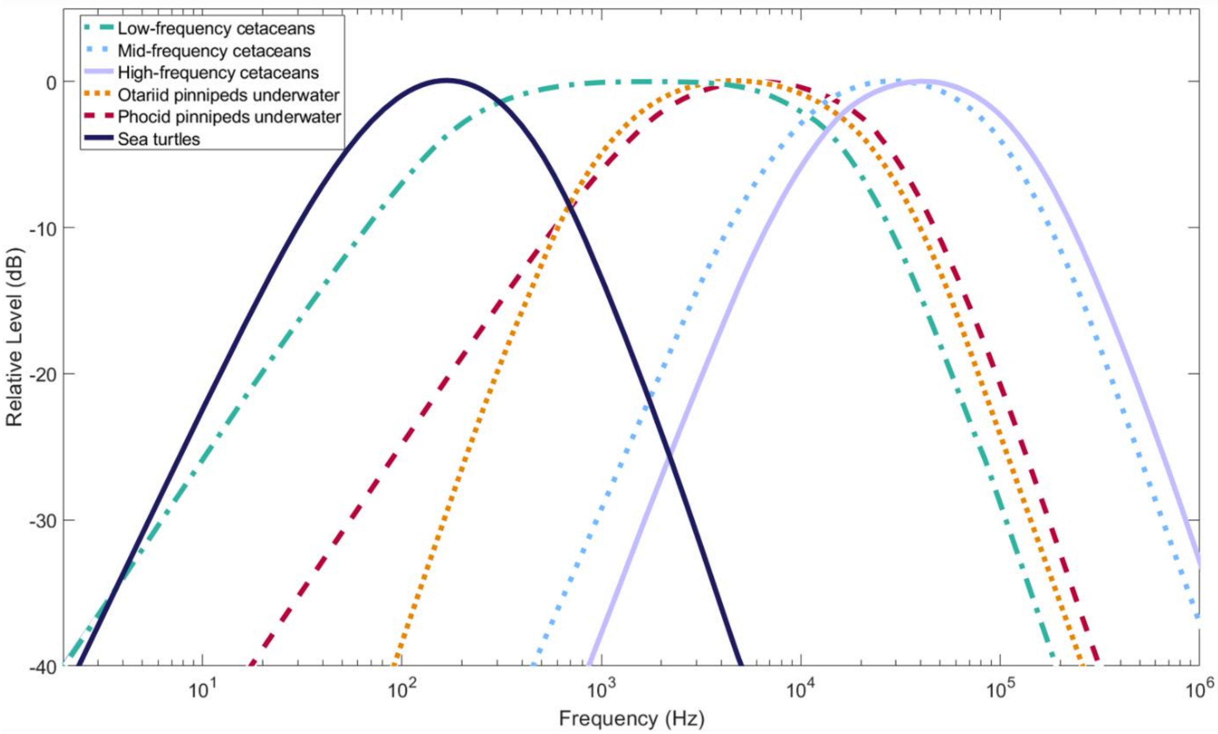

Figure D-1. Auditory weighting functions for functional marine mammal hearing groups included in NMFS (2018).

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

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

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

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

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

where $G(f)$ 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). 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

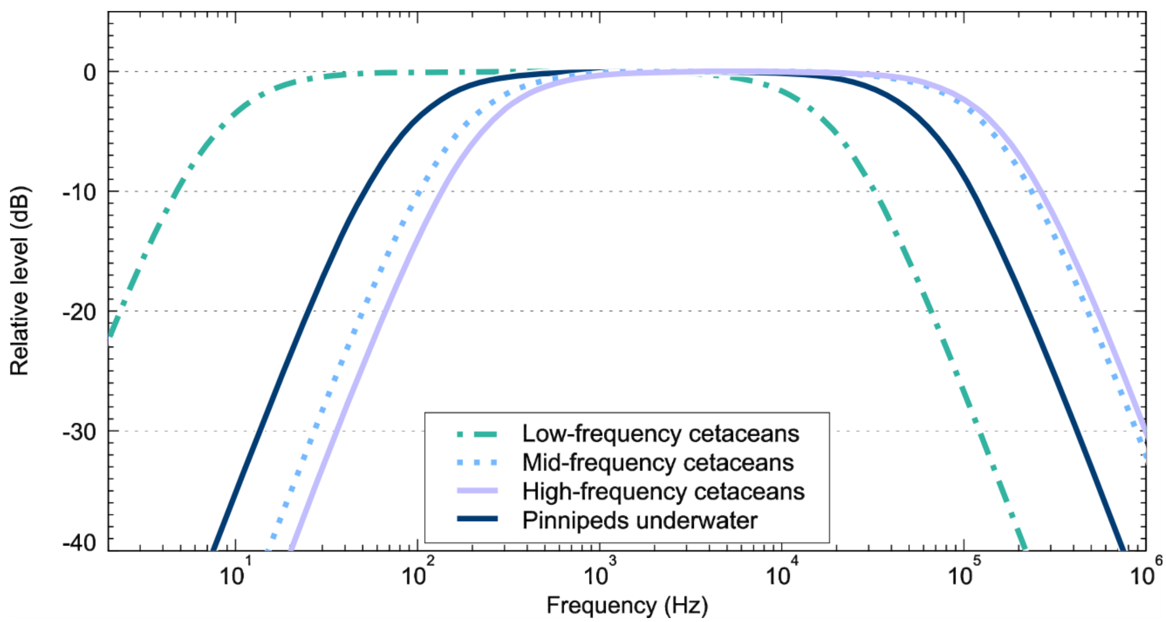

Figure D-2. Auditory weighting functions for the functional marine mammal hearing groups as recommended by Southall et al. (2007).

Appendix E. 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 F.3). MacGillivray (2014) describes the theory behind the physical model in more detail.

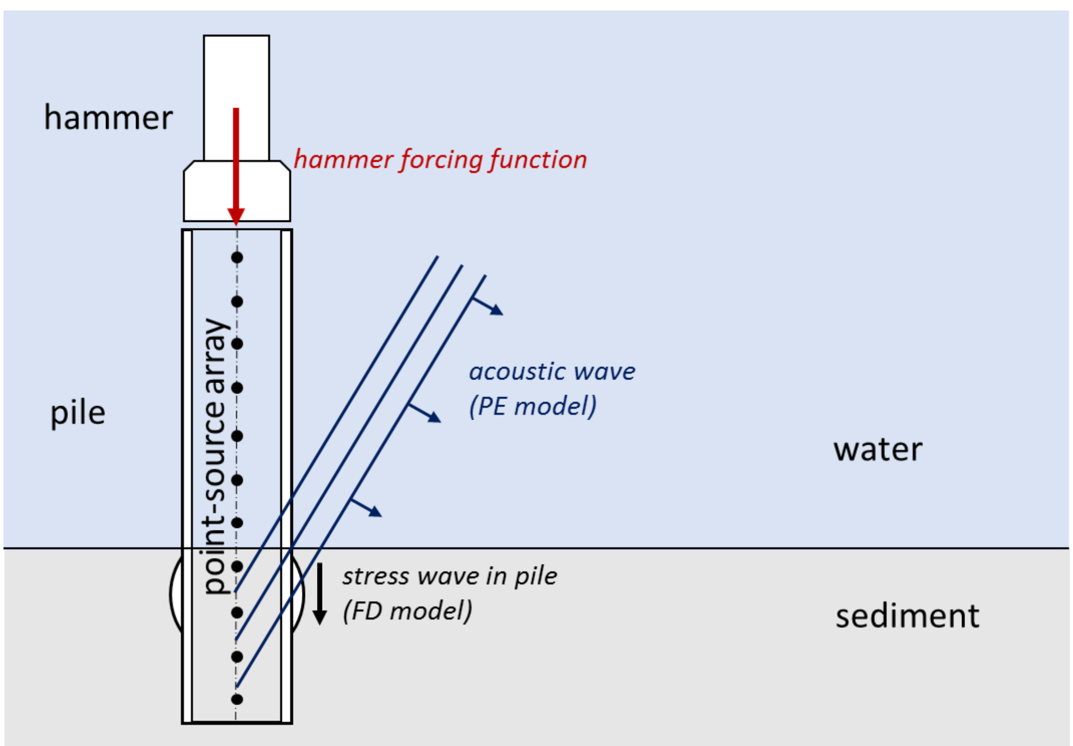

Figure E-1. Physical model geometry for impact driving of a cylindrical pile (vertical cross-section). The hammer forcing function is used with the finite difference (FD) model to compute the stress wave vibration in the pile. A vertical array of point sources is used with the parabolic equation (PE)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

Appendix F. Sound Propagation Modeling

F.1. Environmental Parameters

F.1.1. Bathymetry

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

F.1.2. 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. Compositional data of the surficial sediments were provided by the Proponent. The dominant soil type is expected to be sand. Table F-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 F-1. Estimated geoacoustic properties used for modeling, as a function of depth, in meters below the seabed. Within an indicated depth range, the parameter varies linearly within the stated range.

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)
0–5	Sand	2.086–2.093	1761–1767	0.88–0.879	300	3.65
5–10		2.093–2.099	1767–1774	0.879–0.877		
10–15		2.099–2.106	1774–1780	0.877–0.876		
15–65		2.106–2.172	1780–1842	0.876–0.861		
65–115		2.172–2.235	1842–1901	0.861–0.843		
115–240		2.235–2.382	1901–2034	0.843–0.79		
240–365		2.382–2.513	2034–2150	0.79–0.73		
365–615		2.513–2.719	2150–2342	0.73–0.616		
615–865		2.719–2.845	2342–2500	0.616–0.541		
>865		2.845	2500	0.541		

F.1.3. 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 does not change substantially from month to month, from May to December. Water depths in the SWDA are less than 100 m; sound speed profiles for the shallow water are provided in (Figure F-1). An average profile, obtained by calculating the mean of all profiles shown in Figure F-1 was assumed representative of the area for modeling purposes.

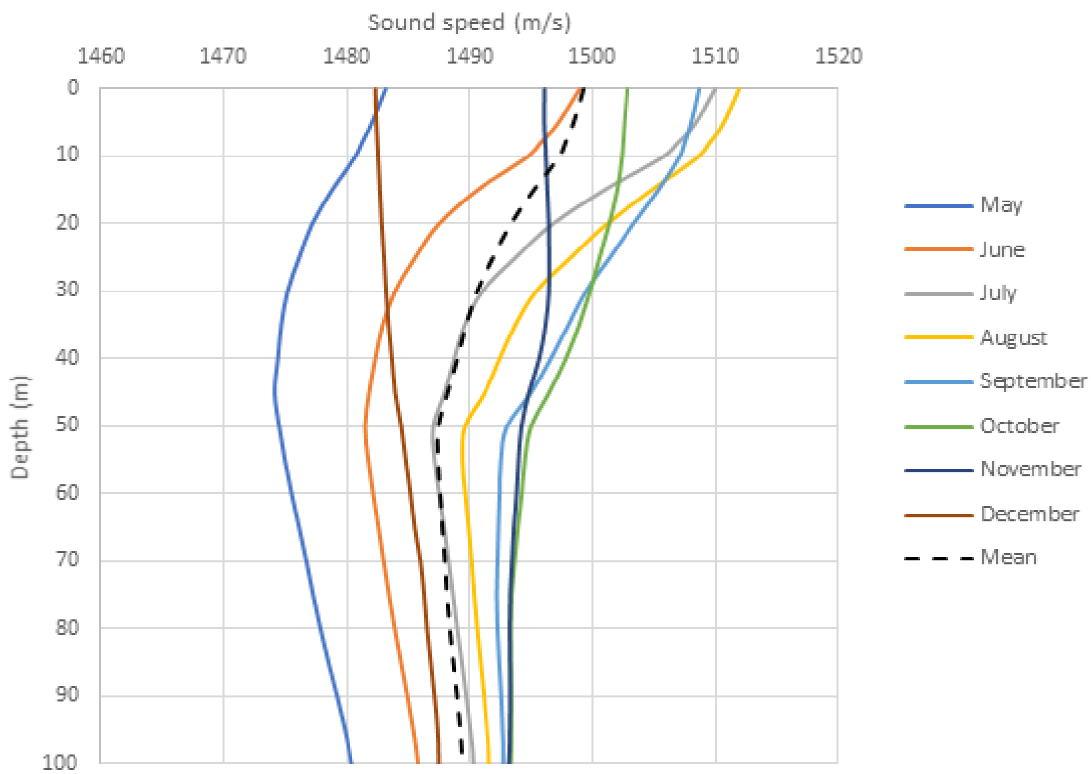

Figure F-1. Sound speed profiles up to 100 m depth for the months of May through December for Southern Wind Development Area (SWDA), and the mean profile used in the modeling and obtained by taking the average of all profiles.

F.2. Propagation Loss

The propagation of sound through the environment can be modeled by predicting the acoustic propagation 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 propagation loss occurs. Propagation 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. Propagation 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 propagation loss (PL), 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:

$$\mathrm{RL} = \mathrm{SL} - \mathrm{PL} \qquad \text{(F-1)}$$

F.3. Sound Propagation with MONM

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

MONM treats frequency dependence by computing acoustic propagation loss at the center frequencies of 1/3-octave-bands. At each center frequency, the propagation loss is modeled as a function of depth and range from the source. Composite broadband received SEL are then computed by summing the received 1/3-octave-band 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 F.4). It is the total sound energy propagation 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 F-2). These vertical radial planes are separated by an angular step size of $\Delta\theta$, yielding N = 360°/$\Delta\theta$ planes.

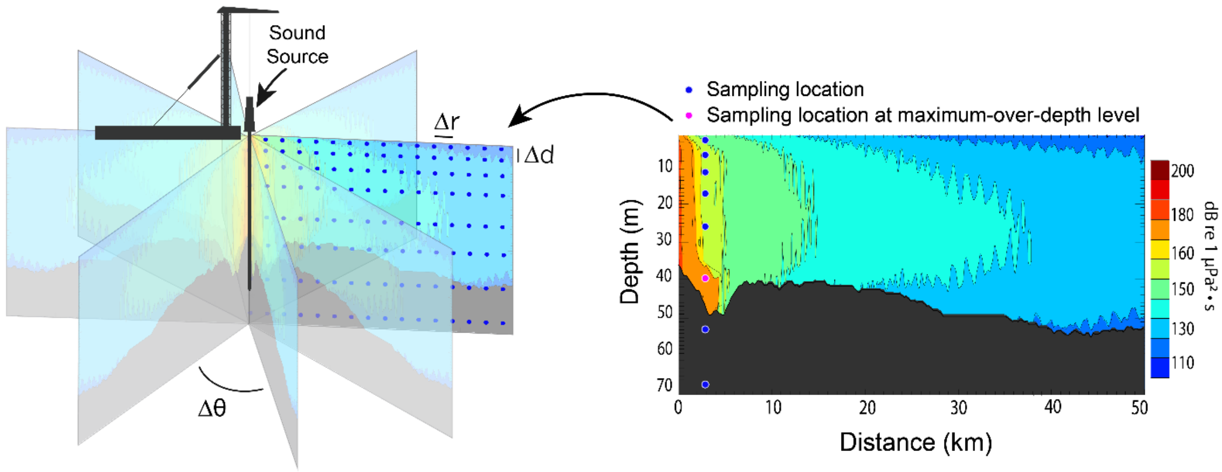

Figure F-2. Modeled three-dimensional sound field (N×2-D method) and maximum-over-depth modeling approach. Sampling locations are shown as blue dots on both figures. On the right panel, the pink dot represents the sampling location where the sound level is maximum over the water column. This maximum-over-depth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

F.4. 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 10–2048 Hz, inside a 1 s window (e.g., Figure F-3). 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.

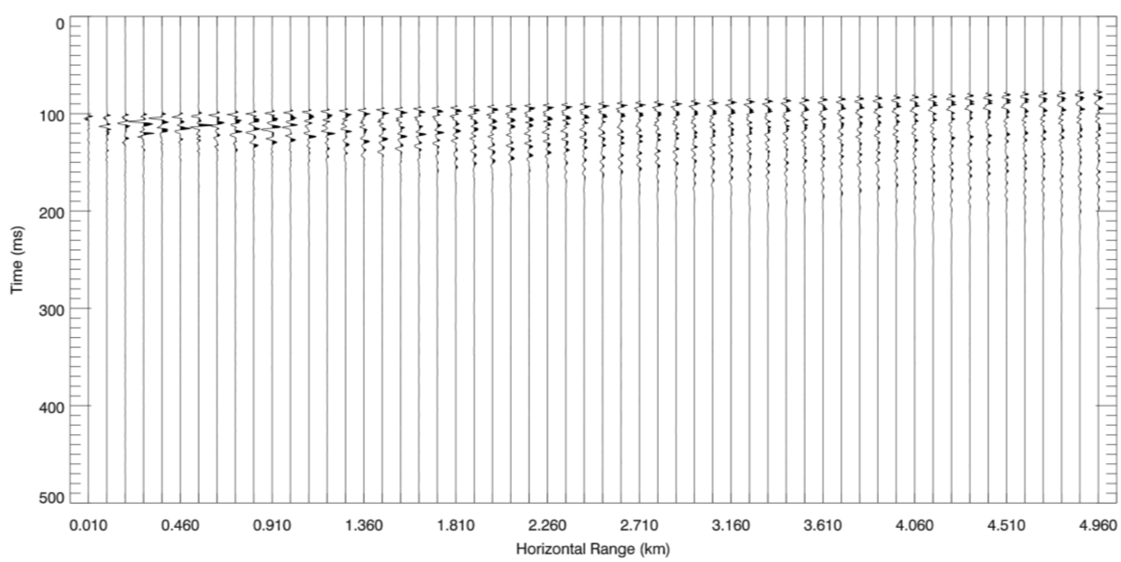

Figure F-3. Example of synthetic pressure waveforms computed by FWRAM at multiple range offsets. Receiver depth is 35 m and the amplitudes of the pressure traces have been normalised for display purposes.

F.5. 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 F-4 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.

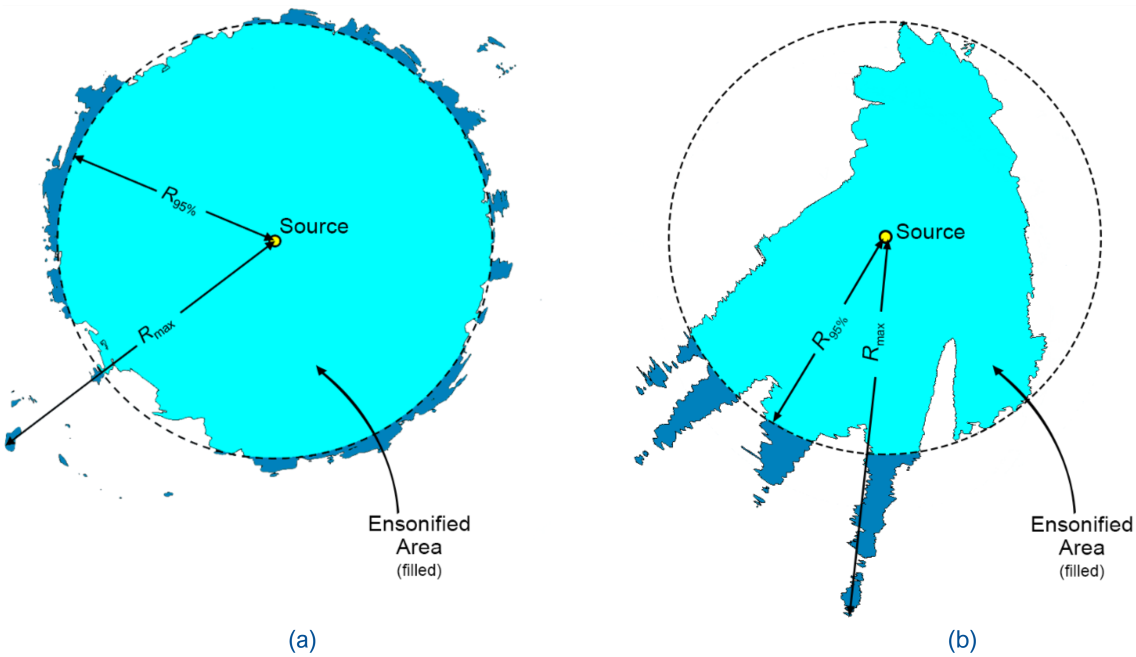

Figure F-4. Sample areas ensonified to an arbitrary sound level with R_{max} and $R_{95\%}$ ranges shown for two different scenarios. (a) Largely symmetric sound level contour with small protrusions. (b) Strongly asymmetric sound level contour with long protrusions. Light blue indicates the ensonified areas bounded by $R_{95\%}$; darker blue indicates the areas outside this boundary which determine R_{max}.

F.6. Model Validation Information

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

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

Appendix G. Ranges to Regulatory Thresholds

The following subsections contain tables of ranges to injury and behavior thresholds described in Sections 2.4 and 2.5. Results are presented for pile driving operations assuming a 0, 6, 10, and 12 dB broadband attenuation achieved using noise attenuation systems.

G.1. Ranges to Acoustic Thresholds for a 12 m (5000 kJ hammer energy) Monopile Foundation with Attenuation

G.1.1. Marine Mammals

G.1.1.1. 0 dB Attenuation

Table G-1. Modeled 5000 kJ monopile foundation ranges for auditory injury thresholds for marine mammals (NMFS 2018) for one, 12 m monopile foundation pile. Numbers represent the distance at $R_{95\%}$ (in meters) at which the auditory injury threshold may be reached with 0 dB attenuation.

Faunal group	Metric	Threshold (dB)	Hammer energy (kJ)			
			1000	2000	3000	5000
Low-frequency (LF) cetaceans	L_{pk}	219	33	54	61	79
	L_E	183	17437			
Mid-frequency (MF) cetaceans	L_{pk}	230	4	6	7	9
	L_E	185	644			
High-frequency (HF) cetaceans	L_{pk}	202	580	600	660	720
	L_E	155	11686			
Phocid seals in water (PW)	L_{pk}	218	38	59	68	94
	L_E	185	5024			

L_{pk}= unweighted peak sound pressure level (dB re 1 µPa); L_E = frequency-weighted sound exposure level (dB re 1 µPa^2·s).

Table G-2. Modeled 5000 kJ monopile foundation ranges for auditory behavioral disturbance thresholds for marine mammals (Wood et al. 2012, NOAA 2005) for one, 12 m monopile foundation pile. Numbers represent the mean distance at $R_{95\%}$ (in meters) at which the auditory behavioral threshold may be reached with 0 dB attenuation.

Faunal group	L_p Threshold (dB)	Hammer energy (kJ)			
		1000	2000	3000	5000
Flat	160	7107	8570	9303	10867
Low-frequency (LF) cetaceans	120	100018	103606	104936	107079
	140	30590	34419	35996	38930
	160	7084	8545	9268	10835
	180	1397	1727	2074	2524
Mid-frequency (MF) cetaceans	120	97114	100118	101308	103633
	140	25335	28567	29859	32248
	160	4150	4919	5188	6181
	180	412	581	707	978
High-frequency (HF) cetaceans	120	94970	98888	99797	49856
	140	23379	26463	27590	12051
	160	3982	4173	4262	2141
	180	322	424	490	63
Phocid seals in water (PW)	120	99221	102402	103888	61308
	140	28602	32270	33810	17073
	160	5275	6838	7308	3422
	180	769	1131	1181	224

L_p = sound pressure level (dB re 1 µPa).

G.1.1.2. 6 dB Attenuation

Table G-3. Modeled 5000 kJ monopile foundation ranges for auditory injury thresholds for marine mammals (NMFS 2018) for one, 12 m monopile foundation pile. Numbers represent the distance at $R_{95\%}$ (in meters) at which the auditory injury threshold may be reached with 6 dB attenuation.

Faunal group	Metric	Threshold (dB)	Hammer energy (kJ)			
			1000	2000	3000	5000
Low-frequency (LF) cetaceans	L_{pk}	219	7	12	17	36
	L_E	183	10485			
Mid-frequency (MF) cetaceans	L_{pk}	230	3	4	4	4
	L_E	185	161			
High-frequency (HF) cetaceans	L_{pk}	202	173	250	360	400
	L_E	155	7344			
Phocid seals in water (PW)	L_{pk}	218	9	15	22	42
	L_E	185	2120			

L_{pk}= unweighted peak sound pressure level (dB re 1 µPa); L_E = frequency-weighted sound exposure level (dB re 1 µPa^2·s).

Table G-4. Modeled 5000 kJ monopile foundation ranges for auditory behavioral disturbance thresholds for marine mammals (Wood et al. 2012, NOAA 2005) for one, 12 m monopile foundation pile. Numbers represent the mean distance at $R_{95\%}$ (in meters) at which the auditory behavioral threshold may be reached with 6 dB attenuation.

Faunal group	L_p Threshold (dB)	Hammer energy (kJ)			
		1000	2000	3000	5000
Flat	160	4168	4745	5213	6350
Low-frequency (LF) cetaceans	120	81789	92729	93752	95823
	140	21462	24103	25253	27613
	160	4162	4714	5187	6325
	180	552	727	896	1160
Mid-frequency (MF) cetaceans	120	65272	80474	87533	92223
	140	16420	19051	20128	21985
	160	3186	3476	3545	3907
	180	122	197	241	322
High-frequency (HF) cetaceans	120	59894	70724	76783	88004
	140	14720	17182	18141	19847
	160	2988	3219	3281	3462
	180	100	122	134	224
Phocid seals in water (PW)	120	74839	91110	92854	94358
	140	19465	22260	23399	25451
	160	3721	4053	4153	4630
	180	279	394	440	608

L_p = sound pressure level (dB re 1 µPa).

G.1.1.3. 10 dB Attenuation

Table G-5. Modeled 5000 kJ monopile foundation ranges for auditory injury thresholds for marine mammals (NMFS 2018) for one, 12 m monopile foundation pile. Numbers represent the distance at R95% (in meters) at which the auditory injury threshold may be reached with 10 dB attenuation.

Faunal group	Metric	Threshold (dB)	Hammer energy (kJ)			
			1000	2000	3000	5000
Low-frequency (LF) cetaceans	L_{pk}	219	4	6	8	11
	L_E	183	7036			
Mid-frequency (MF) cetaceans	L_{pk}	230	2	3	3	3
	L_E	185	89			
High-frequency (HF) cetaceans	L_{pk}	202	78	105	177	230
	L_E	155	5126			
Phocid seals in water (PW)	L_{pk}	218	5	7	9	14
	L_E	185	1121			

L_{pk}= unweighted peak sound pressure level (dB re 1 µPa); L_E = frequency-weighted sound exposure level (dB re 1 µPa^2·s).

Table G-6. Modeled 5000 kJ monopile foundation ranges for auditory behavioral disturbance thresholds for marine mammals (Wood et al. 2012, NOAA 2005) for one, 12 m monopile foundation pile. Numbers represent the mean distance at $R_{95\%}$ (in meters) at which the auditory behavioral threshold may be reached with 10 dB attenuation.

Faunal group	L_p Threshold (dB)	Hammer energy (kJ)			
		1000	2000	3000	5000
Flat	160	3614	3909	4048	4244
Low-frequency (LF) cetaceans	120	56755	65673	69563	79400
	140	16157	18657	19805	22062
	160	3604	3899	4038	4235
	180	269	354	424	600
Mid-frequency (MF) cetaceans	120	47947	55053	57995	63370
	140	11562	13818	14728	16283
	160	2110	2884	2999	3188
	180	63	85	102	128
High-frequency (HF) cetaceans	120	44415	50855	53387	57960
	140	9989	12127	12971	14500
	160	1949	2128	2308	2947
	180	45	63	72	100
Phocid seals in water (PW)	120	53702	61954	65493	72473
	140	14374	16655	17670	19783
	160	3088	3371	3479	3716
	180	108	184	224	310

L_p = sound pressure level (dB re 1 µPa).

G.1.1.4. 12 dB Attenuation

Table G-7. Modeled 5000 kJ monopile foundation ranges for auditory injury thresholds for marine mammals (NMFS 2018) for one, 12 m monopile foundation pile. Numbers represent the distance at $R_{95\%}$ (in meters) at which the auditory injury threshold may be reached with 12 dB attenuation.

Faunal group	Metric	Threshold (dB)	Hammer energy (kJ)			
			1000	2000	3000	5000
Low-frequency (LF) cetaceans	L_{pk}	219	4	5	6	8
	L_E	183	5549			
Mid-frequency (MF) cetaceans	L_{pk}	230	2	3	3	3
	L_E	185	63			
High-frequency (HF) cetaceans	L_{pk}	202	64	83	108	191
	L_E	155	4159			
Phocid seals in water (PW)	L_{pk}	218	4	6	7	9
	L_E	185	1075			

L_{pk} = unweighted peak sound pressure level (dB re 1 µPa); L_E = frequency-weighted sound exposure level (dB re 1 µPa^2·s).

Table G-8. Modeled 5000 kJ monopile foundation ranges for auditory behavioral disturbance thresholds for marine mammals (Wood et al. 2012, NOAA 2005) for one, 12 m monopile foundation pile. Numbers represent the mean distance at $R_{95\%}$ (in meters) at which the auditory behavioral threshold may be reached with 12 dB attenuation.

Faunal group	L_p Threshold (dB)	Hammer energy (kJ)			
		1000	2000	3000	5000
Flat	160	3289	3565	3672	4026
Low-frequency (LF) cetaceans	120	49514	56384	59512	65410
	140	14005	16172	17179	19408
	160	3278	3557	3661	4015
	180	184	244	303	424
Mid-frequency (MF) cetaceans	120	41928	47595	49994	54089
	140	9476	11472	12270	13886
	160	1669	2108	2235	2896
	180	45	63	72	100
High-frequency (HF) cetaceans	120	39144	44122	46104	49856
	140	8098	9920	10653	12051
	160	1164	1727	2072	2141
	180	28	45	57	63
Phocid seals in water (PW)	120	46788	53336	56069	61308
	140	12109	14321	15246	17073
	160	2462	3101	3188	3422
	180	82	108	128	224

L_p = sound pressure level (dB re 1 µPa).

G.1.2. Fish and Sea Turtles

Table G-9. Modeled 5000 kJ monopile foundation ranges to auditory injury and behavioral thresholds for sea turtles and fish using one, 12 m monopile foundation pile. Numbers represent the distance at $R_{95\%}$ (in meters) at which the auditory behavioral and injury threshold may be reached with 0 dB attenuation.

Faunal group	Metric	Threshold (dB)	Hammer energy (kJ)			
			1000	2000	3000	5000
Sea turtles	L_{pk}	232	4	5	5	7
	L_E	204	2860			
	L_p	175	2664	3105	3236	3486
Fish without swim bladder	L_{pk}	213	72	91	162	210
	L_E	216	439			
Fish with swim bladder not involved in hearing	L_{pk}	207	193	270	380	540
	L_E	203	3170			
Fish with swim bladder involved in hearing	L_{pk}	207	193	270	380	540
	L_E	203	3170			
Fish greater than or equal to 2 g	L_{pk}	206	290	360	410	580
	L_E	187	15184			
	L_p	150	16181	18684	19836	22085
Fish less than 2 g	L_{pk}	206	290	360	410	580
	L_E	183	20182			
	L_p	150	16181	18684	19836	22085

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 level (dB re 1 µPa).

Table G-10. Modeled 5000 kJ monopile foundation ranges to auditory injury and behavioral thresholds for sea turtles and fish using one, 12 m monopile foundation pile. Numbers represent the distance at $R_{95\%}$ (in meters) at which the auditory behavioral and injury threshold may be reached with 6 dB attenuation.

Faunal group	Metric	Threshold (dB)	Hammer energy (kJ)			
			1000	2000	3000	5000
Sea turtles	L_{pk}	232	2	3	3	4
	L_E	204	1181			
	L_p	175	1199	1515	1760	2310
Fish without swim bladder	L_{pk}	213	33	54	61	79
	L_E	216	134			
Fish with swim bladder not involved in hearing	L_{pk}	207	72	91	162	210
	L_E	203	1407			
Fish with swim bladder involved in hearing	L_{pk}	207	72	91	162	210
	L_E	203	1407			
Fish greater than or equal to 2 g	L_{pk}	206	78	105	177	230
	L_E	187	9357			
	L_p	150	10137	12018	12864	14724
Fish less than 2 g	L_{pk}	206	78	105	177	230
	L_E	183	13033			
	L_p	150	10137	12018	12864	14724

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 level (dB re 1 μPa).

Table G-11. Modeled 5000 kJ monopile foundation ranges to auditory injury and behavioral thresholds for sea turtles and fish using one, 12 m monopile foundation pile. Numbers represent the distance at $R_{95\%}$ (in meters) at which the auditory behavioral and injury threshold may be reached with 10 dB attenuation.

Faunal group	Metric	Threshold (dB)	Hammer energy (kJ)			
			1000	2000	3000	5000
Sea turtles	L_{pk}	232	2	3	3	3
	L_E	204	612			
	L_p	175	632	896	1002	1365
Fish without swim bladder	L_{pk}	213	12	18	36	47
	L_E	216	63			
Fish with swim bladder not involved in hearing	L_{pk}	207	48	64	75	105
	L_E	203	762			
Fish with swim bladder involved in hearing	L_{pk}	207	48	64	75	105
	L_E	203	762			
Fish greater than or equal to 2 g	L_{pk}	206	55	71	84	157
	L_E	187	6356			
	L_p	150	7107	8570	9303	10867
Fish less than 2 g	L_{pk}	206	55	71	84	157
	L_E	183	9357			
	L_p	150	7107	8570	9303	10867

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 level (dB re 1 μPa).

Table G-12. Modeled 5000 kJ monopile foundation ranges to auditory injury and behavioral thresholds for sea turtles and fish using one, 12 m monopile foundation pile. Numbers represent the distance at $R_{95\%}$ (in meters) at which the auditory behavioral and injury threshold may be reached with 12 dB attenuation.

Faunal group	Metric	Threshold (dB)	Hammer energy (kJ)			
			1000	2000	3000	5000
Sea turtles	L_{pk}	232	0	2	2	3
	L_E	204	439			
	L_p	175	474	600	747	984
Fish without swim bladder	L_{pk}	213	7	12	17	36
	L_E	216	45			
Fish with swim bladder not involved in hearing	L_{pk}	207	33	54	61	79
	L_E	203	539			
Fish with swim bladder involved in hearing	L_{pk}	207	33	54	61	79
	L_E	203	539			
Fish greater than or equal to 2 g	L_{pk}	206	38	59	68	94
	L_E	187	5101			
	L_p	150	5866	7128	7825	9200
Fish less than 2 g	L_{pk}	206	38	59	68	94
	L_E	183	7786			
	L_p	150	5866	7128	7825	9200

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 level (dB re 1 µPa).

G.2. Ranges to Acoustic Thresholds for a 12 m Monopile Foundation (6000 kJ hammer energy) with Attenuation

G.2.1. Marine Mammals

G.2.1.1. 0 dB Attenuation

Table G-13. Modeled 6000 kJ monopile foundation ranges for auditory injury thresholds for marine mammals (NMFS 2018) for one, 12 m monopile foundation pile. Numbers represent the distance at $R_{95\%}$ (in meters) at which the auditory injury threshold may be reached with 0 dB attenuation.

Faunal group	Metric	Threshold (dB)	Hammer energy (kJ)				
			1000	2000	3000	4500	6000
Low-frequency (LF) cetaceans	L_{pk}	219	24	42	58	73	79
	L_E	183	20770				
Mid-frequency (MF) cetaceans	L_{pk}	230	4	5	6	8	9
	L_E	185	1101				
High-frequency (HF) cetaceans	L_{pk}	202	560	500	600	700	720
	L_E	155	13769				
Phocid seals in water (PW)	L_{pk}	218	33	52	62	80	94
	L_E	185	6320				

L_{pk} = unweighted peak sound pressure level (dB re 1 µPa); L_E = frequency-weighted sound exposure level (dB re 1 µPa^2·s).

Table G-14. Modeled 6000 kJ monopile foundation ranges for auditory behavioral disturbance thresholds for marine mammals (Wood et al. 2012, NOAA 2005) for one, 12 m monopile foundation pile. Numbers represent the mean distance at $R_{95\%}$ (in meters) at which the auditory behavioral threshold may be reached with 0 dB attenuation.

Faunal group	L_p Threshold (dB)	Hammer energy (kJ)				
		1000	2000	3000	4500	6000
Flat	160	8822	10377	11307	12850	14103
Low-frequency (LF) cetaceans	120	105561	109742	110505	111108	113100
	140	36173	40504	42168	44575	48731
	160	8790	10357	11284	12825	14073
	180	1893	2181	2552	3075	3200
Mid-frequency (MF) cetaceans	120	102063	107005	108098	109136	111332
	140	30375	34803	36111	37480	41011
	160	5203	6706	7121	8078	9225
	180	671	1071	1128	1222	1660
High-frequency (HF) cetaceans	120	100350	105306	106556	107459	110217
	140	28130	32311	33559	34779	38153
	160	4289	5660	6106	6827	7944
	180	495	710	955	1089	1159
Phocid seals in water (PW)	120	104585	109099	109920	110581	112595
	140	34160	38497	39997	41851	45879
	160	7115	8784	9518	10784	12081
	180	1149	1469	1720	2154	2468

L_p = sound pressure level (dB re 1 µPa).

G.2.1.2. 6 dB Attenuation

Table G-15. Modeled 6000 kJ monopile foundation ranges for auditory injury thresholds for marine mammals (NMFS 2018) for one, 12 m monopile foundation pile. Numbers represent the distance at $R_{95\%}$ (in meters) at which the auditory injury threshold may be reached with 6 dB attenuation.

Faunal group	Metric	Threshold (dB)	Hammer energy (kJ)				
			1000	2000	3000	4500	6000
Low-frequency (LF) cetaceans	L_{pk}	219	6	9	15	23	36
	L_E	183	12996				
Mid-frequency (MF) cetaceans	L_{pk}	230	2	4	3	4	4
	L_E	185	301				
High-frequency (HF) cetaceans	L_{pk}	202	165	210	320	400	400
	L_E	155	8902				
Phocid seals in water (PW)	L_{pk}	218	8	12	18	36	42
	L_E	185	3111				

L_{pk} = unweighted peak sound pressure level (dB re 1 µPa); L_E = frequency-weighted sound exposure level (dB re 1 µPa^2·s).

Table G-16. Modeled 6000 kJ monopile foundation ranges for auditory behavioral disturbance thresholds for marine mammals (Wood et al. 2012, NOAA 2005) for one, 12 m monopile foundation pile. Numbers represent the mean distance at $R_{95\%}$ (in meters) at which the auditory behavioral threshold may be reached with 6 dB attenuation.

Faunal group	L_p Threshold (dB)	Hammer energy (kJ)				
		1000	2000	3000	4500	6000
Flat	160	4880	5868	6539	7801	8568
Low-frequency (LF) cetaceans	120	94059	98540	99378	100220	102986
	140	25171	28217	29505	31547	34284
	160	4851	5839	6505	7761	8543
	180	767	961	1157	1500	1723
Mid-frequency (MF) cetaceans	120	89683	94685	95980	97226	99667
	140	20443	23604	24543	25646	28125
	160	3647	4005	4102	4190	4832
	180	228	341	394	475	585
High-frequency (HF) cetaceans	120	80881	93129	94038	95059	98350
	140	18535	21693	22617	23592	25961
	160	3341	3703	3889	4022	4160
	180	141	242	291	356	422
Phocid seals in water (PW)	120	93335	97452	98557	99363	101797
	140	23505	26540	27682	29211	31965
	160	4113	4403	5050	5982	6834
	180	405	566	707	948	1137

L_p = sound pressure level (dB re 1 µPa).

G.2.1.3. 10 dB Attenuation

Table G-17. Modeled 6000 kJ monopile foundation ranges for auditory injury thresholds for marine mammals (NMFS 2018) for one, 12 m monopile foundation pile. Numbers represent the distance at $R_{95\%}$ (in meters) at which the auditory injury threshold may be reached with 10 dB attenuation.

Faunal group	Metric	Threshold (dB)	Hammer energy (kJ)				
			1000	2000	3000	4500	6000
Low-frequency (LF) cetaceans	L_{pk}	219	4	5	7	9	11
	L_E	183	8924				
Mid-frequency (MF) cetaceans	L_{pk}	230	2	3	3	3	3
	L_E	185	113				
High-frequency (HF) cetaceans	L_{pk}	202	71	90	165	220	230
	L_E	155	6414				
Phocid seals in water (PW)	L_{pk}	218	4	6	8	11	14
	L_E	185	2037				

L_{pk} = unweighted peak sound pressure level (dB re 1 µPa); L_E = frequency-weighted sound exposure level (dB re 1 µPa^2·s).

Table G-18. Modeled 6000 kJ monopile foundation ranges for auditory behavioral disturbance thresholds for marine mammals (Wood et al. 2012, NOAA 2005) for one, 12 m monopile foundation pile. Numbers represent the mean distance at R95% (in meters) at which the auditory behavioral threshold may be reached with 10 dB attenuation.

Faunal group	L_p Threshold (dB)	Hammer energy (kJ)				
		1000	2000	3000	4500	6000
Flat	160	3959	4152	4274	5174	5827
Low-frequency (LF) cetaceans	120	71035	89658	91821	93196	95626
	140	19501	22213	23381	25039	27061
	160	3952	4148	4263	5153	5795
	180	382	484	600	797	967
Mid-frequency (MF) cetaceans	120	59542	71277	76488	82586	92113
	140	14912	17560	18444	19554	21751
	160	3025	3259	3334	3569	3821
	180	102	128	161	228	301
High-frequency (HF) cetaceans	120	54757	65205	68398	71931	87785
	140	13260	15833	16662	17563	19687
	160	2363	3117	3161	3268	3429
	180	72	108	117	134	206
Phocid seals in water (PW)	120	67054	84920	89560	91753	94246
	140	17670	20451	21530	23077	25047
	160	3479	3777	3949	4149	4257
	180	200	291	342	440	561

L_p = sound pressure level (dB re 1 µPa).

G.2.1.4. 12 dB Attenuation

Table G-19. Modeled 6000 kJ monopile foundation ranges for auditory injury thresholds for marine mammals (NMFS 2018) for one, 12 m monopile foundation pile. Numbers represent the distance at $R_{95\%}$ (in meters) at which the auditory injury threshold may be reached with 12 dB attenuation.

Faunal group	Metric	Threshold (dB)	Hammer energy (kJ)				
			1000	2000	3000	4500	6000
Low-frequency (LF) cetaceans	L_{pk}	219	4	5	5	7	8
	L_E	183	7140				
Mid-frequency (MF) cetaceans	L_{pk}	230	0	2	2	3	3
	L_E	185	89				
High-frequency (HF) cetaceans	L_{pk}	202	59	75	99	186	191
	L_E	155	5272				
Phocid seals in water (PW)	L_{pk}	218	4	5	6	8	9
	L_E	185	1128				

L_{pk} = unweighted peak sound pressure level (dB re 1 µPa); L_E = frequency-weighted sound exposure level (dB re 1 µPa^2·s).

Table G-20. Modeled 6000 kJ monopile foundation ranges for auditory behavioral disturbance thresholds for marine mammals (Wood et al. 2012, NOAA 2005) for one, 12 m monopile foundation pile. Numbers represent the mean distance at $R_{95\%}$ (in meters) at which the auditory behavioral threshold may be reached with 12 dB attenuation.

Faunal group	L_p Threshold (dB)	Hammer energy (kJ)				
		1000	2000	3000	4500	6000
Flat	160	3648	3893	4065	4242	4702
Low-frequency (LF) cetaceans	120	60482	71224	76550	83762	92189
	140	16826	19382	20580	22381	24105
	160	3639	3884	4054	4235	4671
	180	272	342	422	595	728
Mid-frequency (MF) cetaceans	120	51097	59975	62847	65721	76870
	140	12444	14927	15737	16773	18787
	160	2206	3017	3122	3252	3389
	180	72	100	108	128	201
High-frequency (HF) cetaceans	120	47209	55193	57675	60222	68471
	140	10879	13338	14088	14947	16833
	160	2079	2371	2845	3052	3180
	180	60	72	85	108	126
Phocid seals in water (PW)	120	57114	67333	70837	76130	90012
	140	15169	17595	18641	20223	22183
	160	3152	3408	3524	3890	4048
	180	117	189	240	322	400

L_p = sound pressure level (dB re 1 μPa).

G.2.2. Fish and Sea Turtles

Table G-21. Modeled 6000 kJ monopile foundation ranges to auditory injury and behavioral thresholds for sea turtles and fish using one, 12 m monopile foundation pile. Numbers represent the distance at $R_{95\%}$ (in meters) at which the auditory behavioral and injury threshold may be reached with 0 dB attenuation.

Faunal group	Metric	Threshold (dB)	Hammer energy (kJ)				
			1000	2000	3000	4500	6000
Sea turtles	L_{pk}	232	3	5	5	6	7
	L_E	204	3620				
	L_p	175	3149	3372	3530	3892	4025
Fish without swim bladder	L_{pk}	213	64	83	111	200	210
	L_E	216	611				
Fish with swim bladder not involved in hearing	L_{pk}	207	174	240	360	420	540
	L_E	203	4111				
Fish with swim bladder involved in hearing	L_{pk}	207	174	240	360	420	540
	L_E	203	4111				
Fish greater than or equal to 2 g	L_{pk}	206	193	260	390	560	580
	L_E	187	17808				
	L_p	150	19525	22237	23403	25067	27084
Fish less than 2 g	L_{pk}	206	193	260	390	560	580
	L_E	183	23220				
	L_p	150	19525	22237	23403	25067	27084

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 level (dB re 1 µPa).

Table G-22. Modeled 6000 kJ monopile foundation ranges to auditory injury and behavioral thresholds for sea turtles and fish using one, 12 m monopile foundation pile. Numbers represent the distance at $R_{95\%}$ (in meters) at which the auditory behavioral and injury threshold may be reached with 6 dB attenuation.

Faunal group	Metric	Threshold (dB)	Hammer energy (kJ)				
			1000	2000	3000	4500	6000
Sea turtles	L_{pk}	232	2	3	3	3	4
	L_E	204	1690				
	L_p	175	1682	2058	2322	2873	3055
Fish without swim bladder	L_{pk}	213	24	42	58	73	79
	L_E	216	224				
Fish with swim bladder not involved in hearing	L_{pk}	207	64	83	111	200	210
	L_E	203	1921				
Fish with swim bladder involved in hearing	L_{pk}	207	64	83	111	200	210
	L_E	203	1921				
Fish greater than or equal to 2 g	L_{pk}	206	71	90	165	220	230
	L_E	187	11280				
	L_p	150	12394	14481	15462	17144	18740
Fish less than 2 g	L_{pk}	206	71	90	165	220	230
	L_E	183	15420				
	L_p	150	12394	14481	15462	17144	18740

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 level (dB re 1 µPa).

Table G-23. Modeled 6000 kJ monopile foundation ranges to auditory injury and behavioral thresholds for sea turtles and fish using one, 12 m monopile foundation pile. Numbers represent the distance at R95% (in meters) at which the auditory behavioral and injury threshold may be reached with 10 dB attenuation.

Faunal group	Metric	Threshold (dB)	Hammer energy (kJ)				
			1000	2000	3000	4500	6000
Sea turtles	L_{pk}	232	0	2	2	3	3
	L_E	204	930				
	L_p	175	943	1145	1374	1738	2068
Fish without swim bladder	L_{pk}	213	9	14	23	42	47
	L_E	216	89				
Fish with swim bladder not involved in hearing	L_{pk}	207	38	57	69	87	105
	L_E	203	1104				
Fish with swim bladder involved in hearing	L_{pk}	207	38	57	69	87	105
	L_E	203	1104				
Fish greater than or equal to 2 g	L_{pk}	206	42	62	77	104	157
	L_E	187	7912				
	L_p	150	8822	10377	11307	12850	14103
Fish less than 2 g	L_{pk}	206	42	62	77	104	157
	L_E	183	11280				
	L_p	150	8822	10377	11307	12850	14103

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 level (dB re 1 µPa).

Table G-24. Modeled 6000 kJ monopile foundation ranges to auditory injury and behavioral thresholds for sea turtles and fish using one and two, 12 m monopile foundation piles. Numbers represent the mean distance at $R_{95\%}$ (in meters) at which the auditory behavioral and injury threshold may be reached with 12 dB attenuation.

Faunal group	Metric	Threshold (dB)	Hammer energy (kJ)				
			1000	2000	3000	4500	6000
Sea turtles	L_{pk}	232	0	2	2	2	3
	L_E	204	611				
	L_p	175	628	800	1009	1354	1513
Fish without swim bladder	L_{pk}	213	6	9	15	23	36
	L_E	216	63				
Fish with swim bladder not involved in hearing	L_{pk}	207	24	42	58	73	79
	L_E	203	764				
Fish with swim bladder involved in hearing	L_{pk}	207	24	42	58	73	79
	L_E	203	764				
Fish greater than or equal to 2 g	L_{pk}	206	33	52	62	80	94
	L_E	187	6440				
	L_p	150	7257	8700	9520	10998	12041
Fish less than 2 g	L_{pk}	206	33	52	62	80	94
	L_E	183	9491				
	L_p	150	7257	8700	9520	10998	12041

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 level (dB re 1 µPa).

G.3. Ranges to Acoustic Thresholds for a 13 m Monopile Foundation (5000 kJ hammer energy) with Attenuation

G.3.1. Marine Mammals

G.3.1.1. 0 dB Attenuation

Table G-25. Modeled 5000 kJ monopile foundation ranges for auditory injury thresholds for marine mammals (NMFS 2018) for one, 13 m monopile foundation pile. Numbers represent the distance at $R_{95\%}$ (in meters) at which the auditory injury threshold may be reached with 0 dB attenuation.

<table>
<tr><th rowspan="2">Faunal group</th><th rowspan="2">Metric</th><th rowspan="2">Threshold (dB)</th><th colspan="4">Hammer energy (kJ)</th></tr>
<tr><th>1000</th><th>2000</th><th>3000</th><th>5000</th></tr>
<tr><td rowspan="2">Low-frequency (LF) cetaceans</td><td>L_{pk}</td><td>219</td><td>23</td><td>49</td><td>73</td><td>93</td></tr>
<tr><td>L_E</td><td>183</td><td colspan="4">19473</td></tr>
<tr><td rowspan="2">Mid-frequency (MF) cetaceans</td><td>L_{pk}</td><td>230</td><td>6</td><td>7</td><td>8</td><td>13</td></tr>
<tr><td>L_E</td><td>185</td><td colspan="4">480</td></tr>
<tr><td rowspan="2">High-frequency (HF) cetaceans</td><td>L_{pk}</td><td>202</td><td>440</td><td>580</td><td>740</td><td>860</td></tr>
<tr><td>L_E</td><td>155</td><td colspan="4">11896</td></tr>
<tr><td rowspan="2">Phocid seals in water (PW)</td><td>L_{pk}</td><td>218</td><td>35</td><td>52</td><td>80</td><td>104</td></tr>
<tr><td>L_E</td><td>185</td><td colspan="4">4936</td></tr>
</table>

L_{pk} = unweighted peak sound pressure level (dB re 1 µPa); L_E = frequency-weighted sound exposure level (dB re 1 µPa^2·s).

Table G-26. Modeled 5000 kJ monopile foundation ranges for auditory behavioral disturbance thresholds for marine mammals (Wood et al. 2012, NOAA 2005) for one, 13 m monopile foundation pile. Numbers represent the mean distance at $R_{95\%}$ (in meters) at which the auditory behavioral threshold may be reached with 0 dB attenuation.

Faunal group	L_p Threshold (dB)	Hammer energy (kJ)			
		1000	2000	3000	5000
Flat	160	7662	8853	10623	12815
Low-frequency (LF) cetaceans	120	114664	117832	117798	117503
	140	37226	46966	50956	62209
	160	7616	8822	10577	12759
	180	1300	1484	2014	2629
Mid-frequency (MF) cetaceans	120	112881	117597	117748	117739
	140	25821	34960	36461	43539
	160	3795	4631	5002	6552
	180	272	482	541	856
High-frequency (HF) cetaceans	120	112245	115457	115749	117874
	140	22907	30975	31941	38761
	160	3500	4111	4188	5249
	180	184	342	397	582
Phocid seals in water (PW)	120	113891	117913	117884	117574
	140	32357	42142	44640	54066
	160	5020	6664	7841	9754
	180	566	859	1119	1601

L_p = sound pressure level (dB re 1 µPa).

G.3.1.2. 6 dB Attenuation

Table G-27. Modeled 5000 kJ monopile foundation ranges for auditory injury thresholds for marine mammals (NMFS 2018) for one, 13 m monopile foundation pile. Numbers represent the distance at $R_{95\%}$ (in meters) at which the auditory injury threshold may be reached with 6 dB attenuation.

Faunal group	Metric	Threshold (dB)	Hammer energy (kJ)			
			1000	2000	3000	5000
Low-frequency (LF) cetaceans	L_{pk}	219	8	12	17	27
	L_E	183	11235			
Mid-frequency (MF) cetaceans	L_{pk}	230	4	5	5	6
	L_E	185	144			
High-frequency (HF) cetaceans	L_{pk}	202	124	230	400	540
	L_E	155	7316			
Phocid seals in water (PW)	L_{pk}	218	9	14	20	42
	L_E	185	2348			

L_{pk} = unweighted peak sound pressure level (dB re 1 µPa); L_E = frequency-weighted sound exposure level (dB re 1 µPa^2·s).

Table G-28. Modeled 5000 kJ monopile foundation ranges for auditory behavioral disturbance thresholds for marine mammals (Wood et al. 2012, NOAA 2005) for one, 13 m monopile foundation pile. Numbers represent the mean distance at $R_{95\%}$ (in meters) at which the auditory behavioral threshold may be reached with 6 dB attenuation.

Faunal group	L_p Threshold (dB)	Hammer energy (kJ)			
		1000	2000	3000	5000
Flat	160	4208	4638	5762	7223
Low-frequency (LF) cetaceans	120	102724	112786	112980	114670
	140	23979	28956	31902	37447
	160	4200	4610	5724	7188
	180	439	526	752	1118
Mid-frequency (MF) cetaceans	120	95813	109050	109459	112880
	140	15488	21001	21983	25980
	160	2722	3160	3331	3740
	180	100	156	184	286
High-frequency (HF) cetaceans	120	87953	106277	106714	112250
	140	13349	18454	19113	22986
	160	2362	2980	3068	3408
	180	82	128	141	190
Phocid seals in water (PW)	120	100892	111958	112297	113902
	140	20143	25442	27545	32647
	160	3478	3822	4166	4909
	180	201	297	393	558

L_p = sound pressure level (dB re 1 µPa).

G.3.1.3. 10 dB Attenuation

Table G-29. Modeled 5000 kJ monopile foundation ranges for auditory injury thresholds for marine mammals (NMFS 2018) for one, 13 m monopile foundation pile. Numbers represent the distance at $R_{95\%}$ (in meters) at which the auditory injury threshold may be reached with 10 dB attenuation.

Faunal group	Metric	Threshold (dB)	Hammer energy (kJ)			
			1000	2000	3000	5000
Low-frequency (LF) cetaceans	L_{pk}	219	6	8	10	14
	L_E	183	7213			
Mid-frequency (MF) cetaceans	L_{pk}	230	3	4	4	5
	L_E	185	89			
High-frequency (HF) cetaceans	L_{pk}	202	87	112	200	290
	L_E	155	4955			
Phocid seals in water (PW)	L_{pk}	218	6	8	11	16
	L_E	185	1246			

L_{pk} = unweighted peak sound pressure level (dB re 1 µPa); L_E = frequency-weighted sound exposure level (dB re 1 µPa^2·s).

Table G-30. Modeled 5000 kJ monopile foundation ranges for auditory behavioral disturbance thresholds for marine mammals (Wood et al. 2012, NOAA 2005) for one, 13 m monopile foundation pile. Numbers represent the mean distance at $R_{95\%}$ (in meters) at which the auditory behavioral threshold may be reached with 10 dB attenuation.

Faunal group	L_p Threshold (dB)	Hammer energy (kJ)			
		1000	2000	3000	5000
Flat	160	3490	3530	4124	4636
Low-frequency (LF) cetaceans	120	86552	101685	102516	109312
	140	17864	21303	23733	27756
	160	3481	3518	4116	4605
	180	228	267	372	540
Mid-frequency (MF) cetaceans	120	65844	94129	95222	103308
	140	10413	14571	15434	18615
	160	1548	2449	2622	3112
	180	40	89	100	144
High-frequency (HF) cetaceans	120	56202	86067	87170	100049
	140	8515	12543	13273	16111
	160	1259	1939	2301	2707
	180	28	63	80	117
Phocid seals in water (PW)	120	82575	99994	100649	107353
	140	14528	18355	20041	23797
	160	2805	3083	3289	3760
	180	100	144	179	297

L_p = sound pressure level (dB re 1 µPa).

G.3.1.4. 12 dB Attenuation

Table G-31. Modeled 5000 kJ monopile foundation ranges for auditory injury thresholds for marine mammals (NMFS 2018) for one, 13 m monopile foundation pile. Numbers represent the distance at $R_{95\%}$ (in meters) at which the auditory injury threshold may be reached with 12 dB attenuation.

Faunal group	Metric	Threshold (dB)	Hammer energy (kJ)			
			1000	2000	3000	5000
Low-frequency (LF) cetaceans	L_{pk}	219	5	7	7	10
	L_E	183	5716			
Mid-frequency (MF) cetaceans	L_{pk}	230	3	4	4	5
	L_E	185	82			
High-frequency (HF) cetaceans	L_{pk}	202	71	90	119	240
	L_E	155	3917			
Phocid seals in water (PW)	L_{pk}	218	6	7	8	13
	L_E	185	656			

L_{pk} = unweighted peak sound pressure level (dB re 1 µPa); L_E = frequency-weighted sound exposure level (dB re 1 µPa^2·s).

Table G-32. Modeled 5000 kJ monopile foundation ranges for auditory behavioral disturbance thresholds for marine mammals (Wood et al. 2012, NOAA 2005) for one, 13 m monopile foundation piles. Numbers represent the mean distance at $R_{95\%}$ (in meters) at which the auditory behavioral threshold may be reached with 12 dB attenuation.

Faunal group	L_p Threshold (dB)	Hammer energy (kJ)			
		1000	2000	3000	5000
Flat	160	3220	3219	3545	4129
Low-frequency (LF) cetaceans	120	79048	95173	96905	102864
	140	15368	18186	20464	23899
	160	3210	3212	3532	4121
	180	152	184	272	385
Mid-frequency (MF) cetaceans	120	52233	81393	82836	95879
	140	8311	11928	12730	15571
	160	1209	1816	2143	2693
	180	28	63	72	108
High-frequency (HF) cetaceans	120	46019	70674	73201	88050
	140	6738	10094	10747	13392
	160	835	1360	1553	2369
	180	20	28	40	85
Phocid seals in water (PW)	120	66833	90285	92215	100982
	140	12057	15422	17040	20273
	160	2195	2664	3052	3347
	180	80	100	134	200

L_p = sound pressure level (dB re 1 µPa).

G.3.2. Fish and Sea Turtles

Table G-33. Modeled 5000 kJ monopile foundation ranges to auditory injury and behavioral thresholds for sea turtles and fish using one, 13 m monopile foundation pile. Numbers represent the distance at $R_{95\%}$ (in meters) at which the auditory behavioral and injury threshold may be reached with 0 dB attenuation.

Faunal group	Metric	Threshold (dB)	Hammer energy (kJ) 1 Pile Per Day			
			1000	2000	3000	5000
Sea turtles	L_{pk}	232	5	6	7	8
	L_E	204	2987			
	L_p	175	2646	2789	3158	3441
Fish without swim bladder	L_{pk}	213	78	97	132	260
	L_E	216	412			
Fish with swim bladder not involved in hearing	L_{pk}	207	196	240	420	580
	L_E	203	3465			
Fish with swim bladder involved in hearing	L_{pk}	207	196	240	420	580
	L_E	203	3465			
Fish greater than or equal to 2 g	L_{pk}	206	260	380	520	620
	L_E	187	17892			
	L_p	175	17914	21346	23773	27802
Fish less than 2 g	L_{pk}	206	260	380	520	620
	L_E	183	24456			
	L_p	175	17914	21346	23773	27802

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 level (dB re 1 µPa).

Table G-34. Modeled 5000 kJ monopile foundation ranges to auditory injury and behavioral thresholds for sea turtles and fish using one, 13 m monopile foundation pile. Numbers represent the mean distance at $R_{95\%}$ (in meters) at which the auditory behavioral and injury threshold may be reached with 6 dB attenuation.

Faunal group	Metric	Threshold (dB)	Hammer energy (kJ) 1 Pile Per Day			
			1000	2000	3000	5000
Sea turtles	L_{pk}	232	4	5	5	5
	L_E	204	1230			
	L_p	175	1105	1323	1734	2394
Fish without swim bladder	L_{pk}	213	23	49	73	93
	L_E	216	144			
Fish with swim bladder not involved in hearing	L_{pk}	207	78	97	132	260
	L_E	203	1372			
Fish with swim bladder involved in hearing	L_{pk}	207	78	97	132	260
	L_E	203	1372			
Fish greater than or equal to 2 g	L_{pk}	206	87	112	200	290
	L_E	187	10629			
	L_p	175	11071	13029	15020	17683
Fish less than 2 g	L_{pk}	206	87	112	200	290
	L_E	183	15264			
	L_p	175	11071	13029	15020	17683

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 level (dB re 1 µPa).

Table G-35. Modeled 5000 kJ monopile foundation ranges to auditory injury and behavioral thresholds for sea turtles and fish using one, 13 m monopile foundation pile. Numbers represent the mean distance at $R_{95\%}$ (in meters) at which the auditory behavioral and injury threshold may be reached with 10 dB attenuation.

Faunal group	Metric	Threshold (dB)	Hammer energy (kJ) 1 Pile Per Day			
			1000	2000	3000	5000
Sea turtles	L_{pk}	232	3	4	4	5
	L_E	204	560			
	L_p	175	526	641	944	1341
Fish without swim bladder	L_{pk}	213	10	16	24	52
	L_E	216	80			
Fish with swim bladder not involved in hearing	L_{pk}	207	40	70	87	114
	L_E	203	690			
Fish with swim bladder involved in hearing	L_{pk}	207	40	70	87	114
	L_E	203	690			
Fish greater than or equal to 2 g	L_{pk}	206	44	76	97	127
	L_E	187	7084			
	L_p	175	7662	8853	10623	12815
Fish less than 2 g	L_{pk}	206	44	76	97	127
	L_E	183	10629			
	L_p	175	7662	8853	10623	12815

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 level (dB re 1 µPa).

Table G-36. Modeled 5000 kJ monopile foundation ranges to auditory injury and behavioral thresholds for sea turtles and fish using one, 13 m monopile foundation pile. Numbers represent the mean distance at $R_{95\%}$ (in meters) at which the auditory behavioral and injury threshold may be reached with 12 dB attenuation.

Faunal group	Metric	Threshold (dB)	Hammer energy (kJ) 1 Pile Per Day			
			1000	2000	3000	5000
Sea turtles	L_{pk}	232	3	4	4	4
	L_E	204	412			
	L_p	175	379	451	641	1000
Fish without swim bladder	L_{pk}	213	8	12	17	27
	L_E	216	45			
Fish with swim bladder not involved in hearing	L_{pk}	207	23	49	73	93
	L_E	203	464			
Fish with swim bladder involved in hearing	L_{pk}	207	23	49	73	93
	L_E	203	464			
Fish greater than or equal to 2 g	L_{pk}	206	35	52	80	104
	L_E	187	5581			
	L_p	175	6277	7225	8778	10708
Fish less than 2 g	L_{pk}	206	35	52	80	104
	L_E	183	8739			
	L_p	175	6277	7225	8778	10708

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 level (dB re 1 µPa).

G.4. Ranges to Acoustic Thresholds for a 4 m Jacket Foundation (3500 kJ hammer energy) with Attenuations

G.4.1. Marine Mammals

G.4.1.1. 0 dB Attenuation

Table G-37. Modeled 3500 kJ jacket foundation ranges for auditory injury thresholds for marine mammals (NMFS 2018) for one (and four) 4 m pin pile(s). Numbers represent the distance at $R_{95\%}$ (in meters) at which the auditory injury threshold may be reached with 0 dB attenuation.

Faunal group	Metric	Threshold (dB)	Hammer energy (kJ)		
			525	1000	3500
Low-frequency (LF) cetaceans	L_{pk}	219	4	8	33
	L_E	183	18049 (29350)		
Mid-frequency (MF) cetaceans	L_{pk}	230	-	-	2
	L_E	185	481 (1577)		
High-frequency (HF) cetaceans	L_{pk}	202	153	340	580
	L_E	155	11908 (17577)		
Phocid seals in water (PW)	L_{pk}	218	5	10	87
	L_E	185	5738 (10051)		

L_{pk} = unweighted peak sound pressure level (dB re 1 µPa); L_E = frequency-weighted sound exposure level (dB re 1 µPa^2·s). Dashes indicate that thresholds were not reached. L_E values in parentheses are for four pin piles.

Table G-38. Modeled 3500 kJ jacket foundation ranges for auditory behavioral disturbance thresholds for marine mammals (Wood et al. 2012, NOAA 2005) for one 4 m pin pile. Numbers represent the distance at $R_{95\%}$ (in meters) at which the auditory behavioral threshold may be reached with 0 dB attenuation.

Faunal group	L_p Threshold (dB)	Hammer energy (kJ)		
		525	1000	3500
Flat	160	3945	4533	8424
Low-frequency (LF) cetaceans	120	99542	100667	110415
	140	21478	27067	40384
	160	3938	4501	8396
	180	321	505	1485
Mid-frequency (MF) cetaceans	120	96499	99973	108194
	140	15671	20683	32588
	160	2942	3550	4696
	180	122	171	504
High-frequency (HF) cetaceans	120	91173	99842	107076
	140	13901	18555	29780
	160	2463	3433	4213
	180	89	144	361
Phocid seals in water (PW)	120	99207	100150	109770
	140	19104	24650	37403
	160	3536	3968	6718
	180	170	321	935

L_p = sound pressure level (dB re 1 µPa).

G.4.1.2. 6 dB Attenuation

Table G-39. Modeled 3500 kJ jacket foundation ranges for auditory injury thresholds for marine mammals (NMFS 2018) for one (and four) 4 m pin pile(s). Numbers represent the distance at $R_{95\%}$ (in meters) at which the auditory injury threshold may be reached with 6 dB attenuation.

Faunal group	Metric	Threshold (dB)	Hammer energy (kJ)		
			525	1000	3500
Low-frequency (LF) cetaceans	L_{pk}	219	0	2	5
	L_E	183	10461 (18083)		
Mid-frequency (MF) cetaceans	L_{pk}	230	-	-	-
	L_E	185	146 (482)		
High-frequency (HF) cetaceans	L_{pk}	202	111	131	380
	L_E	155	7326 (11922)		
Phocid seals in water (PW)	L_{pk}	218	0	2	7
	L_E	185	2377 (5743)		

L_{pk} = unweighted peak sound pressure level (dB re 1 µPa); L_E = frequency-weighted sound exposure level (dB re 1 µPa^2·s). Dashes indicate that thresholds were not reached. L_E values in parentheses are for four pin piles.

Table G-40. Modeled 3500 kJ jacket foundation ranges for auditory behavioral disturbance thresholds for marine mammals (Wood et al. 2012, NOAA 2005) for one 4 m pin pile. Numbers represent the distance at $R_{95\%}$ (in meters) at which the auditory behavioral threshold may be reached with 6 dB attenuation.

Faunal group	L_p Threshold (dB)	Hammer energy (kJ)		
		525	1000	3500
Flat	160	2946	3451	4485
Low-frequency (LF) cetaceans	120	62281	91985	100219
	140	13403	17200	26576
	160	2930	3444	4446
	180	117	171	519
Mid-frequency (MF) cetaceans	120	49797	70696	99892
	140	8880	12051	20077
	160	1253	2236	3479
	180	28	85	161
High-frequency (HF) cetaceans	120	45142	62436	99740
	140	7616	10570	17988
	160	1183	1649	3091
	180	28	45	141
Phocid seals in water (PW)	120	57474	86190	100035
	140	11407	15058	24124
	160	2200	2962	3928
	180	82	122	306

L_p = sound pressure level (dB re 1 µPa).

G.4.1.3. 10 dB Attenuation

Table G-41. Modeled 3500 kJ jacket foundation ranges for auditory injury thresholds for marine mammals (NMFS 2018) for one (and four) 4 m pin pile(s). Numbers represent the distance at $R_{95\%}$ (in meters) at which the auditory injury threshold may be reached with 10 dB attenuation.

Faunal group	Metric	Threshold (dB)	Hammer energy (kJ)		
			525	1000	3500
Low-frequency (LF) cetaceans	L_{pk}	219	-	0	2
	L_E	183	6885 (12677)		
Mid-frequency (MF) cetaceans	L_{pk}	230	-	-	-
	L_E	185	89 (268)		
High-frequency (HF) cetaceans	L_{pk}	202	37	103	139
	L_E	155	5726 (8847)		
Phocid seals in water (PW)	L_{pk}	218	-	0	2
	L_E	185	1234 (3510)		

L_{pk} = unweighted peak sound pressure level (dB re 1 µPa); L_E = frequency-weighted sound exposure level (dB re 1 µPa^2·s). Dashes indicate that thresholds were not reached. L_E values in parentheses are for four pin piles.

Table G-42. Modeled 3500 kJ jacket foundation ranges for auditory behavioral disturbance thresholds for marine mammals (Wood et al. 2012, NOAA 2005) for one 4 m pin pile. Numbers represent the distance at $R_{95\%}$ (in meters) at which the auditory behavioral threshold may be reached with 10 dB attenuation.

Faunal group	L_p Threshold (dB)	Hammer energy (kJ)		
		525	1000	3500
Flat	160	1797	2502	3642
Low-frequency (LF) cetaceans	120	44164	57519	98346
	140	9332	12372	19704
	160	1794	2496	3638
	180	45	89	268
Mid-frequency (MF) cetaceans	120	35506	46528	89400
	140	5366	8069	14195
	160	608	1215	2502
	180	0	28	89
High-frequency (HF) cetaceans	120	32496	42263	79019
	140	4672	6906	12362
	160	467	879	2302
	180	0	20	85
Phocid seals in water (PW)	120	40891	53398	96910
	140	7457	10449	17460
	160	1194	1800	3224
	180	28	45	146

L_p = sound pressure level (dB re 1 µPa).

G.4.1.4. 12 dB Attenuation

Table G-43. Modeled 3500 kJ jacket foundation ranges for auditory injury thresholds for marine mammals (NMFS 2018) for one (and four) 4 m pin pile(s). Numbers represent the distance at $R_{95\%}$ (in meters) at which the auditory injury threshold may be reached with 12 dB attenuation.

Faunal group	Metric	Threshold (dB)	Hammer energy (kJ)		
			525	1000	3500
Low-frequency (LF) cetaceans	L_{pk}	219	-	-	0
	L_E	183	5248 (10482)		
Mid-frequency (MF) cetaceans	L_{pk}	230	-	-	-
	L_E	185	80 (146)		
High-frequency (HF) cetaceans	L_{pk}	202	15	75	123
	L_E	155	4651 (7339)		
Phocid seals in water (PW)	L_{pk}	218	-	-	2
	L_E	185	1174 (2377)		

L_{pk} = unweighted peak sound pressure level (dB re 1 µPa); L_E = frequency-weighted sound exposure level (dB re 1 µPa^2·s). Dashes indicate that thresholds were not reached. L_E values in parentheses are for four pin piles.

Table G-44. Modeled 3500 kJ jacket foundation ranges for auditory behavioral disturbance thresholds for marine mammals (Wood et al. 2012, NOAA 2005) for one 4 m pin pile. Numbers represent the distance at $R_{95\%}$ (in meters) at which the auditory behavioral threshold may be reached with 12 dB attenuation.

Faunal group	L_p Threshold (dB)	Hammer energy (kJ)		
		525	1000	3500
Flat	160	1242	2183	3414
Low-frequency (LF) cetaceans	120	37870	48370	89065
	140	7569	10372	16912
	160	1238	2178	3408
	180	28	63	171
Mid-frequency (MF) cetaceans	120	30593	39218	67285
	140	4580	6248	11695
	160	425	747	2193
	180	0	20	82
High-frequency (HF) cetaceans	120	27860	35727	59400
	140	4061	5317	10278
	160	322	597	1582
	180	0	0	40
Phocid seals in water (PW)	120	35109	45055	82122
	140	5915	8470	14735
	160	740	1244	2910
	180	20	28	117

L_p = sound pressure level (dB re 1 µPa).

G.4.2. Fish and Sea Turtles

Table G-45. Modeled 3500 kJ jacket foundation ranges to auditory injury and behavioral thresholds for sea turtles and fish using one (and four) 4 m pin pile(s). Numbers represent the distance at $R_{95\%}$ (in meters) at which the auditory behavioral and injury thresholds may be reached with 0 dB attenuation.

Faunal group	Metric	Threshold (dB)	Hammer energy (kJ)		
			525	1000	3500
Sea turtles	L_{pk}	232	-	-	0
	L_E	204	2426 (5224)		
	L_p	175	752	1231	2819
Fish without swim bladder	L_{pk}	213	23	92	131
	L_E	216	306 (945)		
Fish with swim bladder not involved in hearing	L_{pk}	207	117	138	410
	L_E	203	2723 (5858)		
Fish with swim bladder involved in hearing	L_{pk}	207	117	138	410
	L_E	203	2723 (5858)		
Fish greater than or equal to 2 g	L_{pk}	206	125	145	440
	L_E	187	15463 (24399)		
	L_p	150	9365	12406	19734
Fish less than 2 g	L_{pk}	206	125	145	440
	L_E	183	21005 (32006)		
	L_p	150	9365	12406	19734

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 level (dB re 1 µPa). Dashes indicate that thresholds were not reached. L_E values in parentheses are for four pin piles.

Table G-46. Modeled 3500 kJ jacket foundation ranges to auditory injury and behavioral thresholds for sea turtles and fish using one (and four) 4 m pin pile(s). Numbers represent the distance at $R_{95\%}$ (in meters) at which the auditory behavioral and injury thresholds may be reached with 6 dB attenuation.

Faunal group	Metric	Threshold (dB)	Hammer energy (kJ)		
			525	1000	3500
Sea turtles	L_{pk}	232	-	-	0
	L_E	204	943 (2433)		
	L_p	175	269	422	1232
Fish without swim bladder	L_{pk}	213	4	8	33
	L_E	216	108 (310)		
Fish with swim bladder not involved in hearing	L_{pk}	207	23	92	131
	L_E	203	1189 (2736)		
Fish with swim bladder involved in hearing	L_{pk}	207	23	92	131
	L_E	203	1189 (2736)		
Fish greater than or equal to 2 g	L_{pk}	206	37	103	139
	L_E	187	9046 (15490)		
	L_p	150	5011	7006	12171
Fish less than 2 g	L_{pk}	206	37	103	139
	L_E	183	13128 (21040)		
	L_p	150	5011	7006	12171

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 level (dB re 1 µPa). Dashes indicate that thresholds were not reached. L_E values in parentheses are for four pin piles.

Table G-47. Modeled 3500 kJ jacket foundation ranges to auditory injury and behavioral thresholds for sea turtles and fish using one (and four) 4 m pin pile(s). Numbers represent the distance at $R_{95\%}$ (in meters) at which the auditory behavioral and injury thresholds may be reached with 10 dB attenuation.

Faunal group	Metric	Threshold (dB)	Hammer energy (kJ)		
			525	1000	3500
Sea turtles	L_{pk}	232	-	-	0
	L_E	204	422 (1230)		
	L_p	175	134	213	626
Fish without swim bladder	L_{pk}	213	2	3	8
	L_E	216	45 (144)		
Fish with swim bladder not involved in hearing	L_{pk}	207	7	13	100
	L_E	203	511 (1493)		
Fish with swim bladder involved in hearing	L_{pk}	207	7	13	100
	L_E	203	511 (1493)		
Fish greater than or equal to 2 g	L_{pk}	206	9	17	108
	L_E	187	5843 (11027)		
	L_p	150	3945	4533	8424
Fish less than 2 g	L_{pk}	206	9	17	108
	L_E	183	9046 (15490)		
	L_p	150	3945	4533	8424

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 level (dB re 1 µPa). Dashes indicate that thresholds were not reached. L_E values in parentheses are for four pin piles.

Table G-48. Modeled 3500 kJ jacket foundation ranges to auditory injury and behavioral thresholds for sea turtles and fish using one (and four) 4 m pin pile(s). Numbers represent the distance at $R_{95\%}$ (in meters) at which the auditory behavioral and injury thresholds may be reached with 12 dB attenuation.

Faunal group	Metric	Threshold (dB)	Hammer energy (kJ)		
			525	1000	3500
Sea turtles	L_{pk}	232	-	-	0
	L_E	204	306 (945)		
	L_p	175	89	146	425
Fish without swim bladder	L_{pk}	213	0	2	5
	L_E	216	28 (108)		
Fish with swim bladder not involved in hearing	L_{pk}	207	4	8	33
	L_E	203	358 (1190)		
Fish with swim bladder involved in hearing	L_{pk}	207	4	8	33
	L_E	203	358 (1190)		
Fish greater than or equal to 2 g	L_{pk}	206	5	10	87
	L_E	187	4571 (9068)		
	L_p	150	3624	4056	6950
Fish less than 2 g	L_{pk}	206	5	10	87
	L_E	183	7315 (13150)		
	L_p	150	3624	4056	6950

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 level (dB re 1 µPa). Dashes indicate that thresholds were not reached. L_E values in parentheses are for four pin piles.

Appendix H. 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. Inside JASMINE, the sound source location mimics the movement of the source vessel through the proposed survey pattern. 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 (Appendix H-2). 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).

H.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.

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.

H.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 maximum distance of 70 km (43.5 mi) from the Offshore Development Area (see figures in Appendix H.2). In the simulation, every animat that reaches and leaves a border of the simulation area is replaced by another animat entering at an opposite border—e.g., an animat departing at the northern border of the simulation area is replaced by an animat entering the simulation area at the southern border at the same longitude. When this action places the animat in an inappropriate water depth, the animat is randomly placed on the map at a depth suited to its species definition (Appendix H.2). 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.

H.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 H-1 and H-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 H-1 and H-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 H-1 and H-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 H-1. Aversion parameters for the animal movement simulation of North Atlantic right whales 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 H-2. Aversion parameters for the animal movement simulation of harbor porpoise 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

H.1.3. Seeding Density and Scaling

The exposure criteria for impulsive sounds were used to determine the number of animats exceeding exposure thresholds. To generate statistically reliable probability density functions, all simulations were seeded with an animat density of 0.5 animats/km^2 over the entire simulation area. Some species have depth preference restrictions, e.g., sperm whales prefer water greater than 1000 m (Aoki et al. 2007), and the simulation location contained a relatively high portion of shallow water areas. For each species, the local modeling density, that is the density of animats near the construction area, was determined by dividing the simulation seeding density by the proportion of seedable area. To evaluate potential Level A or B 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. (2016a, 2016b, 2017, 2018, 2021).

H.2. Animal Movement Modeling Supplemental Results

This section contains supplemental exposure modeling results assuming 0, 6, 10, and 12 dB broadband attenuation. Tables H-3 to H-6 describe the number of days of piling per month for each year of Construction Schedules A and B.

For each year of Construction Schedules A and B for both marine mammals and turtles, exposure estimates are provided in Appendices H.2.1 and H.2.2, and potential impacts relative to species' abundance are provided in Appendix H.2.3. Exposure ranges for modeled foundation types not included in Construction Schedules A and B are provided in Appendix H.2.4.

Table H-3. Construction Schedule A, Year 1: The number of potential piling days per month under the maximum envelope used to estimate the total number of marine mammal and sea turtle acoustic exposures for New England Wind.

Construction month	12 m Monopile, 5000 kJ		12 m Monopile, 6000 kJ		13 m Monopile, 5000 kJ		4 m Pin Pile, 3500 kJ
	1 pile/day	2 piles/day	1 pile/day	2 piles/day	1 pile/day	2 piles/day	4 pin piles/day
May	4	0	0	0	0	0	0
June	2	5	0	0	0	0	0
July	0	9	0	0	0	0	0
August	0	9	0	0	0	0	0
September	0	1	0	0	1	6	2
October	0	0	0	0	0	6	0
November	0	0	0	0	0	3	0
December	0	0	0	0	4	0	0
Total # Days	**6**	**24**	**0**	**0**	**5**	**15**	**2**

Table H-4. Construction Schedule A, Year 2: The number of potential piling days per month under the maximum envelope used to estimate the total number of marine mammal and sea turtle acoustic exposures for New England Wind.

Construction month	12 m Monopile, 5000 kJ		12 m Monopile, 6000 kJ		13 m Monopile, 5000 kJ		4 m Pin Pile, 3500 kJ
	1 pile/day	2 piles/day	1 pile/day	2 piles/day	1 pile/day	2 piles/day	4 pin piles/day
May	0	0	4	0	0	0	0
June	0	0	0	3	0	0	0
July	0	0	0	4	0	0	0
August	0	0	0	0	0	0	8
September	0	0	0	0	0	0	7
October	0	0	0	0	0	0	6
November	0	0	0	0	0	0	2
December	0	0	0	0	0	0	1
Total # Days	**0**	**0**	**4**	**7**	**0**	**0**	**24**

Table H-5. Construction Schedule B, Year 1: The number of potential piling days per month under the maximum envelope used to estimate the total number of marine mammal and sea turtle acoustic exposures for New England Wind.

Construction month	12 m Monopile, 5000 kJ		4 m Pin Pile, 3500 kJ
	1 pile/day	2 piles/day	4 pin piles/day
May	4	0	0
June	6	4	0
July	0	7	0
August	1	5	1
September	0	3	1
October	1	1	1
November	2	0	0
December	1	0	0
Total	**15**	**20**	**3**

Table H-6. Construction Schedule B, Year 2: The number of potential piling days per month under the maximum envelope used to estimate the total number of marine mammal and sea turtle acoustic exposures for New England Wind.

Construction month	12 m Monopile, 5000 kJ		4 m Pin Pile, 3500 kJ
	1 pile/day	2 piles/day	4 pin piles/day
May	0	0	1
June	0	0	9
July	0	0	14
August	0	0	14
September	0	0	8
October	0	0	4
November	0	0	2
December	0	0	1
Total	**0**	**0**	**53**

Table H-7. Construction Schedule B, Year 3: The number of potential piling days per month under the maximum envelope used to estimate the total number of marine mammal and sea turtle acoustic exposures for New England Wind.

Construction month	12 m Monopile, 5000 kJ		4 m Pin Pile, 3500 kJ
	1 pile/day	2 piles/day	4 pin piles/day
May	0	0	1
June	0	0	4
July	0	0	5
August	0	0	5
September	0	0	5
October	0	0	1
November	0	0	1
December	0	0	0
Total	**0**	**0**	**22**

H.2.1. Marine Mammal Exposure Estimates

Table H-8. Construction Schedule A, All Years Summed: The mean number of marine mammals predicted to receive sound levels above exposure criteria with sound attenuation. Summed construction schedule assumptions are summarized in Section 1.2.7.

Species	Injury								Behavior							
	L_E				L_{pk}				L_p [a]				L_p [b]			
	Attenuation (dB)								Attenuation (dB)							
	0	6	10	12	0	6	10	12	0	6	10	12	0	6	10	12
Low-frequency cetaceans																
Fin whale[c]	146.36	49.61	21.51	13.94	0.14	0.04	0.04	0.02	147.36	57.06	33.58	28.56	205.54	103.84	66.20	53.73
Minke whale	49.59	20.24	9.71	6.32	0.06	0.04	0.03	0.03	74.94	37.66	26.79	23.90	422.12	281.60	207.05	175.39
Humpback whale	81.08	29.12	13.69	9.09	0.13	0.05	0.05	0.05	68.89	26.90	16.46	14.11	97.99	49.67	31.83	25.69
North Atlantic right whale[c]	18.08	6.56	3.09	2.16	0.02	<0.01	<0.01	<0.01	26.02	10.89	7.01	5.98	36.32	18.67	11.99	9.72
Sei whale[c]	3.60	1.20	0.53	0.36	0.01	<0.01	<0.01	<0.01	5.44	2.17	1.29	1.09	42.29	27.66	20.13	16.86
Mid-frequency cetaceans																
Atlantic white-sided dolphin	0.62	0.21	0.21	0.21	1.56	1.56	1.56	1.56	3610.99	1830.24	1334.89	1189.53	2722.32	1532.12	1021.70	814.92
Atlantic spotted dolphin	0	0	0	0	0	0	0	0	14.74	5.28	3.92	3.38	17.04	7.47	4.18	3.03
Short-beaked common dolphin	4.05	2.55	1.28	0	6.96	5.77	5.09	5.09	16247.71	9083.36	6999.42	6371.06	11666.25	6902.20	4697.60	3805.18
Bottlenose dolphin	1.13	0.44	0.15	0	0.62	0.62	0.62	0.62	825.16	505.51	387.83	331.24	690.84	387.84	246.92	194.13
Risso's dolphin	0.04	0.02	0.02	<0.01	0.04	0.03	0.03	0.03	19.27	8.75	6.23	5.59	16.53	8.82	5.65	4.45
Long-finned pilot whale	0.06	0.06	0.06	0	0.15	0.15	0.15	0.15	447.66	227.09	165.24	147.76	324.89	187.96	126.66	100.70
Short-finned pilot whale	0.05	0.03	<0.01	<0.01	0.24	0.24	0.24	0.24	337.97	168.12	121.26	108.08	251.74	143.39	94.85	74.60
Sperm whale[c]	<0.01	<0.01	<0.01	0	<0.01	<0.01	<0.01	<0.01	8.93	3.91	2.64	2.34	7.71	4.04	2.52	1.92
High-frequency cetacean																
Harbor porpoise	359.73	173.92	97.62	67.84	34.26	14.77	5.91	3.87	758.01	367.08	258.58	227.94	11092.63	7737.44	5509.56	4618.70
Pinnipeds in water																
Gray seal	10.12	3.00	1.07	0.54	<0.01	<0.01	<0.01	<0.01	170.45	62.85	32.11	24.86	199.28	97.57	60.51	47.44
Harbor seal	29.00	7.21	1.95	0.91	0.28	0.19	0.18	0.18	321.18	126.64	75.85	61.00	402.88	198.97	123.09	96.25
Harp seal	12.51	2.99	0.94	0.36	0.10	0.04	0	0	187.66	70.59	37.64	30.42	225.05	109.18	67.95	53.16

[a] NOAA (2005), [b] Wood et al. (2012), [c] Listed as Endangered under the ESA.

Table H-9. Construction Schedule A, Year 1: The mean number of marine mammals predicted to receive sound levels above exposure criteria with sound attenuation. Yearly construction schedule assumptions are summarized in Appendix H.2.

Species	Injury								Behavior							
	L_E				L_{pk}				L_p [a]				L_p [b]			
	Attenuation (dB)								Attenuation (dB)							
	0	6	10	12	0	6	10	12	0	6	10	12	0	6	10	12
Low-frequency cetaceans																
Fin whale[c]	71.33	24.05	10.27	6.37	0.06	0.01	0.01	0.01	84.00	32.66	18.93	16.66	115.42	58.85	37.56	30.76
Minke whale	24.01	9.37	4.39	2.87	0.03	0.03	0.02	0.02	37.99	18.67	13.53	12.26	225.15	149.56	107.81	91.13
Humpback whale	39.42	13.57	6.41	4.24	0.08	0.04	0.04	0.04	39.08	15.07	8.99	7.76	55.78	28.23	18.05	14.62
North Atlantic right whale[c]	8.49	2.95	1.35	0.96	0.01	<0.01	<0.01	<0.01	12.83	5.30	3.52	3.04	18.90	9.56	6.12	4.94
Sei whale[c]	1.77	0.58	0.24	0.17	<0.01	<0.01	<0.01	<0.01	2.60	1.05	0.65	0.59	21.63	14.24	10.04	8.27
Mid-frequency cetaceans																
Atlantic white-sided dolphin	0.04	0.01	0.01	0.01	1.08	1.08	1.08	1.08	1883.99	920.68	670.96	605.30	1414.29	790.26	520.33	407.55
Atlantic spotted dolphin	0	0	0	0	0	0	0	0	7.88	3.14	2.34	2.04	8.69	3.83	2.16	1.59
Short-beaked common dolphin	0.33	0.22	0.11	0	5.98	4.79	4.23	4.23	8037.76	4211.55	3142.22	2861.28	5868.59	3333.92	2238.25	1783.86
Bottlenose dolphin	0.23	0.04	0.01	0	0.53	0.53	0.53	0.53	415.04	236.95	175.42	151.05	353.16	187.22	117.19	91.48
Risso's dolphin	0.02	0.01	0.01	<0.01	0.03	0.03	0.02	0.02	10.74	4.75	3.20	2.86	9.13	4.80	3.05	2.37
Long-finned pilot whale	<0.01	<0.01	<0.01	0	0.11	0.11	0.11	0.11	233.51	113.63	80.31	72.04	170.34	97.08	64.28	50.21
Short-finned pilot whale	<0.01	<0.01	<0.01	0	0.19	0.19	0.19	0.19	177.62	82.55	57.73	52.07	131.70	74.05	48.08	37.18
Sperm whale[c]	<0.01	<0.01	<0.01	0	<0.01	<0.01	<0.01	<0.01	4.82	2.05	1.36	1.22	4.06	2.15	1.32	0.98
High-frequency cetacean																
Harbor porpoise	167.25	78.29	43.98	30.77	17.20	7.00	2.82	1.77	371.46	175.46	126.74	113.19	5977.20	4002.28	2806.21	2338.16
Pinnipeds in water																
Gray seal	4.43	1.28	0.39	0.18	<0.01	<0.01	<0.01	<0.01	71.26	25.97	13.53	12.11	84.23	42.13	26.45	20.32
Harbor seal	12.22	2.65	0.67	0.18	0.10	0.10	0.10	0.10	131.20	54.14	34.04	29.25	170.31	84.84	52.58	40.76
Harp seal	5.10	1.23	0.40	0.15	0.05	0	0	0	77.02	28.89	16.61	14.32	92.02	46.03	29.07	22.64

[a] NOAA (2005), [b] Wood et al. (2012), [c] Listed as Endangered under the ESA.

Table H-10. Construction Schedule A, Year 2: The mean number of marine mammals predicted to receive sound levels above exposure criteria with sound attenuation. Yearly construction schedule assumptions are summarized in Appendix H.2.

Species	Injury								Behavior							
	L_E				L_{pk}				L_p [a]				L_p [b]			
	Attenuation (dB)								Attenuation (dB)							
	0	6	10	12	0	6	10	12	0	6	10	12	0	6	10	12
Low-frequency cetaceans																
Fin whale[c]	75.03	25.56	11.24	7.57	0.08	0.02	0.02	<0.01	63.36	24.40	14.65	11.90	90.12	44.99	28.64	22.97
Minke whale	25.58	10.87	5.32	3.44	0.02	0.02	0.01	0.01	36.96	18.98	13.26	11.64	196.97	132.03	99.24	84.26
Humpback whale	41.66	15.54	7.28	4.85	0.05	<0.01	<0.01	<0.01	29.81	11.83	7.47	6.35	42.22	21.44	13.79	11.07
North Atlantic right whale[c]	9.60	3.61	1.74	1.21	<0.01	<0.01	<0.01	<0.01	13.19	5.59	3.49	2.93	17.42	9.11	5.87	4.78
Sei whale[c]	1.83	0.62	0.29	0.19	<0.01	<0.01	<0.01	<0.01	2.85	1.12	0.63	0.50	20.66	13.42	10.08	8.59
Mid-frequency cetaceans																
Atlantic white-sided dolphin	0.58	0.19	0.19	0.19	0.48	0.48	0.48	0.48	1727.00	909.56	663.93	584.23	1308.03	741.86	501.36	407.37
Atlantic spotted dolphin	0	0	0	0	0	0	0	0	6.87	2.14	1.58	1.34	8.35	3.64	2.02	1.45
Short-beaked common dolphin	3.73	2.33	1.17	0	0.98	0.98	0.87	0.87	8209.95	4871.81	3857.21	3509.78	5797.67	3568.28	2459.35	2021.32
Bottlenose dolphin	0.90	0.40	0.13	0	0.09	0.09	0.09	0.09	410.12	268.55	212.42	180.18	337.68	200.62	129.74	102.65
Risso's dolphin	0.02	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	8.53	4.01	3.03	2.73	7.40	4.02	2.60	2.08
Long-finned pilot whale	0.06	0.06	0.06	0	0.04	0.04	0.04	0.04	214.15	113.46	84.93	75.72	154.55	90.88	62.38	50.49
Short-finned pilot whale	0.04	0.03	<0.01	<0.01	0.05	0.05	0.05	0.05	160.35	85.57	63.54	56.01	120.04	69.34	46.77	37.42
Sperm whale[c]	<0.01	<0.01	<0.01	0	<0.01	<0.01	<0.01	<0.01	4.11	1.86	1.28	1.12	3.65	1.90	1.20	0.94
High-frequency cetacean																
Harbor porpoise	192.48	95.63	53.65	37.07	17.06	7.78	3.08	2.10	386.54	191.62	131.84	114.75	5115.43	3735.16	2703.36	2280.54
Pinnipeds in water																
Gray seal	5.69	1.72	0.68	0.36	<0.01	<0.01	<0.01	<0.01	99.20	36.88	18.57	12.75	115.05	55.44	34.06	27.12
Harbor seal	16.78	4.56	1.28	0.73	0.18	0.10	0.09	0.09	189.97	72.51	41.80	31.75	232.57	114.14	70.51	55.50
Harp seal	7.40	1.77	0.54	0.21	0.05	0.04	0	0	110.64	41.70	21.03	16.09	133.03	63.15	38.88	30.52

[a] NOAA (2005), [b] Wood et al. (2012), [c] Listed as Endangered under the ESA.

Table H-11. Construction Schedule B, All Years Summed: The mean number of marine mammals predicted to receive sound levels above exposure criteria with sound attenuation. Summed construction schedule assumptions are summarized in Appendix H.2.

Species	Injury								Behavior							
	L_E				L_{pk}				L_p [a]				L_p [b]			
	Attenuation (dB)								Attenuation (dB)							
	0	6	10	12	0	6	10	12	0	6	10	12	0	6	10	12
Low-frequency cetaceans																
Fin whale[c]	251.74	86.42	37.72	25.35	0.31	0.09	0.09	0.02	160.68	60.16	41.87	37.77	236.43	119.99	78.58	64.38
Minke whale	97.69	42.60	20.59	13.10	0.10	0.05	0.03	0.03	115.38	64.81	50.89	46.74	617.91	404.75	300.67	253.54
Humpback whale	117.67	43.84	20.47	13.67	0.15	0.02	0.02	0.02	69.43	27.97	19.53	17.64	101.72	52.39	34.17	27.70
North Atlantic right whale[c]	19.76	7.84	3.92	2.77	0.02	<0.01	<0.01	<0.01	19.26	9.33	6.92	6.23	25.98	13.89	9.34	7.75
Sei whale[c]	6.78	2.44	1.14	0.83	0.02	<0.01	<0.01	<0.01	6.12	2.64	1.88	1.73	54.33	33.99	24.66	20.41
Mid-frequency cetaceans																
Atlantic white-sided dolphin	2.60	0.87	0.87	0.87	1.17	1.17	1.17	1.17	5332.04	2997.62	2385.18	2160.55	4060.10	2411.65	1638.66	1327.44
Atlantic spotted dolphin	0	0	0	0	0	0	0	0	17.42	5.61	4.31	3.75	21.26	9.38	5.24	3.76
Short-beaked common dolphin	7.55	5.04	2.52	0	5.72	5.72	5.16	5.16	19012.51	11256.30	9012.55	8248.25	13432.98	8331.08	5737.60	4697.05
Bottlenose dolphin	2.02	0.93	0.31	0	0.41	0.41	0.41	0.41	998.97	662.07	526.97	447.68	830.86	490.39	315.02	248.12
Risso's dolphin	0.05	0.03	0.03	<0.01	0.03	0.02	0.02	0.01	23.89	11.46	8.98	8.23	20.92	11.60	7.52	5.97
Long-finned pilot whale	0.18	0.18	0.18	0	0.14	0.14	0.14	0.14	601.70	329.84	260.80	237.32	432.84	265.11	181.87	146.36
Short-finned pilot whale	0.08	0.08	0.01	0	0.14	0.14	0.14	0.14	447.99	248.08	194.21	175.55	334.52	201.46	135.57	107.62
Sperm whale[c]	<0.01	<0.01	<0.01	0	<0.01	<0.01	<0.01	<0.01	13.09	6.10	4.60	4.19	11.90	6.40	4.04	3.13
High-frequency cetacean																
Harbor porpoise	611.86	313.95	173.78	117.38	56.46	27.69	8.82	6.32	932.60	512.43	400.40	363.83	12817.69	8579.47	5868.55	4939.12
Pinnipeds in water																
Gray seal	13.69	4.19	1.55	0.92	<0.01	<0.01	<0.01	<0.01	103.73	36.68	21.91	19.94	131.69	66.08	41.14	31.52
Harbor seal	48.24	12.61	3.85	1.64	0.77	0.19	0.10	0.10	236.43	108.01	77.88	67.72	300.72	155.21	99.42	78.24
Harp seal	20.33	5.56	1.42	0.52	0.19	0	0	0	129.91	52.91	36.14	32.17	159.01	81.27	52.37	41.11

[a] NOAA (2005), [b] Wood et al. (2012), [c] Listed as Endangered under the ESA.

Table H-12. Construction Schedule B, Year 1: The mean number of marine mammals predicted to receive sound levels above exposure criteria with sound attenuation. Yearly construction schedule assumptions are summarized in Appendix H.2.

Species	Injury								Behavior							
	L_E				L_{pk}				L_p [a]				L_p [b]			
	Attenuation (dB)								Attenuation (dB)							
	0	6	10	12	0	6	10	12	0	6	10	12	0	6	10	12
Low-frequency cetaceans																
Fin whale[c]	50.70	17.13	7.37	4.60	0.06	0.03	0.03	0.02	58.72	22.85	13.84	12.25	78.01	41.09	26.64	21.86
Minke whale	19.94	7.58	3.66	2.38	0.04	0.03	0.03	0.03	31.66	15.58	11.40	10.32	188.28	123.16	87.70	73.94
Humpback whale	25.35	8.73	3.95	2.61	0.04	0.02	0.02	0.02	23.68	9.46	5.76	5.08	32.30	17.11	11.07	8.96
North Atlantic right whale[c]	5.61	1.93	0.90	0.68	<0.01	<0.01	<0.01	<0.01	8.00	3.46	2.35	2.07	11.17	5.90	3.84	3.12
Sei whale[c]	1.56	0.51	0.21	0.14	<0.01	<0.01	<0.01	<0.01	2.39	0.97	0.61	0.55	20.03	13.17	9.14	7.47
Mid-frequency cetaceans																
Atlantic white-sided dolphin	0.07	0.02	0.02	0.02	1.17	1.17	1.17	1.17	1380.78	684.50	510.25	461.74	1061.81	603.29	400.45	312.54
Atlantic spotted dolphin	0	0	0	0	0	0	0	0	4.18	1.63	1.18	1.04	4.65	2.12	1.22	0.91
Short-beaked common dolphin	0.44	0.30	0.15	0	5.72	5.72	5.16	5.16	4153.76	2264.72	1765.71	1617.76	3036.60	1815.32	1241.81	998.24
Bottlenose dolphin	0.26	0.05	0.02	0	0.41	0.41	0.41	0.41	227.97	135.57	103.85	89.27	201.32	108.64	67.85	52.49
Risso's dolphin	0.01	<0.01	<0.01	<0.01	0.02	0.02	0.02	0.01	6.14	2.85	2.02	1.82	5.28	2.89	1.86	1.44
Long-finned pilot whale	<0.01	<0.01	<0.01	0	0.14	0.14	0.14	0.14	150.78	74.84	55.12	49.74	111.29	65.60	43.69	34.13
Short-finned pilot whale	0.02	0.02	0.01	0	0.14	0.14	0.14	0.14	113.55	53.98	39.10	35.43	85.78	49.65	32.51	25.13
Sperm whale[c]	<0.01	<0.01	<0.01	0	<0.01	<0.01	<0.01	<0.01	3.42	1.47	1.00	0.90	2.95	1.57	0.97	0.72
High-frequency cetacean																
Harbor porpoise	126.36	59.59	33.97	24.01	13.25	5.66	2.21	1.41	266.79	128.94	94.70	84.39	4271.24	2709.18	1853.85	1564.77
Pinnipeds in water																
Gray seal	3.99	1.20	0.39	0.19	<0.01	<0.01	<0.01	<0.01	63.06	22.80	11.85	10.79	73.66	37.47	23.56	18.07
Harbor seal	11.07	2.38	0.58	0.17	0.11	0.11	0.10	0.10	115.58	48.00	30.64	26.45	150.06	75.38	46.76	36.35
Harp seal	4.44	1.07	0.40	0.15	0.05	0	0	0	67.30	25.29	14.90	12.82	79.55	40.66	25.79	20.11

[a] NOAA (2005), [b] Wood et al. (2012), [c] Listed as Endangered under the ESA.

Table H-13. Construction Schedule B, Year 2: The mean number of marine mammals predicted to receive sound levels above exposure criteria with sound attenuation. Yearly construction schedule assumptions are summarized in Appendix H.2.

Species	Injury								Behavior							
	L_E				L_{pk}				L_p [a]				L_p [b]			
	Attenuation (dB)								Attenuation (dB)							
	0	6	10	12	0	6	10	12	0	6	10	12	0	6	10	12
Low-frequency cetaceans																
Fin whale[c]	141.85	48.89	21.41	14.65	0.18	0.04	0.04	0	71.94	26.33	19.78	18.01	111.77	55.67	36.64	30.01
Minke whale	53.95	24.30	11.75	7.44	0.04	0.01	0	0	58.09	34.16	27.40	25.27	298.11	195.39	147.78	124.62
Humpback whale	63.57	24.18	11.38	7.62	0.07	0	0	0	31.51	12.75	9.48	8.65	47.80	24.30	15.91	12.90
North Atlantic right whale[c]	9.33	3.89	1.99	1.38	0.01	<0.01	0	0	7.42	3.87	3.01	2.74	9.77	5.27	3.63	3.05
Sei whale[c]	3.51	1.30	0.63	0.46	<0.01	<0.01	0	0	2.51	1.12	0.86	0.79	23.05	13.99	10.43	8.70
Mid-frequency cetaceans																
Atlantic white-sided dolphin	1.78	0.59	0.59	0.59	0	0	0	0	2786.78	1631.42	1322.37	1198.16	2114.66	1275.42	873.30	715.80
Atlantic spotted dolphin	0	0	0	0	0	0	0	0	9.32	2.80	2.20	1.91	11.69	5.11	2.83	2.01
Short-beaked common dolphin	5.02	3.35	1.67	0	0	0	0	0	10498.71	6353.16	5120.38	4684.89	7345.74	4603.82	3176.58	2613.45
Bottlenose dolphin	1.24	0.62	0.21	0	0	0	0	0	542.17	370.23	297.54	252.04	442.69	268.45	173.81	137.57
Risso's dolphin	0.03	0.02	0.02	<0.01	<0.01	0	0	0	12.60	6.12	4.94	4.55	11.10	6.18	4.01	3.21
Long-finned pilot whale	0.12	0.12	0.12	0	0	0	0	0	318.65	180.20	145.35	132.56	227.23	140.99	97.65	79.31
Short-finned pilot whale	0.05	0.05	0	0	0	0	0	0	236.34	137.17	109.61	99.02	175.78	107.28	72.83	58.29
Sperm whale[c]	<0.01	<0.01	<0.01	0	0	0	0	0	7.02	3.36	2.62	2.39	6.50	3.51	2.23	1.75
High-frequency cetacean																
Harbor porpoise	331.45	173.65	95.44	63.74	29.50	15.04	4.51	3.35	454.54	261.80	208.70	190.77	5834.57	4007.58	2740.79	2303.63
Pinnipeds in water																
Gray seal	5.93	1.83	0.71	0.45	0	0	0	0	24.89	8.50	6.16	5.60	35.51	17.51	10.76	8.23
Harbor seal	22.75	6.26	2.00	0.90	0.40	0.05	0	0	73.96	36.73	28.91	25.25	92.20	48.85	32.22	25.64
Harp seal	9.72	2.74	0.62	0.22	0.09	0	0	0	38.32	16.91	13.00	11.84	48.63	24.85	16.27	12.86

[a] NOAA (2005), [b] Wood et al. (2012), [c] Listed as Endangered under the ESA.

Table H-14. Construction Schedule B, Year 3: The mean number of marine mammals predicted to receive sound levels above exposure criteria with sound attenuation. Yearly construction schedule assumptions are summarized in Appendix H.2.

Species	Injury								Behavior							
	L_E				L_{pk}				L_p [a]				L_p [b]			
	Attenuation (dB)								Attenuation (dB)							
	0	6	10	12	0	6	10	12	0	6	10	12	0	6	10	12
Low-frequency cetaceans																
Fin whale[c]	59.19	20.40	8.94	6.11	0.07	0.02	0.02	0	30.02	10.98	8.25	7.51	46.64	23.23	15.29	12.52
Minke whale	23.80	10.72	5.19	3.28	0.02	<0.01	0	0	25.63	15.07	12.09	11.15	131.52	86.20	65.19	54.98
Humpback whale	28.74	10.94	5.15	3.44	0.03	0	0	0	14.25	5.76	4.29	3.91	21.62	10.99	7.20	5.83
North Atlantic right whale[c]	4.82	2.01	1.03	0.71	<0.01	<0.01	0	0	3.84	2.00	1.56	1.42	5.05	2.72	1.88	1.58
Sei whale[c]	1.71	0.64	0.31	0.22	<0.01	<0.01	0	0	1.22	0.55	0.42	0.39	11.25	6.82	5.09	4.24
Mid-frequency cetaceans																
Atlantic white-sided dolphin	0.75	0.25	0.25	0.25	0	0	0	0	1164.47	681.70	552.56	500.66	883.62	532.94	364.91	299.10
Atlantic spotted dolphin	0	0	0	0	0	0	0	0	3.92	1.18	0.93	0.80	4.91	2.15	1.19	0.84
Short-beaked common dolphin	2.09	1.39	0.70	0	0	0	0	0	4360.04	2638.43	2126.46	1945.60	3050.64	1911.94	1319.21	1085.35
Bottlenose dolphin	0.52	0.26	0.09	0	0	0	0	0	228.83	156.26	125.58	106.38	186.84	113.30	73.36	58.06
Risso's dolphin	0.01	<0.01	<0.01	<0.01	<0.01	0	0	0	5.15	2.50	2.02	1.86	4.54	2.53	1.64	1.31
Long-finned pilot whale	0.05	0.05	0.05	0	0	0	0	0	132.27	74.80	60.33	55.02	94.32	58.52	40.53	32.92
Short-finned pilot whale	0.02	0.02	0	0	0	0	0	0	98.10	56.94	45.50	41.10	72.96	44.53	30.23	24.20
Sperm whale[c]	<0.01	<0.01	<0.01	0	0	0	0	0	2.65	1.27	0.99	0.90	2.45	1.32	0.84	0.66
High-frequency cetacean																
Harbor porpoise	154.05	80.71	44.36	29.63	13.71	6.99	2.10	1.56	211.27	121.68	97.00	88.67	2711.88	1862.70	1273.91	1070.72
Pinnipeds in water																
Gray seal	3.76	1.16	0.45	0.28	0	0	0	0	15.78	5.39	3.90	3.55	22.52	11.10	6.82	5.22
Harbor seal	14.42	3.97	1.27	0.57	0.25	0.03	0	0	46.89	23.29	18.33	16.01	58.46	30.97	20.43	16.25
Harp seal	6.17	1.74	0.40	0.14	0.06	0	0	0	24.29	10.72	8.24	7.51	30.83	15.76	10.31	8.15

[a] NOAA (2005), [b] Wood et al. (2012), [c] Listed as Endangered under the ESA.

H.2.2. Sea Turtle Exposure Estimates

This section includes sea turtle exposure estimates for Construction Schedules A and B, both combined and per year, and assuming 0, 6, 10, and 12 dB broadband attenuation.

Table H-15. Construction Schedule A, All Years Summed: The mean number of sea turtles predicted to receive sound levels above exposure criteria with sound attenuation. Summed construction schedule assumptions are summarized in Section 1.2.7.

Species	Injury								Behavior			
	L_E				L_{pk}				L_p			
	Attenuation (dB)								Attenuation (dB)			
	0	6	10	12	0	6	10	12	0	6	10	12
Kemp's ridley turtle[a]	0.24	0.04	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	1.15	0.51	0.25	0.18
Leatherback turtle[a]	5.57	0.78	0.23	0.02	0.23	0.23	0.23	0.23	40.48	17.76	8.57	5.69
Loggerhead turtle	2.18	0.51	0.04	<0.01	0.08	0.08	0.08	0.08	22.56	9.62	4.57	3.23
Green turtle	0.49	0.09	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	1.26	0.62	0.32	0.20

[a] Listed as Endangered under the ESA.

Table H-16. Construction Schedule A, Year 1: The mean number of sea turtles predicted to receive sound levels above exposure criteria with sound attenuation Yearly construction schedule assumptions are summarized in Appendix H.2.

Species	Injury								Behavior			
	L_E				L_{pk}				L_p			
	Attenuation (dB)								Attenuation (dB)			
	0	6	10	12	0	6	10	12	0	6	10	12
Kemp's ridley turtle[a]	0.10	0.02	<0.01	0	<0.01	<0.01	<0.01	<0.01	0.61	0.24	0.12	0.09
Leatherback turtle[a]	2.62	0.52	0.14	0	0.18	0.18	0.18	0.18	21.59	9.21	4.98	3.20
Loggerhead turtle	1.07	0.28	0.03	0	0.07	0.07	0.07	0.07	11.23	4.89	2.36	1.64
Green turtle	0.23	0.04	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.70	0.34	0.17	0.11

[a] Listed as Endangered under the ESA.

Table H-17. Construction Schedule A, Year 2: The mean number of sea turtles predicted to receive sound levels above exposure criteria with sound attenuation Yearly construction schedule assumptions are summarized in Appendix H.2.

Species	Injury								Behavior			
	L_E				L_{pk}				L_p			
	Attenuation (dB)								Attenuation (dB)			
	0	6	10	12	0	6	10	12	0	6	10	12
Kemp's ridley turtle[a]	0.14	0.03	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.54	0.26	0.12	0.09
Leatherback turtle[a]	2.95	0.26	0.09	0.02	0.05	0.05	0.05	0.05	18.88	8.55	3.59	2.50
Loggerhead turtle	1.11	0.22	0.01	<0.01	0.02	0.02	0.02	0.02	11.33	4.73	2.21	1.59
Green turtle	0.27	0.05	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.56	0.28	0.15	0.09

[a] Listed as Endangered under the ESA.

Table H-18. Construction Schedule B, All Years Summed: The mean number of sea turtles predicted to receive sound levels above exposure criteria with sound attenuation. Yearly construction schedule assumptions are summarized in Appendix H.2.

Species	Injury								Behavior			
	L_E				L_{pk}				L_p			
	Attenuation (dB)								Attenuation (dB)			
	0	6	10	12	0	6	10	12	0	6	10	12
Kemp's ridley turtle[a]	0.42	0.08	0.01	0	<0.01	<0.01	<0.01	<0.01	1.64	0.74	0.35	0.27
Leatherback turtle[a]	8.07	0.79	0.18	0	0.17	0.17	0.17	0.17	55.79	23.87	10.09	6.82
Loggerhead turtle	2.64	0.49	0	0	0.09	0.09	0.09	0.09	27.72	11.09	5.24	3.88
Green turtle	0.77	0.13	0.02	<0.01	<0.01	<0.01	<0.01	<0.01	1.69	0.80	0.42	0.23

[a] Listed as Endangered under the ESA.

Table H-19. Construction Schedule B, Year 1: The mean number of sea turtles predicted to receive sound levels above exposure criteria with sound attenuation Yearly construction schedule assumptions are summarized in Appendix H.2.

Species	Injury								Behavior			
	L_E				L_{pk}				L_p			
	Attenuation (dB)								Attenuation (dB)			
	0	6	10	12	0	6	10	12	0	6	10	12
Kemp's ridley turtle[a]	0.06	0.01	<0.01	0	<0.01	<0.01	<0.01	<0.01	0.41	0.16	0.08	0.06
Leatherback turtle[a]	1.55	0.32	0.07	0	0.17	0.17	0.17	0.17	13.65	5.47	2.88	1.93
Loggerhead turtle	0.58	0.14	0	0	0.09	0.09	0.09	0.09	6.36	2.48	1.25	0.99
Green turtle	0.14	0.02	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.48	0.22	0.11	0.07

[a] Listed as Endangered under the ESA.

Table H-20. Construction Schedule B, Year 2: The mean number of sea turtles predicted to receive sound levels above exposure criteria with sound attenuation Yearly construction schedule assumptions are summarized in Appendix H.2.

Species	Injury								Behavior			
	L_E				L_{pk}				L_p			
	Attenuation (dB)								Attenuation (dB)			
	0	6	10	12	0	6	10	12	0	6	10	12
Kemp's ridley turtle[a]	0.25	0.05	<0.01	0	0	0	0	0	0.87	0.41	0.19	0.15
Leatherback turtle[a]	4.59	0.33	0.08	0	0	0	0	0	29.67	12.95	5.08	3.44
Loggerhead turtle	1.43	0.24	0	0	0	0	0	0	14.79	5.96	2.77	2.00
Green turtle	0.44	0.08	0.01	<0.01	0	0	0	0	0.86	0.41	0.22	0.11

[a] Listed as Endangered under the ESA.

Table H-21. Construction Schedule B, Year 3: The mean number of sea turtles predicted to receive sound levels above exposure criteria with sound attenuation Yearly construction schedule assumptions are summarized in Appendix H.2.

Species	Injury								Behavior			
	L_E				L_{pk}				L_p			
	Attenuation (dB)								Attenuation (dB)			
	0	6	10	12	0	6	10	12	0	6	10	12
Kemp's ridley turtle[a]	0.11	0.02	<0.01	0	0	0	0	0	0.36	0.17	0.08	0.06
Leatherback turtle[a]	1.93	0.14	0.03	0	0	0	0	0	12.47	5.44	2.14	1.45
Loggerhead turtle	0.64	0.11	0	0	0	0	0	0	6.57	2.65	1.23	0.89
Green turtle	0.18	0.03	<0.01	<0.01	0	0	0	0	0.36	0.17	0.09	0.05

[a] Listed as Endangered under the ESA.

H.2.3. Potential Impacts Relative to Species' Abundance

Table H-22. Construction Schedule A, All Years Summed: Marine mammal exposures as a percent of abundance with sound attenuation. Summed construction schedule assumptions are summarized in Appendix H.2.

Species	Injury								Behavior							
	L_E				L_{pk}				L_p [a]				L_p [b]			
	Attenuation (dB)								Attenuation (dB)							
	0	6	10	12	0	6	10	12	0	6	10	12	0	6	10	12
Low-frequency cetaceans																
Fin whale[c]	2.15	0.73	0.32	0.20	<0.01	<0.01	<0.01	<0.01	2.17	0.84	0.49	0.42	3.02	1.53	0.97	0.79
Minke whale	0.23	0.09	0.04	0.03	<0.01	<0.01	<0.01	<0.01	0.34	0.17	0.12	0.11	1.92	1.28	0.94	0.80
Humpback whale	5.81	2.09	0.98	0.65	<0.01	<0.01	<0.01	<0.01	4.94	1.93	1.18	1.01	7.02	3.56	2.28	1.84
North Atlantic right whale[c]	4.91	1.78	0.84	0.59	<0.01	<0.01	<0.01	<0.01	7.07	2.96	1.91	1.62	9.87	5.07	3.26	2.64
Sei whale[c]	0.06	0.02	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.09	0.03	0.02	0.02	0.67	0.44	0.32	0.27
Mid-frequency cetaceans																
Atlantic white-sided dolphin	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	3.87	1.96	1.43	1.28	2.92	1.64	1.10	0.87
Atlantic spotted dolphin	0	0	0	0	0	0	0	0	0.04	0.01	<0.01	<0.01	0.04	0.02	0.01	<0.01
Short-beaked common dolphin	<0.01	<0.01	<0.01	0	<0.01	<0.01	<0.01	<0.01	9.39	5.25	4.05	3.68	6.74	3.99	2.72	2.20
Bottlenose dolphin	<0.01	<0.01	<0.01	0	<0.01	<0.01	<0.01	<0.01	1.31	0.80	0.62	0.53	1.10	0.62	0.39	0.31
Risso's dolphin	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.05	0.02	0.02	0.02	0.05	0.03	0.02	0.01
Long-finned pilot whale	<0.01	<0.01	<0.01	0	<0.01	<0.01	<0.01	<0.01	1.14	0.58	0.42	0.38	0.83	0.48	0.32	0.26
Short-finned pilot whale	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	1.17	0.58	0.42	0.37	0.87	0.50	0.33	0.26
Sperm whale[c]	<0.01	<0.01	<0.01	0	<0.01	<0.01	<0.01	<0.01	0.21	0.09	0.06	0.05	0.18	0.09	0.06	0.04
High-frequency cetacean																
Harbor porpoise	0.38	0.18	0.10	0.07	0.04	0.02	<0.01	<0.01	0.79	0.38	0.27	0.24	11.61	8.10	5.77	4.83
Pinnipeds in water																
Gray seal	0.04	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.62	0.23	0.12	0.09	0.73	0.36	0.22	0.17
Harbor seal	0.05	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.52	0.21	0.12	0.10	0.66	0.32	0.20	0.16
Harp seal	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0	0	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

[a] NOAA (2005), [b] Wood et al. (2012), [c] Listed as Endangered under the ESA.

Table H-23. Construction Schedule A, Year 1: Marine mammal exposures as a percent of abundance with sound attenuation. Yearly construction schedule assumptions are summarized in Appendix H.2.

Species	Injury								Behavior							
	L_E				L_{pk}				L_p [a]				L_p [b]			
	Attenuation (dB)								Attenuation (dB)							
	0	6	10	12	0	6	10	12	0	6	10	12	0	6	10	12
Low-frequency cetaceans																
Fin whale[c]	1.05	0.35	0.15	0.09	<0.01	<0.01	<0.01	<0.01	1.23	0.48	0.28	0.24	1.70	0.87	0.55	0.45
Minke whale	0.11	0.04	0.02	0.01	<0.01	<0.01	<0.01	<0.01	0.17	0.09	0.06	0.06	1.02	0.68	0.49	0.41
Humpback whale	2.82	0.97	0.46	0.30	<0.01	<0.01	<0.01	<0.01	2.80	1.08	0.64	0.56	4.00	2.02	1.29	1.05
North Atlantic right whale[c]	2.31	0.80	0.37	0.26	<0.01	<0.01	<0.01	<0.01	3.49	1.44	0.96	0.83	5.14	2.60	1.66	1.34
Sei whale[c]	0.03	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.04	0.02	0.01	<0.01	0.34	0.23	0.16	0.13
Mid-frequency cetaceans																
Atlantic white-sided dolphin	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	2.02	0.99	0.72	0.65	1.52	0.85	0.56	0.44
Atlantic spotted dolphin	0	0	0	0	0	0	0	0	0.02	<0.01	<0.01	<0.01	0.02	<0.01	<0.01	<0.01
Short-beaked common dolphin	<0.01	<0.01	<0.01	0	<0.01	<0.01	<0.01	<0.01	4.65	2.43	1.82	1.65	3.39	1.93	1.29	1.03
Bottlenose dolphin	<0.01	<0.01	<0.01	0	<0.01	<0.01	<0.01	<0.01	0.66	0.38	0.28	0.24	0.56	0.30	0.19	0.15
Risso's dolphin	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.03	0.01	<0.01	<0.01	0.03	0.01	<0.01	<0.01
Long-finned pilot whale	<0.01	<0.01	<0.01	0	<0.01	<0.01	<0.01	<0.01	0.60	0.29	0.20	0.18	0.43	0.25	0.16	0.13
Short-finned pilot whale	<0.01	<0.01	<0.01	0	<0.01	<0.01	<0.01	<0.01	0.61	0.29	0.20	0.18	0.46	0.26	0.17	0.13
Sperm whale[c]	<0.01	<0.01	<0.01	0	<0.01	<0.01	<0.01	<0.01	0.11	0.05	0.03	0.03	0.09	0.05	0.03	0.02
High-frequency cetacean																
Harbor porpoise	0.18	0.08	0.05	0.03	0.02	<0.01	<0.01	<0.01	0.39	0.18	0.13	0.12	6.26	4.19	2.94	2.45
Pinnipeds in water																
Gray seal	0.02	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.26	0.10	0.05	0.04	0.31	0.15	0.10	0.07
Harbor seal	0.02	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.21	0.09	0.06	0.05	0.28	0.14	0.09	0.07
Harp seal	<0.01	<0.01	<0.01	<0.01	<0.01	0	0	0	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

[a] NOAA (2005), [b] Wood et al. (2012), [c] Listed as Endangered under the ESA.

Table H-24. Construction Schedule A, Year 2: Marine mammal exposures as a percent of abundance with sound attenuation. Yearly construction schedule assumptions are summarized in Appendix H.2.

Species	Injury								Behavior							
	L_E				L_{pk}				L_p [a]				L_p [b]			
	Attenuation (dB)								Attenuation (dB)							
	0	6	10	12	0	6	10	12	0	6	10	12	0	6	10	12
Low-frequency cetaceans																
Fin whale[c]	1.10	0.38	0.17	0.11	<0.01	<0.01	<0.01	<0.01	0.93	0.36	0.22	0.17	1.32	0.66	0.42	0.34
Minke whale	0.12	0.05	0.02	0.02	<0.01	<0.01	<0.01	<0.01	0.17	0.09	0.06	0.05	0.90	0.60	0.45	0.38
Humpback whale	2.98	1.11	0.52	0.35	<0.01	<0.01	<0.01	<0.01	2.14	0.85	0.54	0.46	3.02	1.54	0.99	0.79
North Atlantic right whale[c]	2.61	0.98	0.47	0.33	<0.01	<0.01	<0.01	<0.01	3.59	1.52	0.95	0.80	4.73	2.48	1.60	1.30
Sei whale[c]	0.03	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.05	0.02	0.01	<0.01	0.33	0.21	0.16	0.14
Mid-frequency cetaceans																
Atlantic white-sided dolphin	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	1.85	0.98	0.71	0.63	1.40	0.80	0.54	0.44
Atlantic spotted dolphin	0	0	0	0	0	0	0	0	0.02	<0.01	<0.01	<0.01	0.02	<0.01	<0.01	<0.01
Short-beaked common dolphin	<0.01	<0.01	<0.01	0	<0.01	<0.01	<0.01	<0.01	4.75	2.82	2.23	2.03	3.35	2.06	1.42	1.17
Bottlenose dolphin	<0.01	<0.01	<0.01	0	<0.01	<0.01	<0.01	<0.01	0.65	0.43	0.34	0.29	0.54	0.32	0.21	0.16
Risso’s dolphin	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.02	0.01	<0.01	<0.01	0.02	0.01	<0.01	<0.01
Long-finned pilot whale	<0.01	<0.01	<0.01	0	<0.01	<0.01	<0.01	<0.01	0.55	0.29	0.22	0.19	0.39	0.23	0.16	0.13
Short-finned pilot whale	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.55	0.30	0.22	0.19	0.42	0.24	0.16	0.13
Sperm whale[c]	<0.01	<0.01	<0.01	0	<0.01	<0.01	<0.01	<0.01	0.09	0.04	0.03	0.03	0.08	0.04	0.03	0.02
High-frequency cetacean																
Harbor porpoise	0.20	0.10	0.06	0.04	0.02	<0.01	<0.01	<0.01	0.40	0.20	0.14	0.12	5.35	3.91	2.83	2.39
Pinnipeds in water																
Gray seal	0.02	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.36	0.14	0.07	0.05	0.42	0.20	0.12	0.10
Harbor seal	0.03	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.31	0.12	0.07	0.05	0.38	0.19	0.11	0.09
Harp seal	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0	0	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

[a] NOAA (2005), [b] Wood et al. (2012), [c] Listed as Endangered under the ESA.

Table H-25. Construction Schedule B, All Years Summed: Marine mammal exposures as a percent of abundance with sound attenuation. Summed construction schedule assumptions are summarized in Section 1.2.7.

Species	Injury								Behavior							
	L_E				L_{pk}				L_p [a]				L_p [b]			
	Attenuation (dB)								Attenuation (dB)							
	0	6	10	12	0	6	10	12	0	6	10	12	0	6	10	12
Low-frequency cetaceans																
Fin whale[c]	3.70	1.27	0.55	0.37	<0.01	<0.01	<0.01	<0.01	2.36	0.88	0.62	0.56	3.48	1.76	1.16	0.95
Minke whale	0.44	0.19	0.09	0.06	<0.01	<0.01	<0.01	<0.01	0.53	0.30	0.23	0.21	2.81	1.84	1.37	1.15
Humpback whale	8.43	3.14	1.47	0.98	0.01	<0.01	<0.01	<0.01	4.97	2.00	1.40	1.26	7.29	3.75	2.45	1.98
North Atlantic right whale[c]	5.37	2.13	1.06	0.75	<0.01	<0.01	<0.01	<0.01	5.23	2.54	1.88	1.69	7.06	3.78	2.54	2.11
Sei whale[c]	0.11	0.04	0.02	0.01	<0.01	<0.01	<0.01	<0.01	0.10	0.04	0.03	0.03	0.86	0.54	0.39	0.32
Mid-frequency cetaceans																
Atlantic white-sided dolphin	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	5.72	3.22	2.56	2.32	4.35	2.59	1.76	1.42
Atlantic spotted dolphin	0	0	0	0	0	0	0	0	0.04	0.01	0.01	<0.01	0.05	0.02	0.01	<0.01
Short-beaked common dolphin	<0.01	<0.01	<0.01	0	<0.01	<0.01	<0.01	<0.01	10.99	6.51	5.21	4.77	7.77	4.82	3.32	2.72
Bottlenose dolphin	<0.01	<0.01	<0.01	0	<0.01	<0.01	<0.01	<0.01	1.59	1.05	0.84	0.71	1.32	0.78	0.50	0.39
Risso's dolphin	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.07	0.03	0.03	0.02	0.06	0.03	0.02	0.02
Long-finned pilot whale	<0.01	<0.01	<0.01	0	<0.01	<0.01	<0.01	<0.01	1.53	0.84	0.67	0.61	1.10	0.68	0.46	0.37
Short-finned pilot whale	<0.01	<0.01	<0.01	0	<0.01	<0.01	<0.01	<0.01	1.55	0.86	0.67	0.61	1.16	0.70	0.47	0.37
Sperm whale[c]	<0.01	<0.01	<0.01	0	<0.01	<0.01	<0.01	<0.01	0.30	0.14	0.11	0.10	0.27	0.15	0.09	0.07
High-frequency cetacean																
Harbor porpoise	0.64	0.33	0.18	0.12	0.06	0.03	<0.01	<0.01	0.98	0.54	0.42	0.38	13.42	8.98	6.14	5.17
Pinnipeds in water																
Gray seal	0.05	0.02	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.38	0.13	0.08	0.07	0.48	0.24	0.15	0.12
Harbor seal	0.08	0.02	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.39	0.18	0.13	0.11	0.49	0.25	0.16	0.13
Harp seal	<0.01	<0.01	<0.01	<0.01	<0.01	0	0	0	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

[a] NOAA (2005), [b] Wood et al. (2012), [c] Listed as Endangered under the ESA.

Table H-26. Construction Schedule B, Year 1: Marine mammal exposures as a percent of abundance with sound attenuation. Yearly construction schedule assumptions are summarized in Appendix H.2.

Species	Injury								Behavior							
	L_E				L_{pk}				L_p [a]				L_p [b]			
	Attenuation (dB)								Attenuation (dB)							
	0	6	10	12	0	6	10	12	0	6	10	12	0	6	10	12
Low-frequency cetaceans																
Fin whale[c]	0.75	0.25	0.11	0.07	<0.01	<0.01	<0.01	<0.01	0.86	0.34	0.20	0.18	1.15	0.60	0.39	0.32
Minke whale	0.09	0.03	0.02	0.01	<0.01	<0.01	<0.01	<0.01	0.14	0.07	0.05	0.05	0.86	0.56	0.40	0.34
Humpback whale	1.82	0.63	0.28	0.19	<0.01	<0.01	<0.01	<0.01	1.70	0.68	0.41	0.36	2.31	1.23	0.79	0.64
North Atlantic right whale[c]	1.52	0.53	0.24	0.19	<0.01	<0.01	<0.01	<0.01	2.17	0.94	0.64	0.56	3.03	1.60	1.04	0.85
Sei whale[c]	0.02	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.04	0.02	<0.01	<0.01	0.32	0.21	0.15	0.12
Mid-frequency cetaceans																
Atlantic white-sided dolphin	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	1.48	0.73	0.55	0.50	1.14	0.65	0.43	0.34
Atlantic spotted dolphin	0	0	0	0	0	0	0	0	0.01	<0.01	<0.01	<0.01	0.01	<0.01	<0.01	<0.01
Short-beaked common dolphin	<0.01	<0.01	<0.01	0	<0.01	<0.01	<0.01	<0.01	2.40	1.31	1.02	0.94	1.76	1.05	0.72	0.58
Bottlenose dolphin	<0.01	<0.01	<0.01	0	<0.01	<0.01	<0.01	<0.01	0.36	0.22	0.17	0.14	0.32	0.17	0.11	0.08
Risso's dolphin	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.02	<0.01	<0.01	<0.01	0.01	<0.01	<0.01	<0.01
Long-finned pilot whale	<0.01	<0.01	<0.01	0	<0.01	<0.01	<0.01	<0.01	0.38	0.19	0.14	0.13	0.28	0.17	0.11	0.09
Short-finned pilot whale	<0.01	<0.01	<0.01	0	<0.01	<0.01	<0.01	<0.01	0.39	0.19	0.14	0.12	0.30	0.17	0.11	0.09
Sperm whale[c]	<0.01	<0.01	<0.01	0	<0.01	<0.01	<0.01	<0.01	0.08	0.03	0.02	0.02	0.07	0.04	0.02	0.02
High-frequency cetacean																
Harbor porpoise	0.13	0.06	0.04	0.03	0.01	<0.01	<0.01	<0.01	0.28	0.13	0.10	0.09	4.47	2.84	1.94	1.64
Pinnipeds in water																
Gray seal	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.23	0.08	0.04	0.04	0.27	0.14	0.09	0.07
Harbor seal	0.02	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.19	0.08	0.05	0.04	0.24	0.12	0.08	0.06
Harp seal	<0.01	<0.01	<0.01	<0.01	<0.01	0	0	0	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

[a] NOAA (2005), [b] Wood et al. (2012), [c] Listed as Endangered under the ESA.

Table H-27. Construction Schedule B, Year 2: Marine mammal exposures as a percent of abundance with sound attenuation. Yearly construction schedule assumptions are summarized in Appendix H.2.

Species	Injury								Behavior							
	L_E				L_{pk}				L_p [a]				L_p [b]			
	Attenuation (dB)								Attenuation (dB)							
	0	6	10	12	0	6	10	12	0	6	10	12	0	6	10	12
Low-frequency cetaceans																
Fin whale[c]	2.09	0.72	0.31	0.22	<0.01	<0.01	<0.01	0	1.06	0.39	0.29	0.26	1.64	0.82	0.54	0.44
Minke whale	0.25	0.11	0.05	0.03	<0.01	<0.01	0	0	0.26	0.16	0.12	0.12	1.36	0.89	0.67	0.57
Humpback whale	4.55	1.73	0.82	0.55	<0.01	0	0	0	2.26	0.91	0.68	0.62	3.42	1.74	1.14	0.92
North Atlantic right whale[c]	2.53	1.06	0.54	0.37	<0.01	<0.01	0	0	2.02	1.05	0.82	0.75	2.65	1.43	0.99	0.83
Sei whale[c]	0.06	0.02	<0.01	<0.01	<0.01	<0.01	0	0	0.04	0.02	0.01	0.01	0.37	0.22	0.17	0.14
Mid-frequency cetaceans																
Atlantic white-sided dolphin	<0.01	<0.01	<0.01	<0.01	0	0	0	0	2.99	1.75	1.42	1.29	2.27	1.37	0.94	0.77
Atlantic spotted dolphin	0	0	0	0	0	0	0	0	0.02	<0.01	<0.01	<0.01	0.03	0.01	<0.01	<0.01
Short-beaked common dolphin	<0.01	<0.01	<0.01	0	0	0	0	0	6.07	3.67	2.96	2.71	4.25	2.66	1.84	1.51
Bottlenose dolphin	<0.01	<0.01	<0.01	0	0	0	0	0	0.86	0.59	0.47	0.40	0.70	0.43	0.28	0.22
Risso's dolphin	<0.01	<0.01	<0.01	<0.01	<0.01	0	0	0	0.04	0.02	0.01	0.01	0.03	0.02	0.01	<0.01
Long-finned pilot whale	<0.01	<0.01	<0.01	0	0	0	0	0	0.81	0.46	0.37	0.34	0.58	0.36	0.25	0.20
Short-finned pilot whale	<0.01	<0.01	0	0	0	0	0	0	0.82	0.47	0.38	0.34	0.61	0.37	0.25	0.20
Sperm whale[c]	<0.01	<0.01	<0.01	0	0	0	0	0	0.16	0.08	0.06	0.05	0.15	0.08	0.05	0.04
High-frequency cetacean																
Harbor porpoise	0.35	0.18	0.10	0.07	0.03	0.02	<0.01	<0.01	0.48	0.27	0.22	0.20	6.11	4.19	2.87	2.41
Pinnipeds in water																
Gray seal	0.02	<0.01	<0.01	<0.01	0	0	0	0	0.09	0.03	0.02	0.02	0.13	0.06	0.04	0.03
Harbor seal	0.04	0.01	<0.01	<0.01	<0.01	<0.01	0	0	0.12	0.06	0.05	0.04	0.15	0.08	0.05	0.04
Harp seal	<0.01	<0.01	<0.01	<0.01	<0.01	0	0	0	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

[a] NOAA (2005), [b] Wood et al. (2012), [c] Listed as Endangered under the ESA.

Table H-28. Construction Schedule B, Year 3: Marine mammal exposures as a percent of abundance with sound attenuation. Yearly construction schedule assumptions are summarized in Appendix H.2.

Species	Injury								Behavior							
	L_E				L_{pk}				L_p [a]				L_p [b]			
	Attenuation (dB)								Attenuation (dB)							
	0	6	10	12	0	6	10	12	0	6	10	12	0	6	10	12
Low-frequency cetaceans																
Fin whale[c]	0.87	0.30	0.13	0.09	<0.01	<0.01	<0.01	0	0.44	0.16	0.12	0.11	0.69	0.34	0.22	0.18
Minke whale	0.11	0.05	0.02	0.01	<0.01	<0.01	0	0	0.12	0.07	0.06	0.05	0.60	0.39	0.30	0.25
Humpback whale	2.06	0.78	0.37	0.25	<0.01	0	0	0	1.02	0.41	0.31	0.28	1.55	0.79	0.52	0.42
North Atlantic right whale[c]	1.31	0.55	0.28	0.19	<0.01	<0.01	0	0	1.04	0.54	0.42	0.39	1.37	0.74	0.51	0.43
Sei whale[c]	0.03	0.01	<0.01	<0.01	<0.01	<0.01	0	0	0.02	<0.01	<0.01	<0.01	0.18	0.11	0.08	0.07
Mid-frequency cetaceans																
Atlantic white-sided dolphin	<0.01	<0.01	<0.01	<0.01	0	0	0	0	1.25	0.73	0.59	0.54	0.95	0.57	0.39	0.32
Atlantic spotted dolphin	0	0	0	0	0	0	0	0	<0.01	<0.01	<0.01	<0.01	0.01	<0.01	<0.01	<0.01
Short-beaked common dolphin	<0.01	<0.01	<0.01	0	0	0	0	0	2.52	1.53	1.23	1.12	1.76	1.11	0.76	0.63
Bottlenose dolphin	<0.01	<0.01	<0.01	0	0	0	0	0	0.36	0.25	0.20	0.17	0.30	0.18	0.12	0.09
Risso's dolphin	<0.01	<0.01	<0.01	<0.01	<0.01	0	0	0	0.01	<0.01	<0.01	<0.01	0.01	<0.01	<0.01	<0.01
Long-finned pilot whale	<0.01	<0.01	<0.01	0	0	0	0	0	0.34	0.19	0.15	0.14	0.24	0.15	0.10	0.08
Short-finned pilot whale	<0.01	<0.01	0	0	0	0	0	0	0.34	0.20	0.16	0.14	0.25	0.15	0.10	0.08
Sperm whale[c]	<0.01	<0.01	<0.01	0	0	0	0	0	0.06	0.03	0.02	0.02	0.06	0.03	0.02	0.02
High-frequency cetacean																
Harbor porpoise	0.16	0.08	0.05	0.03	0.01	<0.01	<0.01	<0.01	0.22	0.13	0.10	0.09	2.84	1.95	1.33	1.12
Pinnipeds in water																
Gray seal	0.01	<0.01	<0.01	<0.01	0	0	0	0	0.06	0.02	0.01	0.01	0.08	0.04	0.02	0.02
Harbor seal	0.02	<0.01	<0.01	<0.01	<0.01	<0.01	0	0	0.08	0.04	0.03	0.03	0.10	0.05	0.03	0.03
Harp seal	<0.01	<0.01	<0.01	<0.01	<0.01	0	0	0	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

[a] NOAA (2005), [b] Wood et al. (2012), [c] Listed as Endangered under the ESA.

H.2.4. Marine Mammal Exposure Ranges

Table H-29. 12 m monopile, 5000 kJ hammer, one pile per day: Exposure ranges (ER95%) in km to marine mammal threshold criteria with sound attenuation.

Species	Injury								Behavior							
	L_E				L_{pk}				L_p [a]				L_p [b]			
	Attenuation (dB)								Attenuation (dB)							
	0	6	10	12	0	6	10	12	0	6	10	12	0	6	10	12
Low-frequency cetaceans																
Fin whale[c]	7.99	3.98	2.37	1.91	0.04	0.01	0.01	0.01	10.45	6.17	4.00	3.71	10.46	6.18	3.99	3.72
Minke whale	6.38	2.91	1.50	0.97	0.04	0.04	0.02	0.02	10.04	5.79	3.89	3.50	36.32	25.89	20.29	17.93
Humpback whale	9.08	4.68	2.76	2.12	0	0	0	0	10.45	6.09	3.99	3.74	10.47	6.03	3.99	3.74
North Atlantic right whale[c]	7.81	3.74	1.84	1.52	0	0	0	0	10.01	5.82	3.94	3.62	10.12	5.83	3.97	3.60
Sei whale[c]	7.20	3.36	1.95	1.26	<0.01	<0.01	<0.01	<0.01	10.21	5.84	3.88	3.67	38.10	26.74	21.02	18.41
Mid-frequency cetaceans																
Atlantic white-sided dolphin	0	0	0	0	0.01	0.01	0.01	0.01	9.76	5.52	3.78	3.48	5.52	3.36	2.75	2.35
Atlantic spotted dolphin	0	0	0	0	0	0	0	0	10.11	5.91	4.15	2.98	5.69	2.80	2.57	1.93
Short-beaked common dolphin	0	0	0	0	0.01	0.01	0.01	0.01	9.79	5.52	3.79	3.51	5.61	3.45	2.86	2.42
Bottlenose dolphin	0	0	0	0	0.01	0.01	0.01	0.01	9.35	4.97	3.40	2.97	5.03	2.96	2.34	1.74
Risso's dolphin	0.02	0.02	0	0	0.02	<0.01	<0.01	<0.01	10.20	5.98	3.85	3.62	6.07	3.47	2.94	2.65
Long-finned pilot whale	0	0	0	0	0.02	0.02	0.02	0.02	9.90	5.69	3.85	3.53	5.55	3.41	2.93	2.39
Short-finned pilot whale	<0.01	<0.01	<0.01	0	<0.01	<0.01	<0.01	<0.01	9.91	5.61	3.83	3.56	5.56	3.46	2.86	2.39
Sperm whale[c]	0	0	0	0	0.02	0.02	0.02	0.02	10.18	5.76	3.90	3.72	5.71	3.64	2.96	2.32
High-frequency cetaceans																
Harbor porpoise	5.17	2.68	1.55	1.07	0.56	0.33	0.13	0.11	9.97	5.74	3.94	3.66	97.57	74.91	53.67	46.82
Pinnipeds in water																
Gray seal	2.23	0.89	0.51	0.42	0	0	0	0	10.73	6.31	4.13	3.95	8.67	4.54	3.56	3.28
Harbor seal	2.03	0.67	0.21	0.02	0.02	0.02	0.02	0.02	10.28	5.92	3.75	3.56	8.33	4.21	3.33	3.09
Harp seal	1.80	0.57	0.15	0.06	0.05	0	0	0	10.43	6.13	4.00	3.54	8.50	4.51	3.48	3.16

[a] NOAA (2005), [b] Wood et al. (2012), [c] Listed as Endangered under the ESA.

Table H-30. 12 m monopile, 5000 kJ hammer, two piles per day: Exposure ranges ($ER_{95\%}$) in km to marine mammal threshold criteria with sound attenuation.

Species	Injury								Behavior							
	L_E				L_{pk}				L_p [a]				L_p [b]			
	Attenuation (dB)								Attenuation (dB)							
	0	6	10	12	0	6	10	12	0	6	10	12	0	6	10	12
Low-frequency cetaceans																
Fin whale[c]	9.66	5.05	2.79	2.19	0.02	0	0	0	10.31	6.00	3.98	3.80	10.37	6.00	4.00	3.82
Minke whale	7.29	3.32	1.67	1.29	0.07	0.02	0.02	0.02	9.67	5.43	3.80	3.55	36.30	25.68	20.44	17.74
Humpback whale	10.91	5.67	3.44	2.46	0.03	0.01	0.01	0.01	10.44	5.91	3.98	3.66	10.50	5.89	3.98	3.66
North Atlantic right whale[c]	8.81	4.03	2.34	1.69	0.04	<0.01	<0.01	<0.01	9.99	5.75	3.75	3.52	10.10	5.79	3.76	3.53
Sei whale[c]	8.50	4.09	2.04	1.50	0.03	0.03	0.02	0.02	10.17	5.82	3.85	3.54	38.42	26.84	20.94	18.42
Mid-frequency cetaceans																
Atlantic white-sided dolphin	0	0	0	0	0.02	0.02	0.02	0.02	9.47	5.39	3.74	3.35	5.48	3.26	2.77	2.32
Atlantic spotted dolphin	0	0	0	0	0	0	0	0	9.60	5.20	3.66	3.32	5.17	3.17	2.78	2.33
Short-beaked common dolphin	0	0	0	0	0.02	0.02	0.02	0.02	9.62	5.42	3.81	3.46	5.51	3.39	2.87	2.36
Bottlenose dolphin	<0.01	0	0	0	0.01	0.01	0.01	0.01	8.99	4.91	3.25	2.96	5.04	2.96	2.21	1.92
Risso's dolphin	0.02	<0.01	<0.01	<0.01	0.02	0.02	0.02	0.01	10.01	5.77	3.80	3.55	5.82	3.46	2.85	2.49
Long-finned pilot whale	0	0	0	0	0.01	0.01	0.01	0.01	9.70	5.56	3.74	3.46	5.56	3.43	2.89	2.34
Short-finned pilot whale	0	0	0	0	0.02	0.02	0.02	0.02	9.71	5.59	3.78	3.48	5.58	3.41	2.85	2.31
Sperm whale[c]	0.29	0	0	0	<0.01	<0.01	<0.01	<0.01	9.75	5.75	3.79	3.55	5.54	3.43	2.82	2.39
High-frequency cetacean																
Harbor porpoise	5.50	2.92	1.60	1.28	0.56	0.25	0.15	0.09	9.91	5.44	3.86	3.63	97.41	74.49	53.14	46.68
Pinnipeds in water																
Gray seal	2.51	1.22	0.56	0.38	0.01	0.01	0.01	0.01	10.49	6.03	4.17	3.94	8.58	4.43	3.68	3.28
Harbor seal	2.43	0.74	0.21	0.16	<0.01	<0.01	<0.01	<0.01	10.20	6.04	3.81	3.63	8.32	4.35	3.45	3.14
Harp seal	2.20	0.65	0.31	0.09	0.06	0	0	0	10.40	5.99	4.01	3.60	8.36	4.35	3.54	3.12

[a] NOAA (2005), [b] Wood et al. (2012), [c] Listed as Endangered under the ESA.

Table H-31. 12 m monopile, 5000 kJ hammer, four piles per day: Exposure ranges ($ER_{95\%}$) in km to marine mammal threshold criteria with sound attenuation.

Species	Injury								Behavior							
	L_E				L_{pk}				L_p [a]				L_p [b]			
	Attenuation (dB)								Attenuation (dB)							
	0	6	10	12	0	6	10	12	0	6	10	12	0	6	10	12
Low-frequency cetaceans																
Fin whale[c]	12.12	6.39	3.63	2.72	0.03	0.02	0.02	0.02	10.32	5.89	3.94	3.62	10.40	5.90	3.95	3.63
Minke whale	8.07	3.78	1.92	1.42	0.05	0.02	0.02	0.02	9.56	5.42	3.78	3.52	36.15	25.69	20.12	17.60
Humpback whale	13.09	7.20	4.30	3.20	0.03	0.01	0.01	0.01	10.31	5.95	3.93	3.63	10.39	5.96	3.93	3.63
North Atlantic right whale[c]	10.09	5.02	2.64	2.01	0.03	0.02	0.02	0.02	9.68	5.71	3.78	3.52	9.88	5.73	3.80	3.53
Sei whale[c]	10.37	4.98	2.67	1.83	0.03	0.02	0.02	0.02	10.05	5.84	3.76	3.53	38.24	26.80	20.81	18.36
Mid-frequency cetaceans																
Atlantic white-sided dolphin	0	0	0	0	0.02	0.02	0.02	0.02	9.44	5.33	3.78	3.40	5.52	3.32	2.80	2.36
Atlantic spotted dolphin	0	0	0	0	0.02	0.02	0.02	0.02	9.73	5.31	3.75	3.37	5.31	3.28	2.77	2.36
Short-beaked common dolphin	<0.01	<0.01	<0.01	0	0.02	0.02	0.02	0.02	9.39	5.33	3.80	3.46	5.49	3.40	2.87	2.40
Bottlenose dolphin	0.20	0	0	0	0.01	0.01	0.01	0.01	8.38	4.26	3.09	2.88	4.25	2.88	2.16	1.91
Risso's dolphin	0.02	<0.01	<0.01	<0.01	0.01	0.01	0.01	<0.01	9.88	5.63	3.79	3.49	5.72	3.43	2.83	2.43
Long-finned pilot whale	0	0	0	0	0.02	0.02	0.02	0.02	9.48	5.46	3.73	3.46	5.44	3.40	2.82	2.18
Short-finned pilot whale	0	0	0	0	0.02	0.02	0.02	0.02	9.47	5.37	3.73	3.44	5.34	3.36	2.80	2.22
Sperm whale[c]	0.29	0	0	0	0.01	0.01	0.01	0.01	9.71	5.48	3.74	3.44	5.50	3.39	2.78	2.39
High-frequency cetacean																
Harbor porpoise	6.05	3.14	1.80	1.33	0.55	0.27	0.15	0.11	9.65	5.49	3.84	3.57	100.34	78.45	53.99	47.18
Pinnipeds in water																
Gray seal	3.11	1.38	0.63	0.43	0.01	0.01	0.01	0.01	10.61	6.01	4.14	3.84	8.52	4.48	3.60	3.21
Harbor seal	2.96	0.93	0.53	0.17	0.05	0.01	0.01	0.01	10.08	5.88	3.82	3.50	8.15	4.36	3.30	3.03
Harp seal	2.45	0.85	0.32	0.08	0.06	0.01	0.01	0.01	10.29	5.95	3.89	3.54	8.33	4.39	3.42	3.09

[a] NOAA (2005), [b] Wood et al. (2012), [c] Listed as Endangered under the ESA.

Table H-32. 12 m monopile, 6000 kJ hammer, one pile per day: Exposure ranges ($ER_{95\%}$) in km to marine mammal threshold criteria with sound attenuation.

Species	Injury								Behavior							
	L_E				L_{pk}				L_p [a]				L_p [b]			
	Attenuation (dB)								Attenuation (dB)							
	0	6	10	12	0	6	10	12	0	6	10	12	0	6	10	12
Low-frequency cetaceans																
Fin whale[c]	10.14	5.24	3.31	2.45	0.04	0.01	0.01	0.01	15.62	9.16	6.19	4.63	15.63	9.16	6.21	4.66
Minke whale	8.15	4.11	2.40	1.68	0.02	0.02	0.02	0.02	14.49	8.53	5.66	4.27	60.34	37.31	28.63	25.77
Humpback whale	11.12	5.99	3.81	2.89	0.08	0	0	0	15.58	9.12	5.95	4.87	15.57	9.12	5.88	4.87
North Atlantic right whale[c]	9.84	5.03	2.93	2.03	0	0	0	0	14.50	8.44	5.46	4.51	14.58	8.56	5.48	4.52
Sei whale[c]	9.31	4.58	2.47	2.16	<0.01	<0.01	<0.01	<0.01	15.08	8.96	5.79	4.69	73.70	41.86	31.08	26.82
Mid-frequency cetaceans																
Atlantic white-sided dolphin	0	0	0	0	0.01	0.01	0.01	0.01	14.21	8.33	5.35	4.34	8.81	4.19	3.31	2.93
Atlantic spotted dolphin	0	0	0	0	0	0	0	0	15.29	8.91	5.87	4.57	8.91	4.57	3.13	3.04
Short-beaked common dolphin	0	0	0	0	0.01	0.01	0.01	0.01	14.53	8.44	5.68	4.39	9.04	4.30	3.36	2.97
Bottlenose dolphin	0.11	0	0	0	0.01	0.01	0.01	0.01	14.04	7.74	4.77	3.94	8.13	3.96	3.02	2.72
Risso's dolphin	0.02	0.02	0.02	0	0.02	<0.01	<0.01	<0.01	15.28	8.73	5.55	4.52	9.23	4.51	3.46	3.04
Long-finned pilot whale	0	0	0	0	0.02	0.02	0.02	0.02	14.61	8.43	5.55	4.44	8.81	4.17	3.37	3.00
Short-finned pilot whale	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	14.46	8.57	5.57	4.55	8.97	4.40	3.30	3.03
Sperm whale[c]	0.01	0	0	0	0.02	0.02	0.02	0.02	15.19	8.64	5.73	4.59	8.98	4.33	3.47	3.00
High-frequency cetacean																
Harbor porpoise	6.53	3.68	2.26	1.69	0.60	0.28	0.21	0.18	14.64	8.49	5.76	4.45	105.70	95.50	84.55	80.55
Pinnipeds in water																
Gray seal	2.96	1.29	0.84	0.52	0	0	0	0	15.61	9.06	6.06	5.03	13.09	7.05	4.38	3.88
Harbor seal	2.86	1.08	0.43	0.22	0.02	0.02	0.02	0.02	15.39	8.67	6.01	4.48	12.58	6.72	4.09	3.70
Harp seal	2.39	1.07	0.25	0.09	0.05	0.05	0	0	15.38	9.10	5.93	4.89	12.83	6.91	4.22	3.89

[a] NOAA (2005), [b] Wood et al. (2012), [c] Listed as Endangered under the ESA.

Table H-33. 12 m monopile, 6000 kJ hammer, two piles per day: Exposure ranges ($ER_{95\%}$) in km to marine mammal threshold criteria with sound attenuation.

Species	Injury								Behavior							
	L_E				L_{pk}				L_p [a]				L_p [b]			
	Attenuation (dB)								Attenuation (dB)							
	0	6	10	12	0	6	10	12	0	6	10	12	0	6	10	12
Low-frequency cetaceans																
Fin whale[c]	12.55	6.53	3.90	2.86	0.02	0	0	0	15.82	9.11	6.01	4.91	15.86	9.14	5.97	4.90
Minke whale	9.23	4.48	2.59	1.82	0.02	0.02	0.02	0.02	14.65	8.48	5.33	4.39	66.79	38.12	29.19	25.67
Humpback whale	13.59	7.46	4.62	3.60	0.03	0.01	0.01	0.01	15.78	9.14	5.92	4.72	15.81	9.19	5.93	4.72
North Atlantic right whale[c]	11.16	5.82	3.16	2.49	0.04	0.02	<0.01	<0.01	14.51	8.37	5.60	4.45	14.61	8.42	5.65	4.45
Sei whale[c]	11.07	5.47	3.08	2.25	0.02	0.02	0.02	0.02	15.40	8.90	5.79	4.79	76.41	44.02	32.38	27.74
Mid-frequency cetaceans																
Atlantic white-sided dolphin	0	0	0	0	0.02	0.02	0.02	0.02	14.09	8.12	5.40	4.29	8.54	4.12	3.22	2.83
Atlantic spotted dolphin	0	0	0	0	0	0	0	0	15.03	8.64	5.47	3.95	8.53	3.77	2.89	2.72
Short-beaked common dolphin	0.02	0	0	0	0.02	0.02	0.02	0.02	14.35	8.36	5.54	4.34	8.88	4.19	3.33	3.08
Bottlenose dolphin	0.19	0	0	0	0.01	0.01	0.01	0.01	14.12	7.85	4.93	3.77	8.39	3.69	2.92	2.57
Risso's dolphin	0.03	<0.01	<0.01	<0.01	0.02	0.02	0.02	0.02	15.39	8.79	5.89	4.54	9.27	4.48	3.33	3.09
Long-finned pilot whale	0	0	0	0	0.01	0.01	0.01	0.01	14.65	8.53	5.50	4.43	8.80	4.20	3.26	2.95
Short-finned pilot whale	0.02	0	0	0	0.02	0.02	0.02	0.02	14.60	8.48	5.62	4.43	8.85	4.18	3.27	2.99
Sperm whale[c]	0.29	0	0	0	<0.01	<0.01	<0.01	<0.01	14.98	8.38	5.84	4.58	8.81	4.38	3.42	2.96
High-frequency cetacean																
Harbor porpoise	7.01	3.84	2.30	1.69	0.66	0.38	0.17	0.15	14.63	8.51	5.48	4.53	107.40	96.58	86.45	82.28
Pinnipeds in water																
Gray seal	3.29	1.54	1.01	0.56	0.01	0.01	0.01	0.01	15.83	9.33	6.05	4.92	13.02	7.06	4.31	4.07
Harbor seal	3.31	1.38	0.63	0.19	0.07	<0.01	<0.01	<0.01	15.37	8.77	6.03	4.78	12.97	6.97	4.15	3.63
Harp seal	3.07	1.14	0.41	0.20	0	0	0	0	15.69	8.94	5.97	4.86	12.86	7.03	4.23	3.83

[a] NOAA (2005), [b] Wood et al. (2012), [c] Listed as Endangered under the ESA.

Table H-34. 12 m monopile, 6000 kJ hammer, four piles per day: Exposure ranges ($ER_{95\%}$) in km to marine mammal threshold criteria with sound attenuation.

Species	Injury								Behavior							
	L_E				L_{pk}				L_p [a]				L_p [b]			
	Attenuation (dB)								Attenuation (dB)							
	0	6	10	12	0	6	10	12	0	6	10	12	0	6	10	12
Low-frequency cetaceans																
Fin whale[c]	15.60	8.48	5.19	3.84	0.03	0.02	0.02	0.02	15.71	9.14	5.95	4.82	15.82	9.19	5.95	4.80
Minke whale	10.39	5.19	2.85	1.97	0.02	0.02	0.02	0.02	14.34	8.33	5.41	4.37	70.45	37.95	29.15	25.62
Humpback whale	16.38	9.24	5.67	4.48	0.03	0.01	0.01	0.01	15.64	9.01	5.89	4.73	15.72	9.05	5.90	4.81
North Atlantic right whale[c]	13.06	6.90	3.80	2.83	0.06	0.02	0.02	0.02	14.22	8.19	5.59	4.40	14.38	8.33	5.61	4.43
Sei whale[c]	13.19	7.17	3.97	2.87	0.03	0.02	0.02	0.02	15.30	8.73	5.62	4.56	78.14	44.10	32.32	28.00
Mid-frequency cetaceans																
Atlantic white-sided dolphin	0	0	0	0	0.02	0.02	0.02	0.02	14.21	8.19	5.37	4.28	8.63	4.19	3.23	2.92
Atlantic spotted dolphin	0	0	0	0	0.02	0.02	0.02	0.02	15.48	9.07	5.59	4.42	9.17	4.11	2.96	2.72
Short-beaked common dolphin	0.02	<0.01	<0.01	<0.01	0.02	0.02	0.02	0.02	14.09	8.13	5.47	4.35	8.73	4.16	3.29	3.04
Bottlenose dolphin	0.18	0	0	0	0.01	0.01	0.01	0.01	13.32	7.37	4.26	3.55	7.88	3.51	2.85	2.50
Risso's dolphin	0.03	<0.01	<0.01	<0.01	0.01	0.01	0.02	0.02	15.06	8.75	5.64	4.59	9.21	4.45	3.33	3.00
Long-finned pilot whale	0	0	0	0	0.02	0.02	0.02	0.02	14.45	8.40	5.44	4.27	8.71	4.15	3.19	2.87
Short-finned pilot whale	0.02	0	0	0	0.02	0.02	0.02	0.02	14.49	8.26	5.35	4.27	8.71	4.12	3.22	2.98
Sperm whale[c]	0.28	0	0	0	0.01	0.01	0.01	0.01	14.85	8.50	5.55	4.38	8.78	4.24	3.35	2.97
High-frequency cetacean																
Harbor porpoise	7.49	4.04	2.47	1.86	0.65	0.39	0.20	0.15	14.46	8.36	5.54	4.46	111.64	100.40	91.07	87.37
Pinnipeds in water																
Gray seal	3.97	1.80	1.22	0.72	0.01	0.01	0.01	0.01	15.75	9.14	6.02	4.94	13.05	7.02	4.29	3.99
Harbor seal	4.42	1.62	0.67	0.59	0.07	0.01	0.01	0.01	15.12	8.78	5.75	4.63	12.70	6.65	4.15	3.52
Harp seal	3.70	1.24	0.52	0.35	0.05	0.02	0.02	0.02	15.44	8.84	5.86	4.73	12.72	6.92	4.24	3.62

[a] NOAA (2005), [b] Wood et al. (2012), [c] Listed as Endangered under the ESA.

Table H-35. 13 m monopile, 5000 kJ hammer, one pile per day: Exposure ranges ($ER_{95\%}$) in km to marine mammal threshold criteria with sound attenuation.

Species	Injury								Behavior							
	L_E				L_{pk}				L_p [a]				L_p [b]			
	Attenuation (dB)								Attenuation (dB)							
	0	6	10	12	0	6	10	12	0	6	10	12	0	6	10	12
Low-frequency cetaceans																
Fin whale[c]	8.78	4.35	2.56	1.90	0.02	0	0	0	12.46	6.94	4.29	3.88	12.46	6.94	4.24	3.88
Minke whale	6.30	2.96	1.50	1.17	0	0	0	0	11.63	6.51	3.98	3.63	48.40	32.31	24.76	21.91
Humpback whale	9.40	4.80	2.87	2.27	0.03	<0.01	<0.01	<0.01	12.35	6.96	4.26	3.74	12.37	6.91	4.25	3.74
North Atlantic right whale[c]	8.05	3.85	2.26	1.54	0.03	<0.01	<0.01	<0.01	12.11	6.64	4.11	3.70	12.21	6.64	4.17	3.70
Sei whale[c]	7.73	3.56	1.66	1.25	0.03	<0.01	<0.01	<0.01	11.98	6.81	4.21	3.69	61.51	35.18	25.73	22.45
Mid-frequency cetaceans																
Atlantic white-sided dolphin	0	0	0	0	0	0	0	0	11.47	6.22	3.95	3.58	5.68	3.18	2.55	2.27
Atlantic spotted dolphin	0	0	0	0	0	0	0	0	11.50	6.04	4.01	3.76	5.34	3.30	2.64	2.59
Short-beaked common dolphin	0	0	0	0	<0.01	0	0	0	11.57	6.47	3.99	3.48	6.15	3.32	2.64	2.31
Bottlenose dolphin	0	0	0	0	0	0	0	0	10.98	6.02	3.53	3.01	5.73	2.97	2.30	1.97
Risso's dolphin	0.01	<0.01	<0.01	0	<0.01	0	0	0	12.15	6.74	4.26	3.77	6.28	3.17	2.62	2.39
Long-finned pilot whale	0	0	0	0	0	0	0	0	11.69	6.39	4.08	3.52	5.96	3.24	2.68	2.22
Short-finned pilot whale	0	0	0	0	<0.01	<0.01	<0.01	<0.01	11.82	6.48	4.10	3.53	6.04	3.35	2.68	2.40
Sperm whale[c]	0	0	0	0	0	0	0	0	11.88	6.70	4.15	3.64	6.17	3.42	2.61	2.36
High-frequency cetacean																
Harbor porpoise	5.13	2.50	1.51	1.07	0.59	0.25	0.23	0.19	11.79	6.58	4.00	3.63	106.34	97.07	85.66	79.37
Pinnipeds in water																
Gray seal	2.16	0.96	0.59	0.12	0	0	0	0	12.56	7.04	4.53	4.08	9.67	4.84	3.73	3.30
Harbor seal	1.94	0.67	0.16	0	0	0	0	0	12.21	6.95	4.25	3.73	9.48	4.56	3.31	3.17
Harp seal	1.85	0.65	0.09	0	0	0	0	0	12.31	7.03	4.30	3.75	9.48	4.89	3.40	3.07

[a] NOAA (2005), [b] Wood et al. (2012), [c] Listed as Endangered under the ESA.

Table H-36. 13 m monopile, 5000 kJ hammer, two piles per day: Exposure ranges ($ER_{95\%}$) in km to marine mammal threshold criteria with sound attenuation.

Species	Injury								Behavior							
	L_E				L_{pk}				L_p [a]				L_p [b]			
	Attenuation (dB)								Attenuation (dB)							
	0	6	10	12	0	6	10	12	0	6	10	12	0	6	10	12
Low-frequency cetaceans																
Fin whale[c]	10.98	5.37	3.14	2.24	0.02	0	0	0	12.35	6.89	4.20	3.84	12.35	6.89	4.20	3.84
Minke whale	7.37	3.43	1.65	1.20	0	0	0	0	11.51	6.31	3.82	3.55	49.23	32.45	24.59	21.59
Humpback whale	11.59	5.76	3.66	2.79	0.05	<0.01	<0.01	<0.01	12.28	6.80	4.26	3.83	12.30	6.80	4.26	3.84
North Atlantic right whale[c]	9.52	4.53	2.53	1.79	0.02	<0.01	<0.01	<0.01	11.65	6.42	4.03	3.51	11.76	6.46	4.07	3.55
Sei whale[c]	9.48	4.50	2.31	1.62	0.03	<0.01	<0.01	<0.01	11.87	6.64	3.96	3.62	62.48	35.38	25.94	22.40
Mid-frequency cetaceans																
Atlantic white-sided dolphin	0	0	0	0	0	0	0	0	11.12	6.09	3.84	3.31	5.76	3.14	2.43	2.20
Atlantic spotted dolphin	0	0	0	0	0	0	0	0	11.23	5.97	3.85	3.28	5.28	3.01	2.55	2.14
Short-beaked common dolphin	0	0	0	0	<0.01	0	0	0	11.28	6.23	3.95	3.43	5.96	3.27	2.65	2.31
Bottlenose dolphin	0	0	0	0	<0.01	<0.01	<0.01	<0.01	10.63	5.75	3.37	2.91	5.37	2.84	2.22	2.10
Risso's dolphin	0.02	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	11.90	6.48	4.03	3.64	6.24	3.38	2.64	2.42
Long-finned pilot whale	0	0	0	0	0	0	0	0	11.51	6.25	3.90	3.51	5.80	3.23	2.63	2.23
Short-finned pilot whale	0	0	0	0	<0.01	<0.01	<0.01	<0.01	11.58	6.32	3.95	3.50	5.95	3.36	2.64	2.31
Sperm whale[c]	0.30	0	0	0	<0.01	0	0	0	11.77	6.64	4.08	3.60	6.18	3.34	2.58	2.29
High-frequency cetacean																
Harbor porpoise	5.48	2.83	1.50	1.20	0.61	0.31	0.21	0.19	11.46	6.62	3.95	3.58	107.93	98.23	85.98	79.39
Pinnipeds in water																
Gray seal	2.55	1.28	0.57	0.32	0	0	0	0	12.49	7.04	4.52	4.12	9.67	4.82	3.67	3.29
Harbor seal	2.69	0.69	0.19	0.08	0	0	0	0	12.02	6.80	4.25	3.70	9.31	4.53	3.34	3.20
Harp seal	2.22	0.67	0.32	0.05	0.06	0	0	0	12.11	6.87	4.29	3.73	9.40	4.66	3.49	3.16

[a] NOAA (2005), [b] Wood et al. (2012), [c] Listed as Endangered under the ESA.

Table H-37. 13 m monopile, 5000 kJ hammer, four piles per day: Exposure ranges ($ER_{95\%}$) in km to marine mammal threshold criteria with sound attenuation.

Species	Injury								Behavior							
	L_E				L_{pk}				L_p [a]				L_p [b]			
	Attenuation (dB)								Attenuation (dB)							
	0	6	10	12	0	6	10	12	0	6	10	12	0	6	10	12
Low-frequency cetaceans																
Fin whale[c]	13.83	7.00	3.96	3.01	0.03	0.01	<0.01	<0.01	12.27	6.86	4.23	3.69	12.32	6.84	4.23	3.70
Minke whale	8.44	3.84	1.90	1.47	0.01	<0.01	<0.01	<0.01	11.29	6.25	3.85	3.49	49.86	32.38	24.53	21.38
Humpback whale	14.35	7.61	4.42	3.45	0.05	<0.01	<0.01	<0.01	12.17	6.84	4.24	3.74	12.24	6.86	4.22	3.74
North Atlantic right whale[c]	10.90	5.28	2.83	2.19	0.02	<0.01	<0.01	<0.01	11.56	6.23	3.98	3.47	11.67	6.30	4.02	3.51
Sei whale[c]	11.69	5.39	3.13	2.04	0.04	<0.01	<0.01	<0.01	11.86	6.71	4.04	3.53	62.70	35.35	26.00	22.37
Mid-frequency cetaceans																
Atlantic white-sided dolphin	0	0	0	0	<0.01	<0.01	<0.01	<0.01	11.15	6.07	3.84	3.37	5.67	3.22	2.52	2.26
Atlantic spotted dolphin	0	0	0	0	<0.01	<0.01	0	0	11.40	6.09	4.07	3.46	5.48	3.20	2.53	2.20
Short-beaked common dolphin	<0.01	<0.01	<0.01	0	<0.01	<0.01	<0.01	<0.01	10.99	5.95	3.92	3.45	5.76	3.22	2.62	2.28
Bottlenose dolphin	0	0	0	0	<0.01	<0.01	<0.01	<0.01	10.18	4.94	3.21	2.84	4.63	2.83	2.19	1.94
Risso's dolphin	0.02	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	11.79	6.49	4.00	3.54	6.18	3.37	2.62	2.34
Long-finned pilot whale	0	0	0	0	<0.01	<0.01	<0.01	<0.01	11.20	6.10	3.88	3.42	5.72	3.21	2.59	2.17
Short-finned pilot whale	0	0	0	0	<0.01	<0.01	<0.01	<0.01	11.41	6.30	3.89	3.45	5.77	3.22	2.59	2.31
Sperm whale[c]	0.30	0	0	0	<0.01	<0.01	0	0	11.78	6.50	3.93	3.52	5.94	3.22	2.72	2.33
High-frequency cetacean																
Harbor porpoise	6.04	3.11	1.75	1.27	0.61	0.30	0.19	0.17	11.33	6.42	3.95	3.51	112.74	102.05	89.43	83.15
Pinnipeds in water																
Gray seal	3.11	1.49	0.72	0.41	0.08	0	0	0	12.46	6.94	4.51	4.07	9.56	4.83	3.65	3.24
Harbor seal	3.10	0.93	0.51	0.15	0.06	<0.01	<0.01	<0.01	11.78	6.53	4.16	3.74	9.19	4.53	3.29	2.97
Harp seal	2.74	0.88	0.32	0.05	0.06	<0.01	<0.01	<0.01	12.04	6.87	4.25	3.54	9.36	4.69	3.41	3.07

[a] NOAA (2005), [b] Wood et al. (2012), [c] Listed as Endangered under the ESA.

Table H-38. 4 m pin pile, 3500 kJ hammer, four piles per day: Exposure ranges ($ER_{95\%}$) in km to marine mammal threshold criteria with sound attenuation.

Species	Injury								Behavior							
	L_E				L_{pk}				L_p [a]				L_p [b]			
	Attenuation (dB)								Attenuation (dB)							
	0	6	10	12	0	6	10	12	0	6	10	12	0	6	10	12
Low-frequency cetaceans																
Fin whale[c]	13.29	6.84	4.07	3.14	0.02	<0.01	<0.01	0	8.47	4.44	3.56	3.29	8.49	4.46	3.58	3.30
Minke whale	7.87	3.32	1.83	1.26	0.01	<0.01	0	0	8.00	4.18	3.34	3.20	37.71	25.58	19.07	16.46
Humpback whale	13.83	7.50	4.49	3.25	0.02	0	0	0	8.44	4.47	3.56	3.28	8.44	4.47	3.57	3.28
North Atlantic right whale[c]	10.37	4.80	2.54	1.74	0.02	<0.01	0	0	8.15	4.26	3.34	3.16	8.23	4.27	3.38	3.19
Sei whale[c]	10.90	5.27	2.84	1.89	<0.01	<0.01	0	0	8.22	4.29	3.39	3.23	40.08	26.61	19.61	16.97
Mid-frequency cetaceans																
Atlantic white-sided dolphin	0.01	0.01	0.01	0.01	0	0	0	0	8.02	4.17	3.27	3.12	4.43	3.18	2.33	1.97
Atlantic spotted dolphin	0	0	0	0	0	0	0	0	8.40	4.13	3.26	3.17	4.39	3.22	2.27	2.01
Short-beaked common dolphin	<0.01	<0.01	<0.01	0	0	0	0	0	7.98	4.18	3.34	3.15	4.49	3.25	2.41	2.07
Bottlenose dolphin	0.08	0.01	0.01	0	0	0	0	0	6.44	3.45	2.87	2.59	3.79	2.76	1.90	1.50
Risso's dolphin	0.01	0.01	0.01	0.01	<0.01	0	0	0	8.27	4.33	3.38	3.16	4.59	3.24	2.42	2.06
Long-finned pilot whale	<0.01	<0.01	<0.01	0	0	0	0	0	7.96	4.16	3.30	3.10	4.49	3.17	2.32	1.91
Short-finned pilot whale	0.01	0.01	0	0	0	0	0	0	7.95	4.12	3.37	3.16	4.40	3.23	2.38	1.96
Sperm whale[c]	<0.01	<0.01	<0.01	0	0	0	0	0	8.17	4.34	3.36	3.11	4.61	3.20	2.35	1.89
High-frequency cetacean																
Harbor porpoise	5.90	3.10	1.77	1.29	0.53	0.26	0.10	0.10	8.15	4.32	3.38	3.21	96.13	93.76	65.51	54.74
Pinnipeds in water																
Gray seal	4.35	2.19	1.31	0.96	0	0	0	0	8.52	4.54	3.49	3.38	6.83	3.84	3.30	2.91
Harbor seal	3.33	1.06	0.32	0.12	0.06	<0.01	0	0	8.33	4.24	3.44	3.12	6.68	3.68	3.08	2.70
Harp seal	2.85	1.03	0.28	0.15	0.07	0	0	0	8.44	4.45	3.49	3.24	6.77	3.84	3.21	2.81

[a] NOAA (2005), [b] Wood et al. (2012), [c] Listed as Endangered under the ESA.

H.2.5. Sea Turtle Exposure Ranges

Table H-39. 12 m monopile, 5000 kJ hammer, one pile per day: Exposure ranges ($ER_{95\%}$) in km to sea turtle threshold criteria with sound attenuation.

Species	Injury								Behavior			
	L_E				L_{pk}				L_p			
	Attenuation (dB)								Attenuation (dB)			
	0	6	10	12	0	6	10	12	0	6	10	12
Kemp's ridley turtle[a]	0.72	0.07	0.02	0	0	0	0	0	2.91	1.85	0.82	0.69
Leatherback turtle[a]	0.98	0.04	0	0	<0.01	<0.01	<0.01	<0.01	2.76	1.49	0.78	0.44
Loggerhead turtle	0.12	0.02	0	0	0.02	0.02	0.02	0.02	2.65	1.17	0.75	0.38
Green turtle	1.03	0.32	0.02	0.02	0.01	0.01	0.01	0.01	3.19	2.06	1.03	0.77

[a] Listed as Endangered under the ESA.

Table H-40. 12 m monopile, 5000 kJ hammer, two piles per day: Exposure ranges ($ER_{95\%}$) in km to sea turtle threshold criteria with sound attenuation.

Species	Injury								Behavior			
	L_E				L_{pk}				L_p			
	Attenuation (dB)								Attenuation (dB)			
	0	6	10	12	0	6	10	12	0	6	10	12
Kemp's ridley turtle[a]	0.60	0.17	0.02	0	0.02	0.02	0.02	0.02	3.05	1.92	0.83	0.60
Leatherback turtle[a]	0.58	0.15	0.02	0	0.02	0.02	0.02	0.02	2.67	1.50	0.68	0.65
Loggerhead turtle	0.40	0.03	0	0	0.01	0.01	0.01	0.01	2.53	1.48	0.58	0.40
Green turtle	1.38	0.39	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	3.21	1.97	1.17	0.72

[a] Listed as Endangered under the ESA.

Table H-41. 12 m monopile, 5000 kJ hammer, four piles per day: Exposure ranges ($ER_{95\%}$) in km to sea turtle threshold criteria with sound attenuation.

Species	Injury								Behavior			
	L_E				L_{pk}				L_p			
	Attenuation (dB)								Attenuation (dB)			
	0	6	10	12	0	6	10	12	0	6	10	12
Kemp's ridley turtle[a]	0.87	0.20	0.03	0.02	0.02	0.02	0.02	0.02	2.97	1.84	0.85	0.60
Leatherback turtle[a]	0.81	0.13	0.02	0	0.02	0.02	0.02	0.02	2.61	1.46	0.68	0.65
Loggerhead turtle	0.39	0.03	<0.01	0	0.02	0.02	0.02	0.02	2.47	1.44	0.69	0.46
Green turtle	1.82	0.50	0.02	0.02	<0.01	<0.01	<0.01	<0.01	3.16	1.97	1.30	0.74

[a] Listed as Endangered under the ESA.

Table H-42. 12 m monopile, 6000 kJ hammer, one pile per day: Exposure ranges ($ER_{95\%}$) in km to sea turtle threshold criteria with sound attenuation.

Species	Injury								Behavior			
	L_E				L_{pk}				L_p			
	Attenuation (dB)								Attenuation (dB)			
	0	6	10	12	0	6	10	12	0	6	10	12
Kemp's ridley turtle[a]	0.97	0.25	0.07	0.02	0	0	0	0	3.53	2.43	1.66	0.88
Leatherback turtle[a]	1.21	0.06	0.03	0	<0.01	<0.01	<0.01	<0.01	3.12	2.23	1.39	0.91
Loggerhead turtle	0.75	0.09	0.02	<0.01	0.02	0.02	0.02	0.02	3.42	2.49	1.13	1.06
Green turtle	1.87	0.53	0.16	0.07	0.01	0.01	0	0	3.78	2.65	1.97	1.44

[a] Listed as Endangered under the ESA.

Table H-43. 12 m monopile, 6000 kJ hammer, two piles per day: Exposure ranges ($ER_{95\%}$) in km to sea turtle threshold criteria with sound attenuation.

Species	Injury								Behavior			
	L_E				L_{pk}				L_p			
	Attenuation (dB)								Attenuation (dB)			
	0	6	10	12	0	6	10	12	0	6	10	12
Kemp's ridley turtle[a]	1.12	0.25	0.02	0.02	0.02	0.02	0.02	0.02	3.57	2.66	1.77	1.31
Leatherback turtle[a]	1.27	0.15	0.17	0.02	0.02	0.02	0.02	0.02	3.24	2.32	1.35	1.12
Loggerhead turtle	0.63	0.14	<0.01	<0.01	0.01	0.01	0.01	0.01	3.05	2.24	1.20	0.85
Green turtle	2.24	0.77	0.15	0.03	<0.01	<0.01	<0.01	<0.01	3.65	2.89	1.83	1.49

[a] Listed as Endangered under the ESA.

Table H-44. 12 m monopile, 6000 kJ hammer, four piles per day: Exposure ranges ($ER_{95\%}$) in km to sea turtle threshold criteria with sound attenuation.

Species	Injury								Behavior			
	L_E				L_{pk}				L_p			
	Attenuation (dB)								Attenuation (dB)			
	0	6	10	12	0	6	10	12	0	6	10	12
Kemp's ridley turtle[a]	1.32	0.30	0.09	0.03	0.02	0.02	0.02	0.02	3.51	2.42	1.67	1.31
Leatherback turtle[a]	1.78	0.39	0.15	0.03	0.02	0.02	0.02	0.02	3.20	2.29	1.35	1.08
Loggerhead turtle	0.71	0.15	0.02	<0.01	0.02	0.02	0.02	0.02	3.04	1.98	1.34	0.84
Green turtle	2.71	0.88	0.22	0.03	<0.01	<0.01	<0.01	<0.01	3.56	2.79	1.97	1.52

[a] Listed as Endangered under the ESA.

Table H-45. 13 m monopile, 5000 kJ hammer, one pile per day: Exposure ranges ($ER_{95\%}$) in km to sea turtle threshold criteria with sound attenuation.

Species	Injury								Behavior			
	L_E				L_{pk}				L_p			
	Attenuation (dB)								Attenuation (dB)			
	0	6	10	12	0	6	10	12	0	6	10	12
Kemp's ridley turtle[a]	0.60	0.14	0	0	<0.01	<0.01	<0.01	<0.01	2.83	1.78	1.19	0.69
Leatherback turtle[a]	0.58	0.10	0	0	0	0	0	0	2.78	1.37	0.69	0.51
Loggerhead turtle	0.29	0.01	<0.01	0	0	0	0	0	2.54	1.58	0.62	0.55
Green turtle	1.11	0.29	<0.01	<0.01	0	0	0	0	3.27	2.34	1.15	0.98

[a] Listed as Endangered under the ESA.

Table H-46. 13 m monopile, 5000 kJ hammer, two piles per day: Exposure ranges ($ER_{95\%}$) in km to sea turtle threshold criteria with sound attenuation.

Species	Injury								Behavior			
	L_E				L_{pk}				L_p			
	Attenuation (dB)								Attenuation (dB)			
	0	6	10	12	0	6	10	12	0	6	10	12
Kemp's ridley turtle[a]	0.68	0.17	0.02	0	<0.01	<0.01	<0.01	<0.01	2.87	1.79	1.12	0.87
Leatherback turtle[a]	0.56	0.16	0.02	0	0	0	0	0	2.77	1.47	0.98	0.51
Loggerhead turtle	0.37	0.03	<0.01	0	0	0	0	0	2.53	1.66	0.65	0.44
Green turtle	1.59	0.38	0.04	<0.01	0	0	0	0	3.20	2.19	1.23	0.96

[a] Listed as Endangered under the ESA.

Table H-47. 13 m monopile, 5000 kJ hammer, four piles per day: Exposure ranges ($ER_{95\%}$) in km to sea turtle threshold criteria with sound attenuation.

Species	Injury								Behavior			
	L_E				L_{pk}				L_p			
	Attenuation (dB)								Attenuation (dB)			
	0	6	10	12	0	6	10	12	0	6	10	12
Kemp's ridley turtle[a]	0.94	0.21	0.03	0.02	<0.01	<0.01	<0.01	<0.01	2.80	1.76	1.10	0.70
Leatherback turtle[a]	1.30	0.18	0.03	<0.01	<0.01	<0.01	0	0	2.75	1.47	0.90	0.61
Loggerhead turtle	0.40	0.03	<0.01	0	0	0	0	0	2.57	1.58	0.76	0.61
Green turtle	2.09	0.55	0.07	0.02	<0.01	<0.01	<0.01	<0.01	3.10	2.14	1.34	0.95

[a] Listed as Endangered under the ESA.

Table H-48. 4 m pin pile, 3500 kJ hammer, four piles per day: Exposure ranges ($ER_{95\%}$) in km to sea turtle threshold criteria with sound attenuation.

Species	Injury								Behavior			
	L_E				L_{pk}				L_p			
	Attenuation (dB)								Attenuation (dB)			
	0	6	10	12	0	6	10	12	0	6	10	12
Kemp's ridley turtle[a]	0.68	0.14	0.04	0	0	0	0	0	2.34	1.09	0.47	0.33
Leatherback turtle[a]	0.71	0.07	0.03	0	0	0	0	0	2.17	0.98	0.45	0.33
Loggerhead turtle	0.44	0.02	0	0	0	0	0	0	2.15	0.85	0.44	0.27
Green turtle	1.52	0.27	0.03	0.02	0	0	0	0	2.76	1.32	0.58	0.38

[a] Listed as Endangered under the ESA.

H.3. Animat Seeding Areas

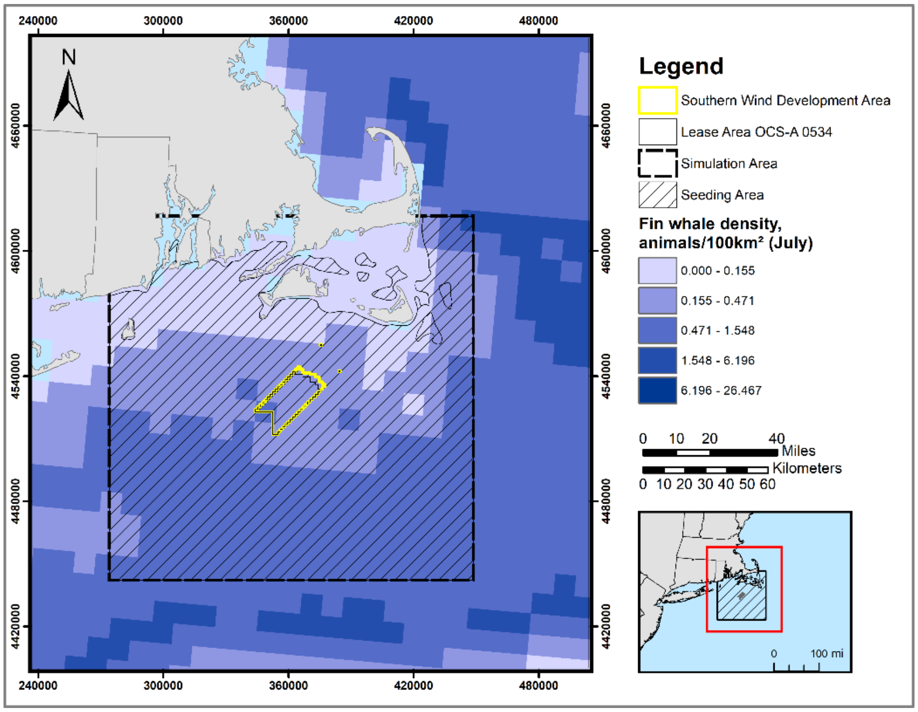

Figure H-1. Map of fin whale seeding area range for July, the month with the highest density.

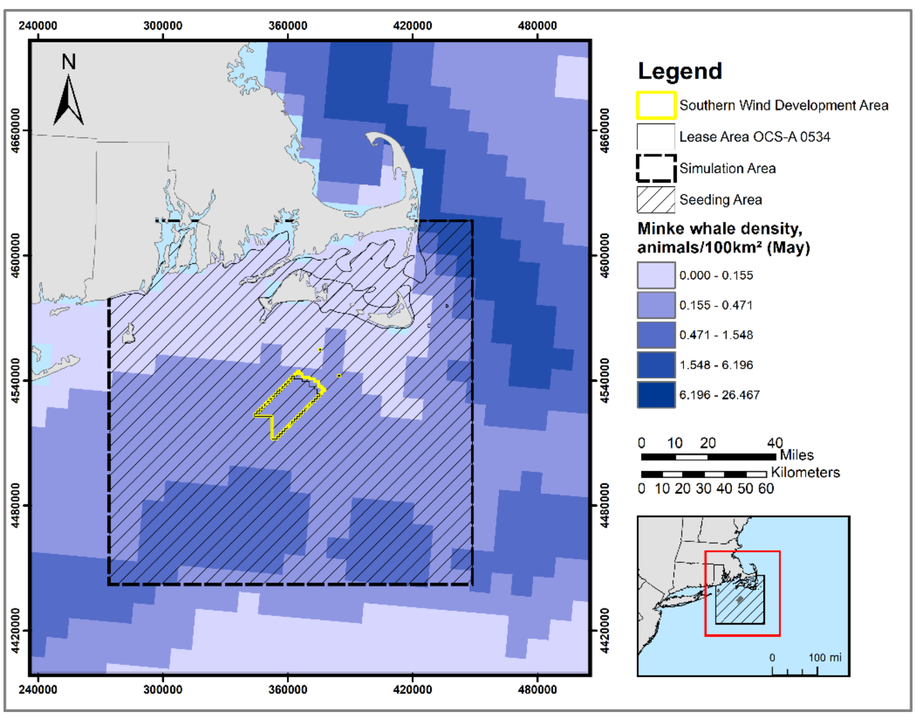

Figure H-2. Map of minke whale seeding area range for May, the month with the highest density.

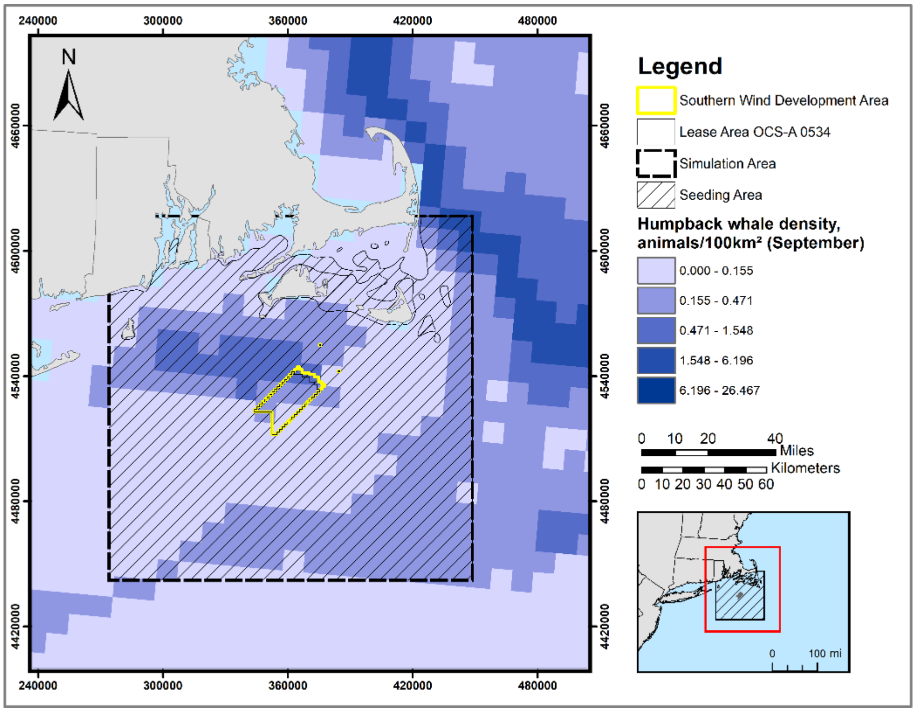

Figure H-3. Map of humpback whale seeding area range for September, the month with the highest density.

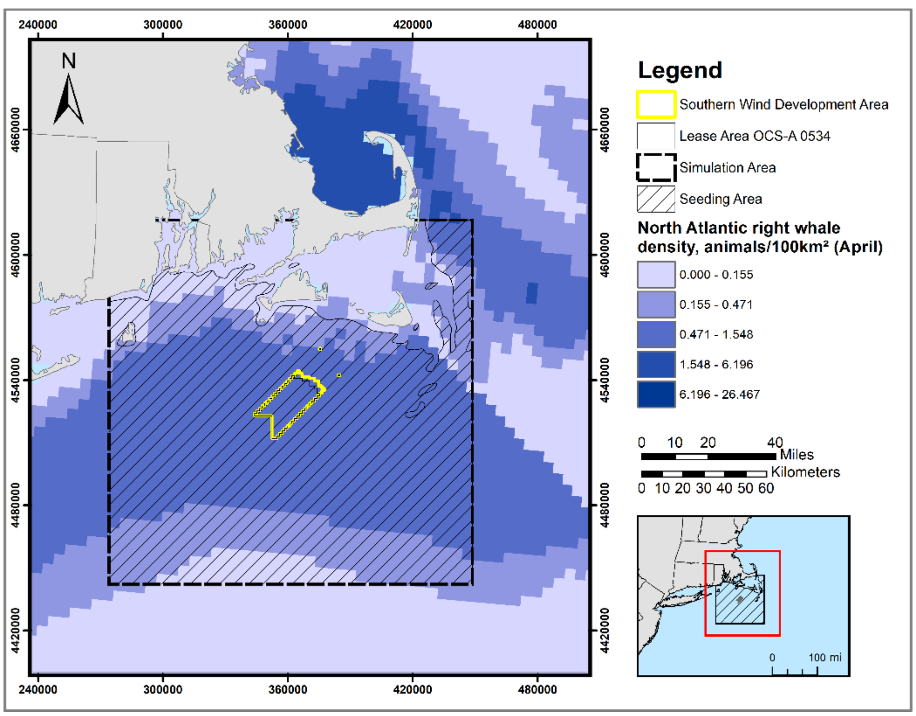

Figure H-4. Map of NARW seeding area range for April, the month with the highest density.

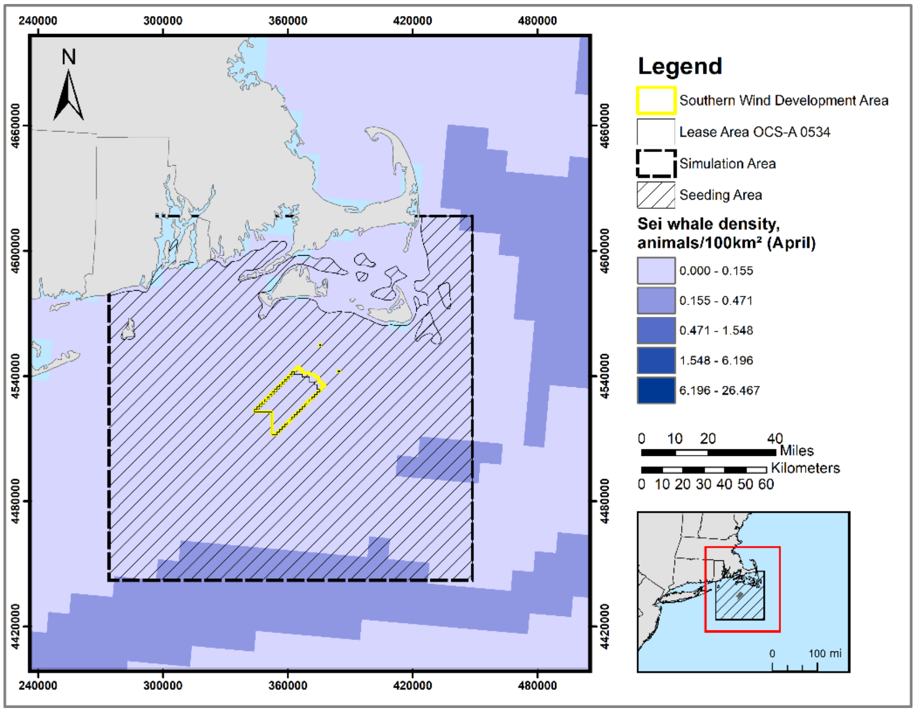

Figure H-5. Map of sei whale seeding area range for April, the month with the highest density.

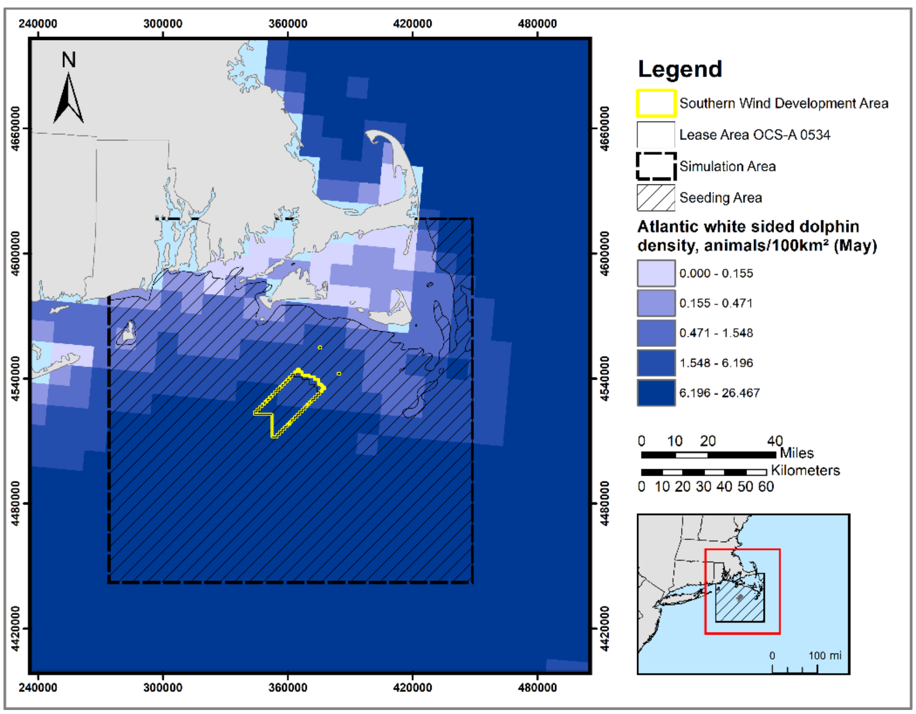

Figure H-6. Map of Atlantic white-sided dolphin seeding area range for May, the month with the highest density.

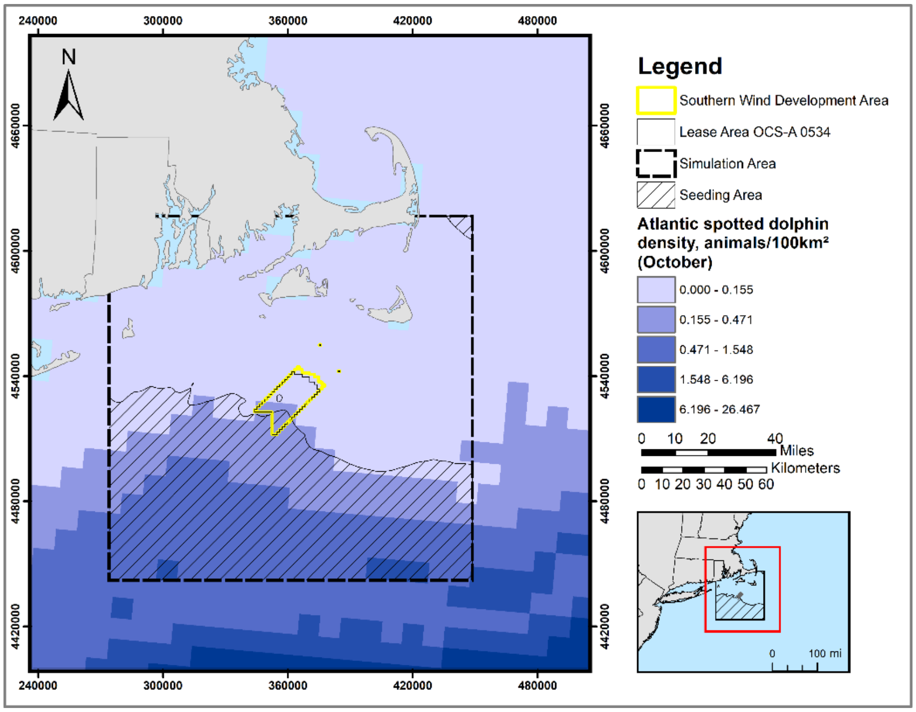

Figure H-7. Map of Atlantic spotted dolphin seeding area range for October, the month with the highest density.

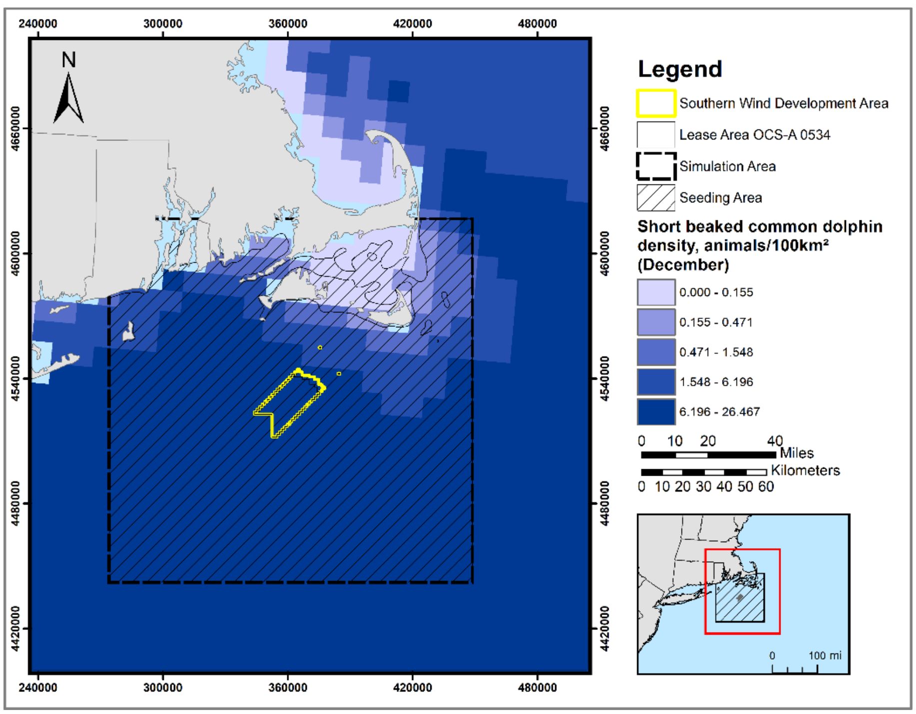

Figure H-8. Map of short-beaked common dolphin seeding area range for December, the month with the highest density.

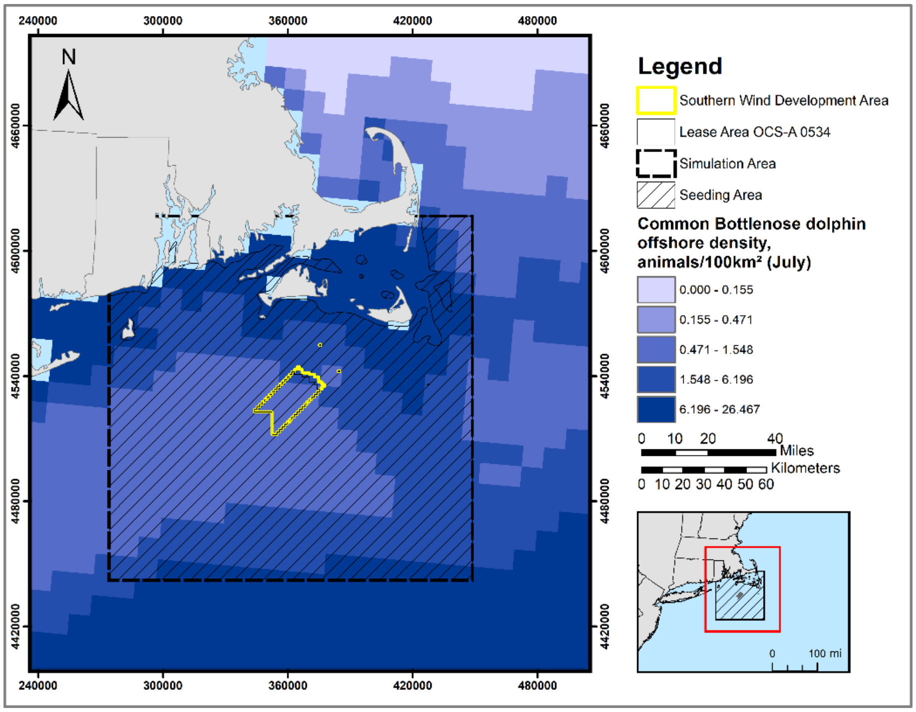

Figure H-9. Map of bottlenose dolphin seeding area range for July, the month with the highest density.

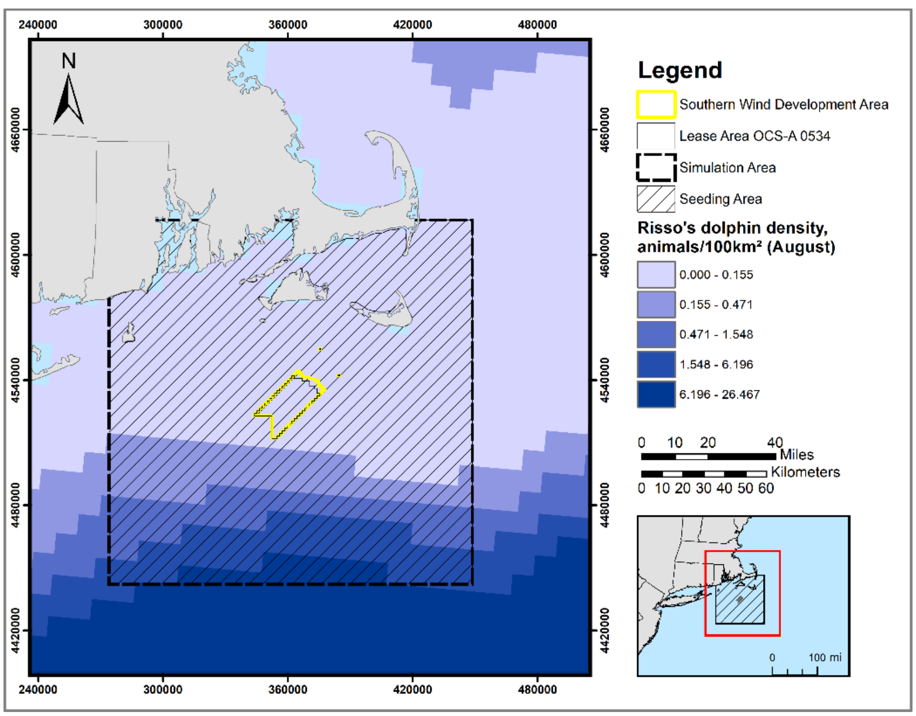

Figure H-10. Map of Risso's dolphin seeding area range for August, the month with the highest density.

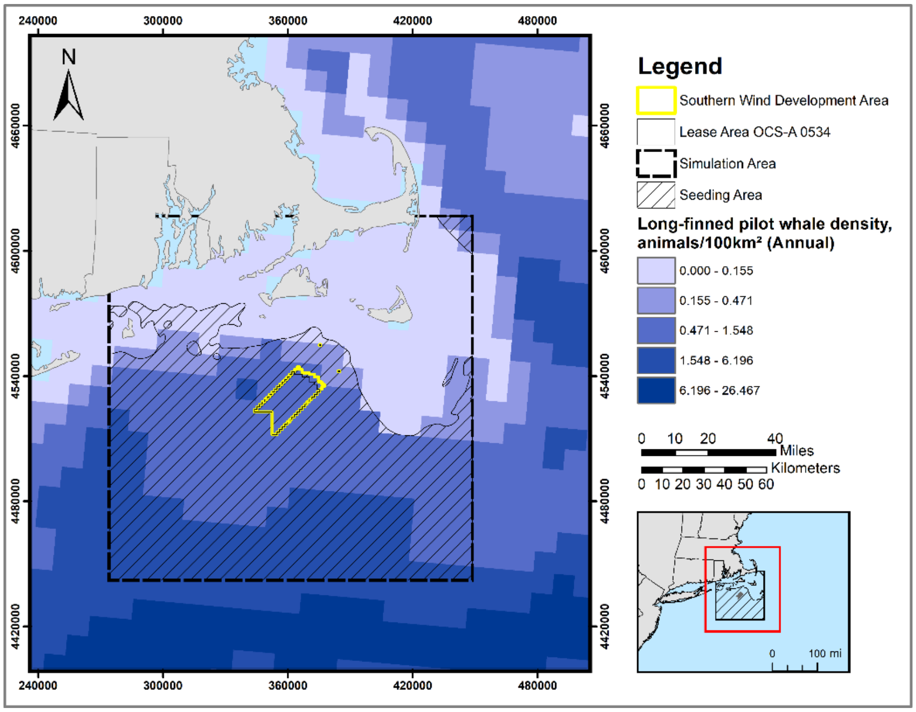

Figure H-11. Map of long-finned pilot whale seeding area range.

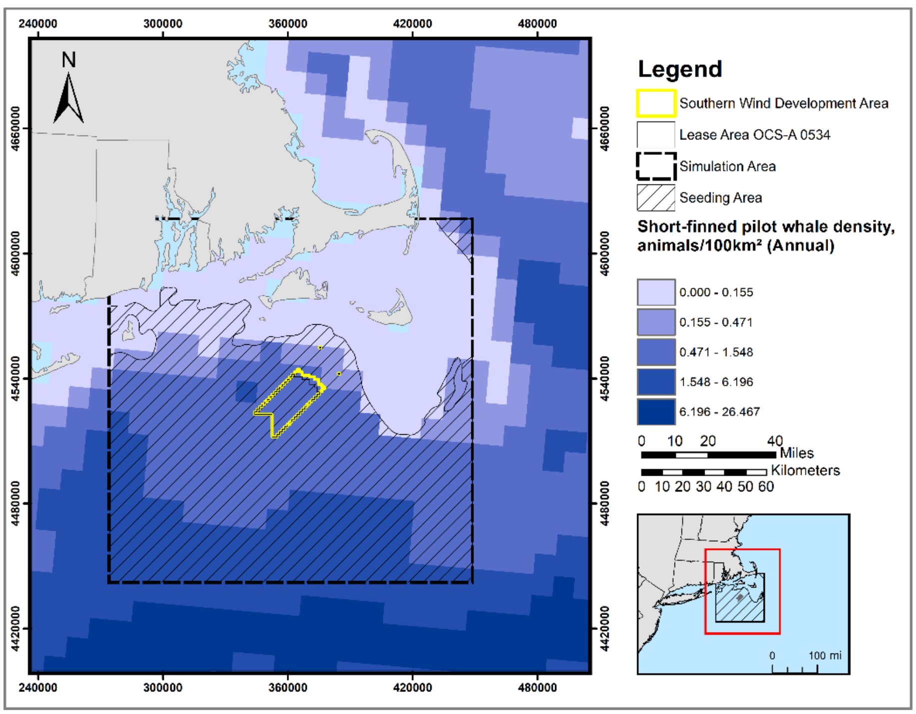

Figure H-12. Map of short-finned pilot whale seeding area range.

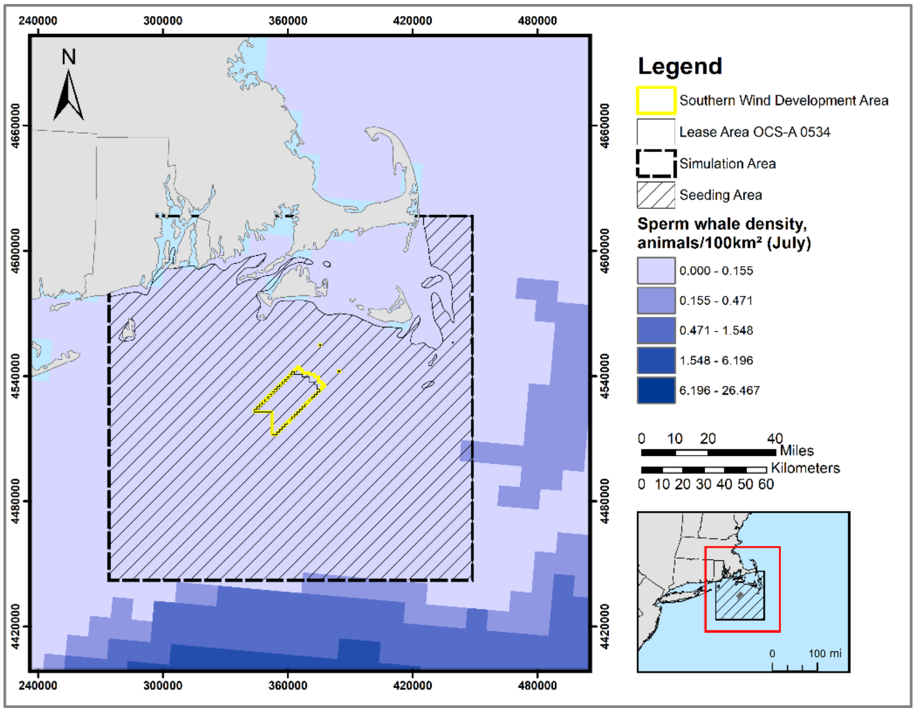

Figure H-13. Map of sperm whale seeding area range for July, the month with the highest density.

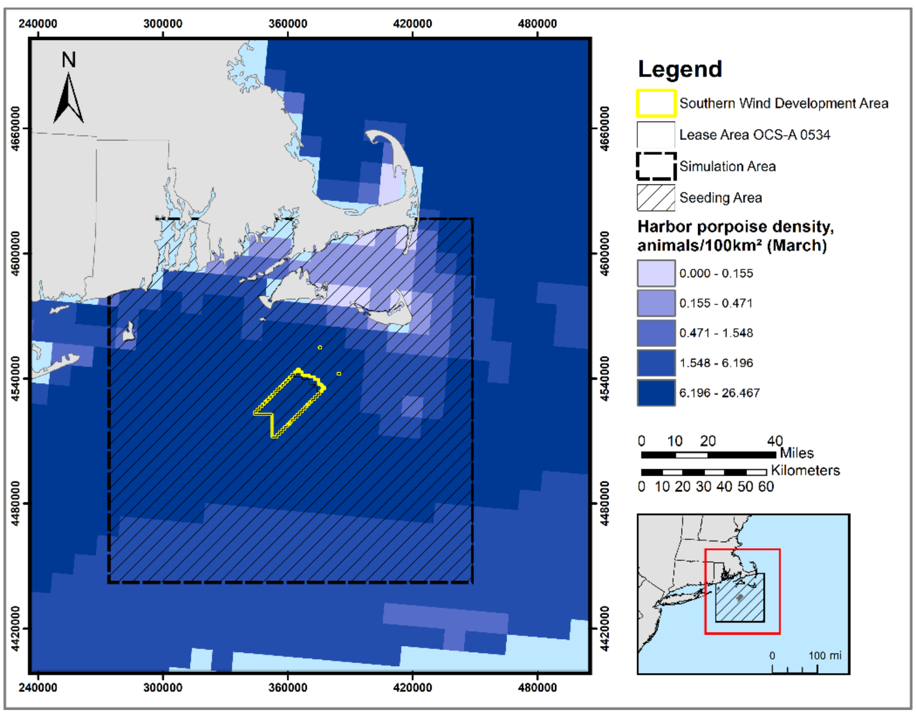

Figure H-14. Map of harbor porpoise seeding area range for March, the month with the highest density.

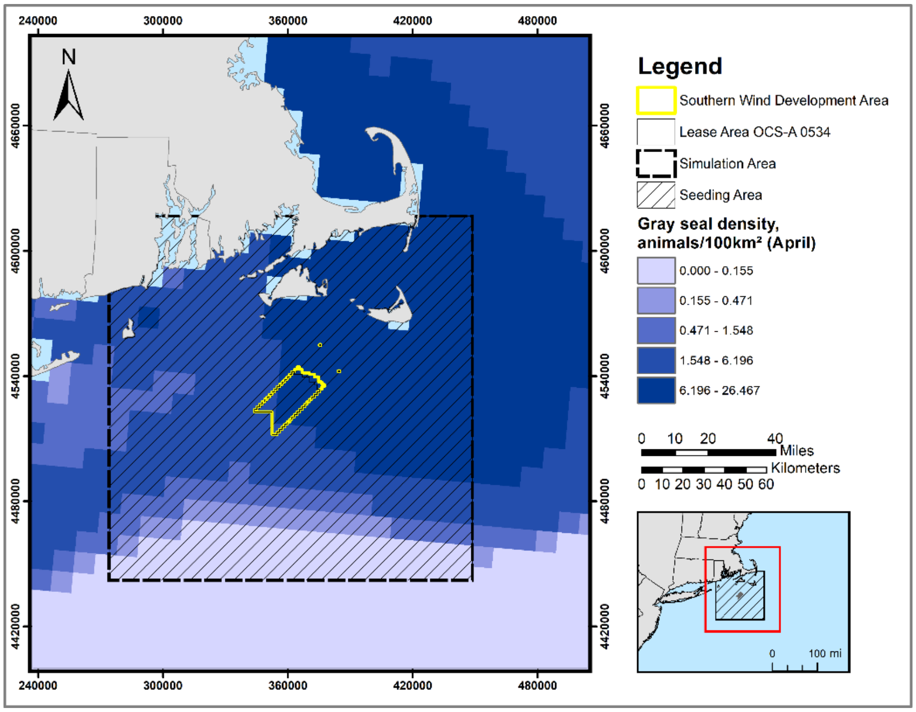

Figure H-15. Map of gray seal seeding area range for April, the month with the highest density.

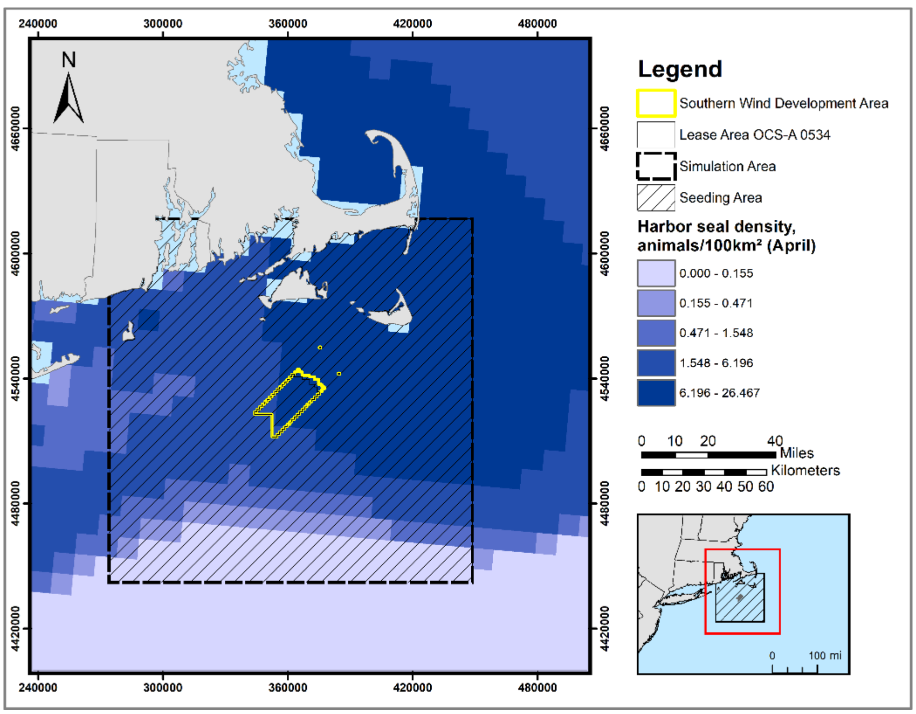

Figure H-16. Map of harbor seal seeding area range for April, the month with the highest density.

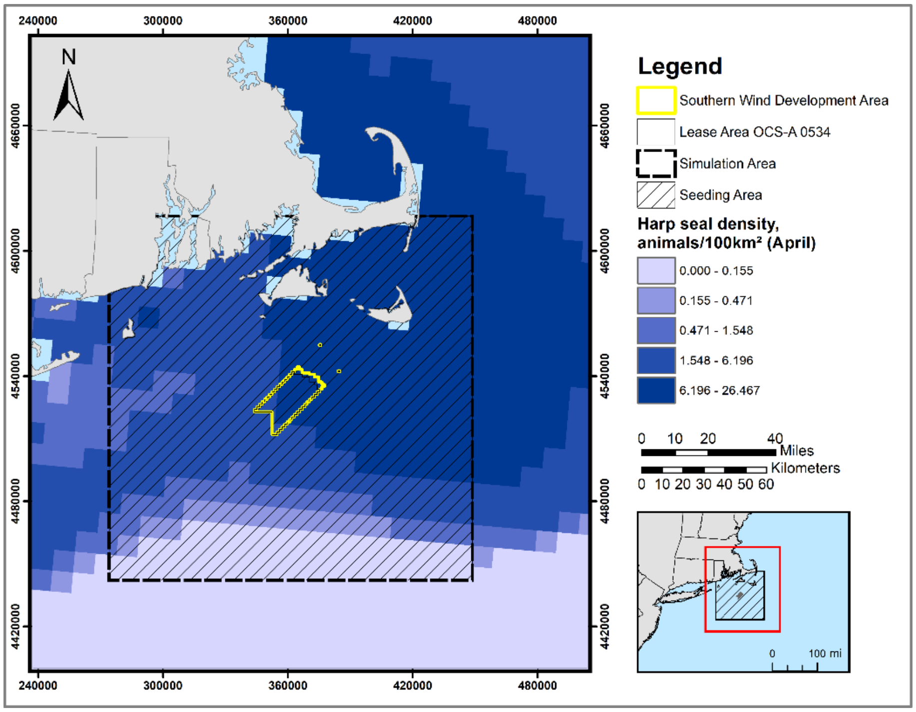

Figure H-17. Map of harp seal seeding area range for April, the month with the highest density

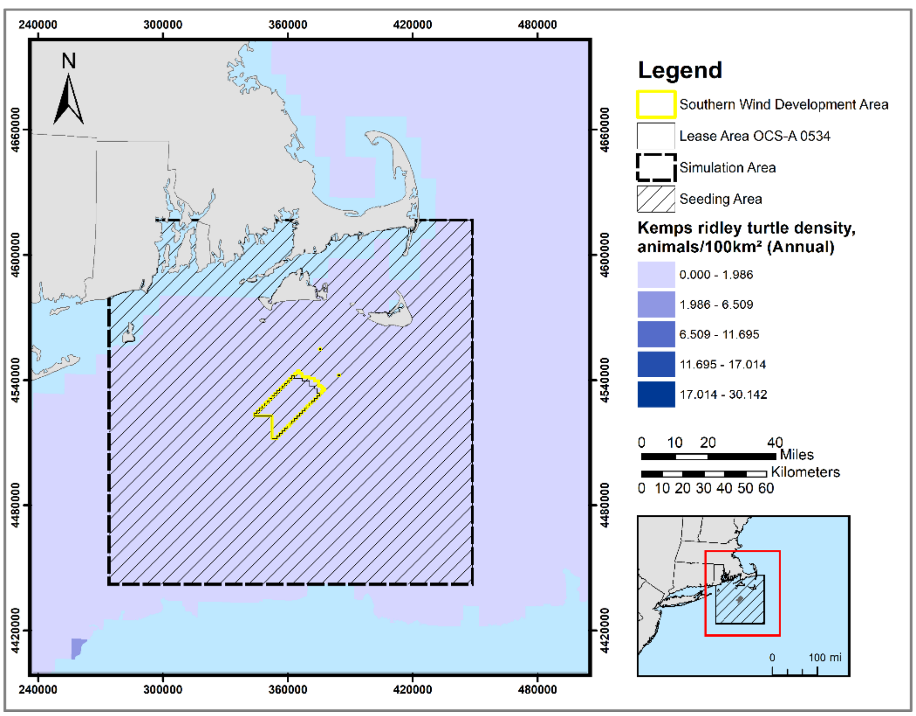

Figure H-18. Map of Kemp's ridley sea turtle seeding area range (DoN 2017). Exposure estimates are calculated using average seasonal density from Kraus et al. (2016) for summer and fall.

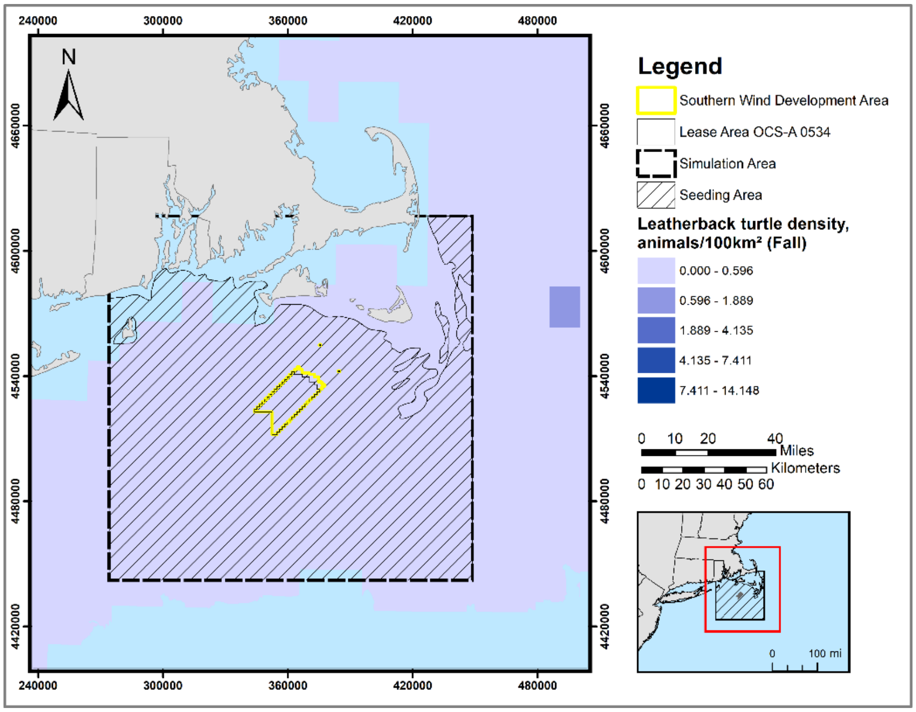

Figure H-19. Map of leatherback sea turtle seeding area range (DoN 2017). Exposure estimates are calculated using average seasonal density from Kraus et al. (2016) for summer and fall.

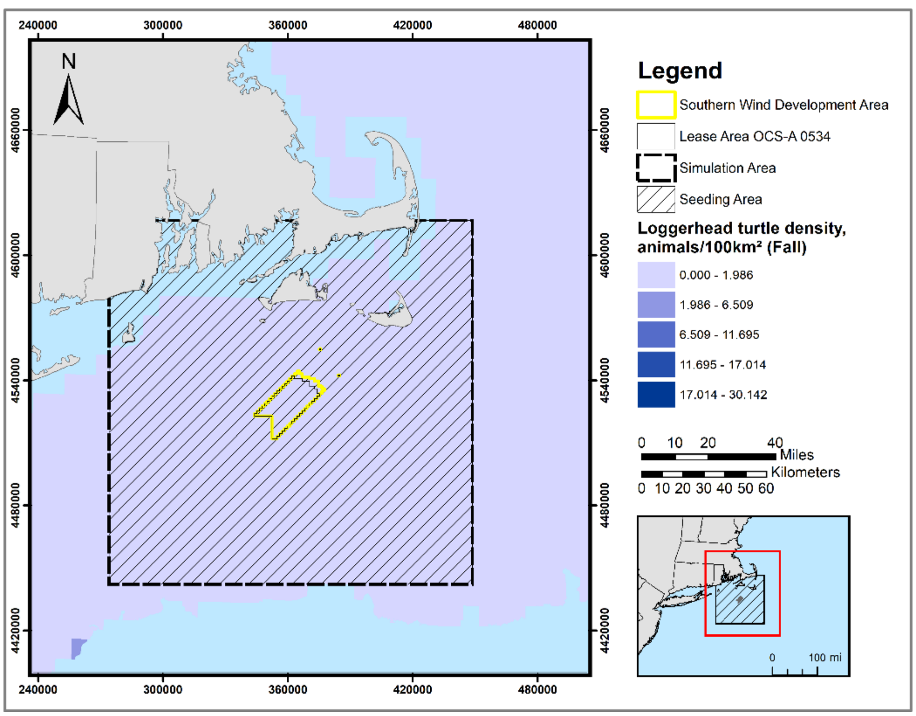

Figure H-20. Map of loggerhead sea turtle seeding area range (DoN 2017). Exposure estimates are calculated using average seasonal density from Kraus et al. (2016) for summer and fall.

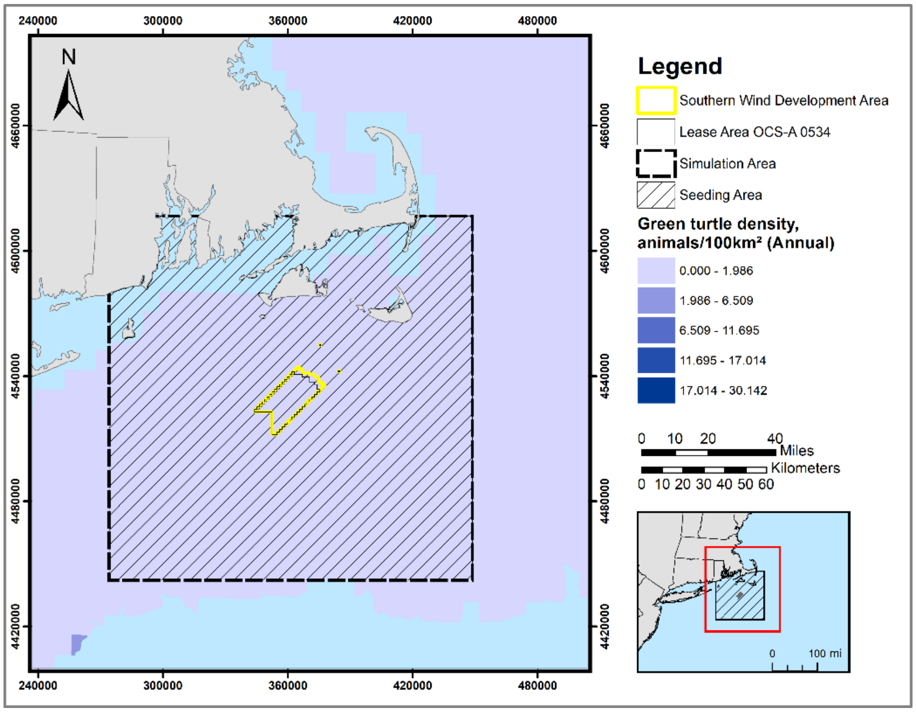

Figure H-21. Map of green sea turtle seeding area range (DoN 2017), showing Kemp's ridley sea turtle density as an example. Exposure estimates are calculated using average seasonal density from Kraus et al. (2016) for summer and fall.

Appendix I. High-Resolution Geophysical Survey Exposure Analysis

Memo

DATE: 23 June 2022

Version: 3.0

FROM: Susan Dufault, Karlee Zammit, Madison Clapsaddle, and David Zeddies
(JASCO Applied Sciences [USA] Inc.)

TO: Park City Wind LLC

Subject: Marine Mammal Exposure Estimates for High Resolution Geophysical Survey Activities During New England Wind Construction

Marine mammals may be exposed to sound from high resolution geophysical (HRG) equipment used during surveys associated with construction of New England Wind. The amount and severity of exposure has been estimated for two deep seismic profilers: the Applied Acoustics AA251 boomer and GeoMarine's Geo Spark 2000 (400 tip) sparker system. JASCO conducted acoustic modeling for this geophysical equipment. Details of that modeling effort are included as Appendix I.

Appendix I, Table 5 provides the model-predicted horizontal impact distances to Level A and Level B thresholds in meters for the various marine mammal hearing groups. The model results for the two deep seismic profiling sources are reproduced here in Table 1 for clarity. No Level A exposures are expected to occur given the short distances to the Level A thresholds and the mitigation measures to be implemented during the surveys.

Table 1. Horizontal impact distances (in meters) to Level A and Level B threshold criteria.

Source	Level A (PK)				Level A (SEL)				Level B (SPL)
	LF	MF	HF	PW	LF	MF	HF	PW	
	Threshold (dB re 1 µPa)				Threshold (dB re 1 µPa²·s)				(dB re 1 µPa)
	219	230	202	218	183	185	155	185	160
Applied Acoustics AA251 Boomer	—	—	3	—	<1	<1	53	<1	178
GeoMarine Geo Spark 2000 (400 tip)	—	—	4	—	<1	<1	4	<1	141

Both sources were considered impulsive. Threshold criteria are defined in Appendix I, Appendices I.1.2 and I.1.3.

Assumptions

Exposure calculations assumed that there would be 25 days of HRG surveying per year over each of 5 years, beginning in the first year of foundation installation and extending two years beyond the estimated 3-year duration of foundation installation. For the purpose of the Letter of Authorization Request, a start year of 2025 is assumed. A distance of 80 km/day was assumed to be the maximum HRG survey distance possible in a 24-hour period and therefore this was used in the exposure calculations.

Because the exact dates of HRG surveys are unknown, as a conservative measure, for each species, it was assumed that the 25 days of surveying each year would occur during the highest density month for that species. Additional details of the density calculations are provided below.

Zone of Influence

The zone of influence (ZOI) is a representation of the maximum extent of the ensonified area around a sound source over a 24-hour period. The ZOI for each of the two deep seismic profilers was calculated using the following equation, which defines ZOI for mobile sources:

$$\mathrm{ZOI} = \left(\frac{\mathrm{distance}}{\mathrm{day}} \times 2r\right) + \pi r^2 , \qquad (1)$$

where distance/day is the linear distance traveled by the survey vessel per day, in this case, 80 km, and r is the horizontal distance to the relevant acoustic threshold. The results of this calculation are provided in Table 2.

Table 2. Zone of influence (km^2) for the two modeled deep seismic profilers.

Source	Level B Zone of Influence
Applied Acoustics AA251 Boomer	28.58
GeoMarine Geo Spark 2000 (400 tip)	22.62

Density Calculations

Marine mammal densities in the potential impact area were estimated using the Marine Geospatial Ecology Laboratory (MGEL)/Duke University Habitat-based Marine Mammal Density Models for the U.S. Atlantic (Roberts et al. 2016a, 2016b, 2017, 2018, 2021a, 2021b). Densities in the MGEL/Duke models are provided as the number of animals per 100 square kilometers (animals/100 km^2) and given for each 10 × 10 km cell in the U.S. Atlantic for most species, with a cell size of 5 × 5 km for the North Atlantic right whale (NARW).

To calculate marine mammal densities for the potential HRG survey impact area, it was assumed that the surveys would occur in four areas of interest (see Figure 1):

1. Phase 2 South Coast Variant Offshore Routing Envelope,
2. New England Wind Offshore Export Cable Corridor,
3. Phase 2 OECC Western Muskeget Variant, and
4. Maximum Size of the Southern Wind Development Area.

Monthly density was calculated for each area of interest and for each species as the average of the densities from all MGEL/Duke model grid cells that overlap partially or completely with each area of interest. Cells entirely on land were not included, but cells that overlap only partially with land were included. As a conservative measure, the month with the highest density among the four areas of interest for each species was carried forward to the exposure calculations.

Because the MGEL/Duke model for pilot whales considers long- and short-finned pilot whales together as the pilot whale guild, densities for these two species were scaled by their relative abundances using the following example equation:

$$d_{short-finned} = d_{both}\left(\frac{a_{short-finned}}{a_{short-finned}+a_{long-finned}}\right), \quad (2)$$

where d is density and a is abundance. Also note that the MGEL/Duke model for the pilot whale guild (Roberts et al. 2016a, 2016b, 2017) provides only an annual density, not monthly, so the densities for these two species are predicted annual densities.

Harbor and gray seals were similarly scaled by their relative abundances using the MGEL/Duke model for the seals guild (Roberts et al. 2016a, 2016b, 2018). The seals guild model is based primarily on harbor and gray seals and harp seals are considered uncommon in the area so lack sufficient data to provide a density estimate. As a conservative approach, the gray seal density (i.e., lesser of gray and harbor seal density) was used as a surrogate for harp seal density.

The monthly densities for each species used to estimate exposures above Level B acoustic thresholds during HRG surveys of New England Wind are shown in Table 3.

Table 3. Maximum monthly density (animals/100 km^2) used to estimate exposures above acoustic thresholds during HRG surveys for New England Wind.

Species	Maximum monthly density (animals/100 km^2)
Fin whale	0.37
Minke whale	0.26
Humpback whale	0.29
North Atlantic right whale	0.90
Sei whale	0.05
Atlantic white-sided dolphin	7.87
Atlantic spotted dolphin	0.13
Short-beaked common dolphin	27.63
Bottlenose dolphin	35.81
Risso's dolphin	0.05
Long-finned pilot whale[a]	0.59
Short-finned pilot whale[a]	0.44
Sperm whale	0.04
Harbor porpoise	15.68
Gray seal[b]	36.59
Harbor seal[b]	82.20
Harp seal[b]	36.59

[a] Long- and short-finned pilot whale densities are the annual pilot whale guild density scaled by their relative abundances.
[b] Gray and harbor seal densities are the seals guild density scaled by their relative abundances; gray seals are used as a surrogate for harp seals.

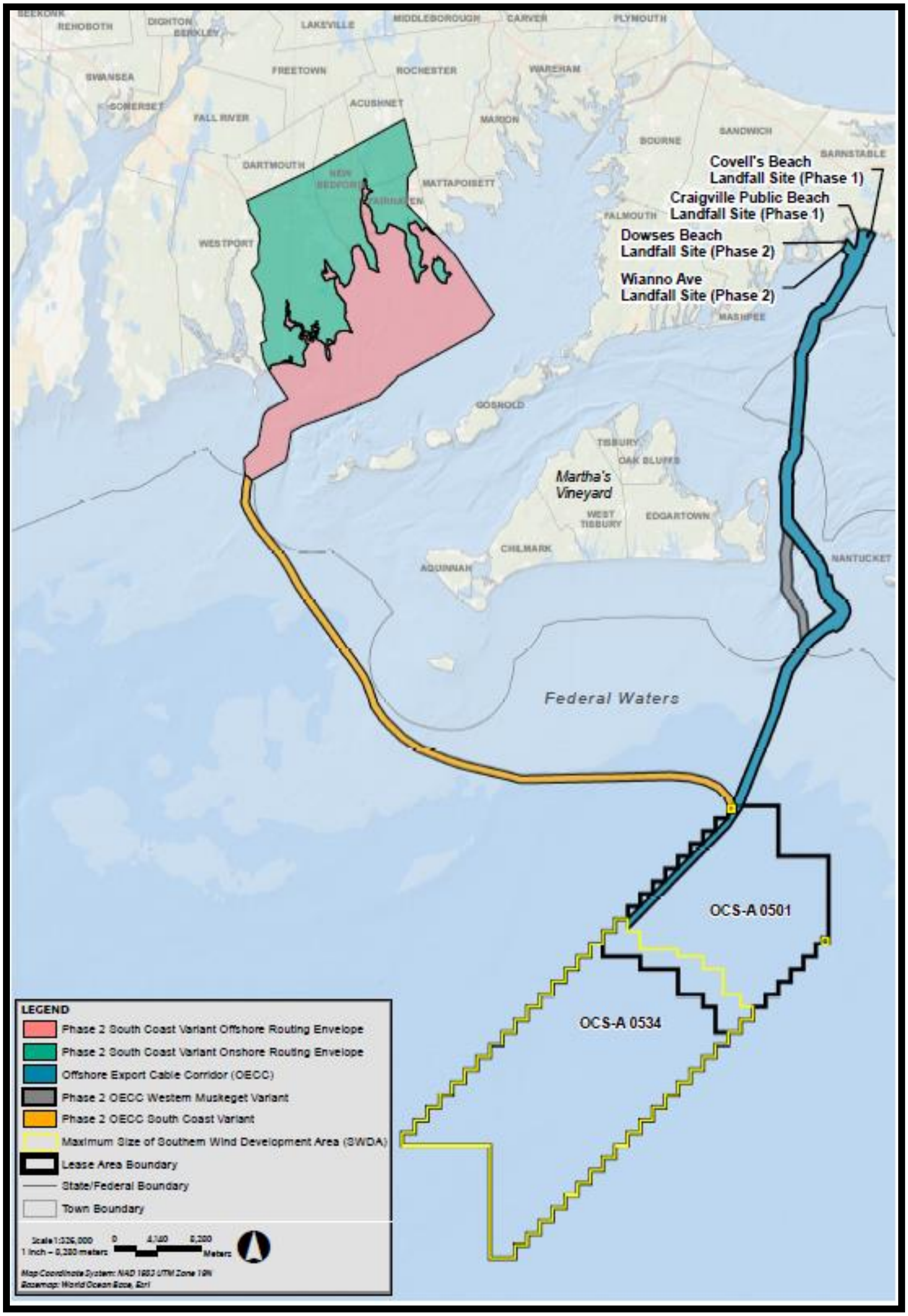

Figure 1. Map showing two potential Phase 2 offshore export cable variants. The four areas of interest used in the HRG survey exposure calculations are: (1) Phase 2 South Coast Variant Offshore Routing Envelope, (2) New England Wind Offshore Export Cable Corridor, (3) Phase 2 OECC Western Muskeget Variant, and (4) Maximum Size of the Southern Wind Development Area.

Estimated Exposures

Exposures above the Level B acoustic thresholds were estimated using the formula:

$$\text{exposures} = \text{ZOI} \times (\text{days}) \times \text{density}, \tag{3}$$

where ZOI is defined in Equation 1, days = 25, and density is from Table 3.

The results of these calculations are shown in Table 4.

Table 4. Estimated exposures: Number of animals of each species estimated to receive sound levels above the Level B threshold annually during HRG surveys of New England Wind.

Species	Applied Acoustics AA251 boomer	GeoMarine Geo Spark 2000
Fin whale[a]	2.67	2.11
Minke whale	1.82	1.44
Humpback whale	2.09	1.65
North Atlantic right whale[a]	6.44	5.10
Sei whale[a]	0.32	0.26
Atlantic white-sided dolphin	56.24	44.52
Atlantic spotted dolphin	0.93	0.73
Short-beaked common dolphin	197.42	156.27
Bottlenose dolphin	255.89	202.55
Risso’s dolphin	0.38	0.30
Long-finned pilot whale	4.22	3.34
Short-finned pilot whale	3.12	2.47
Sperm whale[a]	0.26	0.21
Harbor porpoise	112.02	88.67
Gray seal	261.41	206.92
Harbor seal	3.29	587.32
Harp seal	1.46	261.41

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Distances to Acoustic Thresholds for High Resolution Geophysical Sources

New England Wind HRG Incidental Harassment Authorization Calculations

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23 June 2022

P001398-007
Document 02737
Version 1.0

Suggested citation:

Li, Z. and M. Koessler. 2022. *Distances to Acoustic Thresholds for High Resolution Geophysical Sources: New England Wind HRG Incidental Harassment Authorization Calculations*. Document 02737, Version 1.0. Technical memorandum by JASCO Applied Sciences for New England Wind.

Disclaimer:

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Distance to Acoustic Thresholds for High Resolution Geophysical Sources

I.1. Methods

In this analysis, we compute horizontal impact ranges for High-Resolution Geophysical (HRG) sound sources. We consider both the contribution from the main lobe (in-beam) energy of the source, which is directed toward the seafloor, as well as side-lobe (out-of-beam) energy that propagates horizontally (see Figure I-1). The larger of these two is reported.

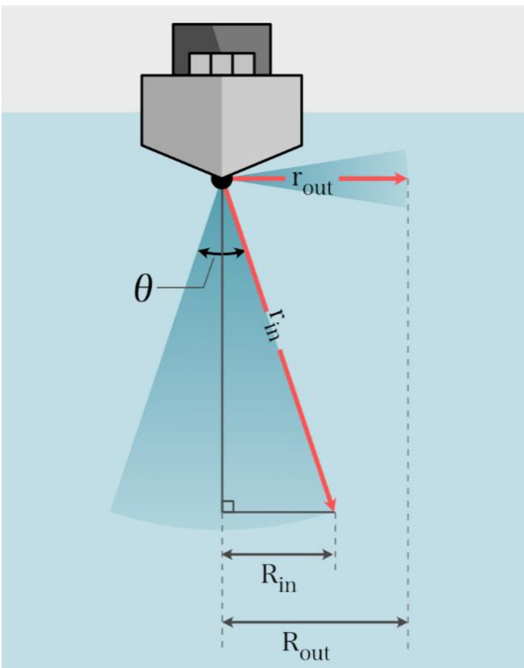


Figure I-1. Geometry used in computing horizontal impact ranges based on in-beam and out-of-beam energy.

Our methodology for computing the horizontal component of the main lobe follows the approach described by NMFS (2019) and Guan (2020). We elected to focus on the more conservative case wherein depth is not limited, which allows for more operational flexibility. For computing the horizontal extent of side-lobe energy, we start with a lower source level and assume that the sound energy propagates horizontally. Propagation loss in both cases is estimated using a modified spreading equation.

Section I.1.1 provides an overview of calculations. Sections I.1.2 and I.1.3 describe how Level A and Level B ranges are determined.

I.1.1. Calculation Summary

Propagation Loss

The sonar equation is used to calculate the received sound pressure level:

$$SPL(r) = SL - PL(r), \tag{I-1}$$

where *SPL* is the sound pressure level (dB re 1 µPa), *r* is the distance (slant range) from the source (m), *SL* is the source level (dB re 1 µPa m), and *PL* is the propagation loss as a function of distance. The propagation loss is calculated using a modified spreading equation:

$$PL(r) = 20\log_{10}\left(\frac{r}{1\text{ m}}\right)\text{ dB} + \alpha(f)\cdot r/1000, \tag{I-2}$$

where $\alpha(f)$ is the absorption coefficient (dB/km) and f is frequency (kHz). The absorption coefficient is approximated by discarding the boric acid term from Ainslie (2010; p29; eq 2.2):

$$\alpha(f) \approx 0.000339f^2 + 48.5f^2/(75.6^2 + f^2)\,. \tag{I-3}$$

When a range of frequencies is produced by a source, we use the lowest frequency to determine the absorption coefficient.

The predicted received level is used to determine the distance at which a threshold level is reached (i.e., solving Equation I-1 for slant range r).

Horizontal range estimation

For a downward-pointing source with a beam width less than 180°, the horizontal impact distance (R_{in}) is calculated from the in-beam slant range using:

$$R_{in} = r_{in}\cdot\sin\left(\frac{\delta\theta}{2}\right), \tag{I-4}$$

where $\delta\theta$ is the -3 dB beamwidth.

To account for energy emitted outside of the primary beam of the source, we estimate a representative out-of-beam source level and propagate the energy horizontally (see Figure I-1). In this method, the horizontal component R_{out} of the out-of-beam energy is equivalent to the out-of-beam slant range:

$$R_{out} = r_{out}. \tag{I-5}$$

The larger of the two horizontal range estimates was then selected for assessing impact distance (presented in Section I.4):

$$R = \max(R_{in}, R_{out}). \tag{I-6}$$

For an omni-directional source the horizontal impact distance (*R*) was calculated based on horizontally propagating energy (i.e., this is equivalent to a beamwidth of 180°).

Out-of-beam source level adjustment

Side lobe energy is generally lower than the main lobe energy. An estimate of the reduction relative to the main lobe energy was generated as a function of the main lobe beam width. Separate approaches were taken for narrow-beam sources (up to 36° beam width), intermediate-beam sources (36° to 90° beam width), and broad-beam sources. Broad-beam sources were treated as omni-directional and had no out-of-beam reduction. The out-of-beam reduction for narrow beam sources was approximated using a theoretical beam pattern. The out-of-beam reduction for intermediate-beam sources was interpolated between the other two approximations.

The narrow-beam side lobe level reduction is estimated by taking the arithmetic average of the upper and lower bounds of the sidelobe levels of an unshaded circular transducer beam pattern. This beam pattern $b(u)$ is described as:

$$b(u) = (2\ J_1(u)/u)^2, \tag{I-7}$$

where $J_1(u)$ is a first order Bessel function of the first kind, whose argument is a function of off-axis angle θ and beam width (full width at half maximum) $\delta\theta$

$$u = u_0 \frac{\sin\theta}{\sin\frac{\delta\theta}{2}}, \tag{I-8}$$

where $u_0 = 1.614$.

For the upper limit we choose the highest sidelobe level of the beam pattern, given by (Ainslie 2010; p265; Table 6.2)

$$B_{\max} = -17.6\ \mathrm{dB}. \tag{I-9}$$

For the lower limit we consider the asymptotic behavior of the beam pattern in the horizontal direction

$$J_1(u) \sim \sqrt{\frac{2}{\pi u}} \cos\left(u - \frac{3\pi}{4}\right), \tag{I-10}$$

where

$$u = \frac{u_0}{\sin\frac{\delta\theta}{2}}. \tag{I-11}$$

In this way we obtain the lower limit as

$$B_{\min} = 10 \log_{10}\left(\frac{8}{\pi\, u_0^3} \sin^3 \frac{\delta\theta}{2}\right) \mathrm{dB}. \tag{I-12}$$

Finally, the out-of-beam source level is found by reducing the in-beam source level by the arithmetic mean of $B_{\min}$ and $B_{\max}$. The resulting correction as a function of beam width is shown in Figure I-2. Note that narrower beam sources have a larger reduction in side lobe levels than wider beam sources.

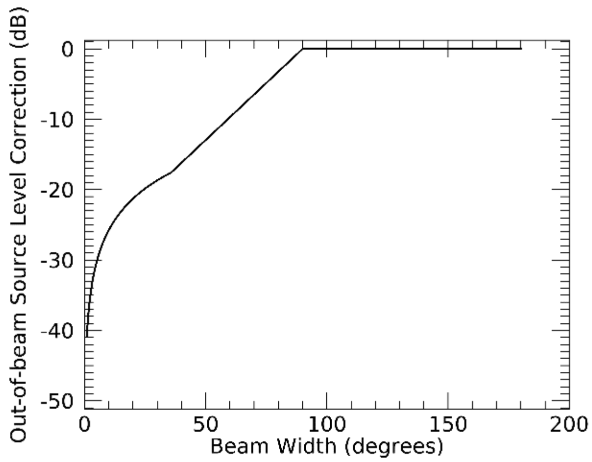


Figure I-2. Correction for calculating out-of-beam source level (i.e., in the horizontal direction) from in-beam source level, as a function of main lobe beam width.

The out-of-beam source level for a given HRG source was calculated by adding the dB correction (Figure I-2) to the in-beam source level. The corrections computed for the sources considered in this study can be found in Table I-4.

I.1.2. Level A

This section describes the methods used to estimate the horizontal distances to the National Marine Fisheries Service (NMFS) acoustic thresholds for injury (Table I-1). There are different thresholds for impulsive and non-impulsive sounds. According to Southall et al. (2007), "Harris (1998) proposed a measurement-based distinction of pulses and non-pulses that is adopted here in defining sound types. Specifically, a ≥3-dB difference in measurements between continuous and impulse [sound level meter] setting indicates that a sound is a pulse; a <3 dB difference indicates that a sound is a non-pulse. We note the interim nature of this distinction for underwater signals and the need for an explicit distinction and measurement standard such as exists for aerial signals (ANSI 1986)."

Classification of impulsive signals is inconsistent across standards, criteria, and guidance. Southall et al. (2007), Finneran et al. (2017), and NMFS (2018) each have different criteria for classifying a signal as impulsive or non-impulsive. The Southall et al. (2007) method described above was used for all of the sources analyzed in this work. Finneran et al. (2017) state that harmonic signals with more than 10 cycles in a pulse are considered steady state (i.e., non-impulsive). NMFS (2018) cites the standard for measurement of sound levels in air (ANSI 2010), but removes the quantitative criteria resulting in a definition that impulsive sound sources "produce sounds that are typically transient, brief (less than 1 second), broadband, and consist of high peak sound pressure with rapid rise time and rapid decay." The ANSI (2010) classification, while more specific than NMFS (2018), does not preclude harmonic signals, especially frequency modulated signals, from being classified as impulsive.

NMFS has determined that deep seismic profilers such as sparkers and boomers are classified as impulsive sources. This classification is based on NMFS' qualitative assessment of the generated waveforms (pers comm, Benjamin Laws [NMFS] 2020).

Table I-1. Peak sound pressure level (PK, dB re 1 µPa) and sound exposure level (SEL, dB re 1 µPa²·s) thresholds for injury (PTS onset) for marine mammals for impulsive sound sources (NMFS 2018).

Functional hearing group	Impulsive source	
	PK	Weighted SEL_{24h}
Low-frequency cetaceans (LFC)	219	183
Mid-frequency cetaceans (MFC)	230	185
High-frequency cetaceans (HFC)	202	155
Phocid pinnipeds in water (PPW)	218	185
Otariid pinnipeds in water (OPW)	232	203

NMFS provides a spreadsheet to calculate these distances, but it is not designed for high-resolution geophysical survey sources. The spreadsheet does not consider seawater absorption or beam patterns, both of which can substantially influence received sound levels. In order to account for these effects, we model sound levels using Equations I-1 to I-12, as follows.

Distances to peak thresholds were calculated using the peak source level and applying propagation loss from Equation A-2. Peak levels were assessed for both in-beam and out-of-beam levels (the latter was assessed using the out-of-beam source level correction described previously).

Range to SEL thresholds were calculated for source locations along a hypothetical survey line. Source spacing was determined from the assumed vessel speed of 3.5 kts and the repetition rate for each source. A single set of fixed receiver locations extended perpendicularly from the middle of the survey line. The propagation loss between each source and receiver pair was calculated (Equation I-2), and then using the appropriate (in beam or out of beam) weighted source level and pulse length (Figure I-2 and Table I-2), the received level from all of the source locations for each receiver was determined. The received levels at a given receiver location from all source locations were summed. The greatest range where the summed SEL exceeded the criteria threshold was the range to impact (Table I-1). This range was determined separately for all sources and all functional hearing groups.

This method accounts for the hearing sensitivity of the marine mammal group, seawater absorption, and beam width for downwards-facing transducers.

In cases where the pulse duration for a source was unknown. The pulse duration was calculated from the difference between source level (SL) and energy source level (ESL) using:

$$T = 10^{(ESL-SL)/10}. \quad \text{(I-13)}$$

I.1.3. Level B

This section describes the methods used to estimate the horizontal distance to the root-mean-square sound pressure level (SPL) 160 dB re 1 µPa isopleth for the purposes of estimating Level B harassment (NOAA 2005). Distances to SPL thresholds were calculated using the source level and applying the method described above. SPL levels were assessed for both in-beam and out-of-beam levels (the latter was assessed using the out-of-beam source level correction described previously).

I.2. Sources

The following subsections describe the source characteristics of HRG equipment provided by Vineyard Wind. The horizontal impact distance to the Level A (Table I-1) and Level B (160 dB re 1 µPa) thresholds were computed for each source by applying the methods from Section Appendix I. We used the following assumptions when calculating impact distances:

- For sources that operate with different beam widths, we used the beam width associated with operational characteristics reported in Crocker and Fratantonio (2016).
- We use the lowest frequency of the source when calculating the absorption coefficient.

I.3. Overview of Source Properties

Table I-2 lists geophysical survey sources considered in this assessment that produce underwater sound at or below 180 kHz frequencies, and their acoustic characteristics. Table I-3 provides the accompanying data source reference.

Table I-2. Considered geophysical survey sources.

Equipment	System	Frequency (kHz)	Source level (dB re 1 µPa m)	Peak source level (dB re 1 µPa m)	Energy source level (dB re 1 µPa²s m²)	Beam width (°)	Pulse duration (ms)	Repetition rate (Hz)
Deep seismic profilers	Applied Acoustics AA251 Boomer	0.2–15	205	212	174	180	0.8	2
	GeoMarine Geo Spark 2000 (400 tip)	0.05–3	203	213	178	180	3.4	1

Table I-3. Data reference for considered geophysical survey sources.

Equipment	System	Frequency	Source level	Peak source level	Energy source level	Beam width	Pulse duration	Repetition rate
Deep seismic profilers	Applied Acoustics AA251 Boomer	Estimated from Figs 14 and 16 in Crocker and Fratantonio (2016)	See Table 5 in Crocker and Fratantonio (2016) source for levels at 300 J	See Table 5 in Crocker and Fratantonio (2016) source for levels at 300 J	See Table 5 in Crocker and Fratantonio (2016) source for levels at 300 J	See Table 5 in Crocker and Fratantonio (2016) source for levels at 300 J	Crocker and Fratantonio (2016), after correcting for full pulse duration	Vineyard Wind indicates they will use this repetition rate
	GeoMarine Geo Spark 2000 (400 tip)	Source specifications provided by Vineyard Wind.	Considered SIG ELC 820 Sparker as proxy for source levels as SIG ELC 820 has similar operation settings as Geo Spark 2000 (Sect. I.5.1). See Table 9 in Crocker and Fratantonio (2016) source for levels at 5 m source depth, 750 J setting.	Considered SIG ELC 820 Sparker as proxy for source levels as SIG ELC 820 has similar operation settings as Geo Spark 2000 (Sect. I.5.1). See Table 9 in Crocker and Fratantonio (2016) source for levels at 5 m source depth, 750 J setting.	Considered SIG ELC 820 Sparker as proxy for source levels as SIG ELC 820 has similar operation settings as Geo Spark 2000 (Sect. I.5.1). See Table 9 in Crocker and Fratantonio (2016) source for levels at 5 m source depth, 750 J setting.	Assume omnidirectional source to be conservative.	Considered SIG ELC 820 Sparker as proxy for source levels as SIG ELC 820 has similar operation settings as Geo Spark 2000 (Sect. I.5.1). See Table 9 in Crocker and Fratantonio (2016) source for levels at 5 m source depth, 750 J setting.	Vineyard Wind indicates they will use this repetition rate

I.3.1. Derived Out-of-beam Levels

Table I-4 lists the corrections applied to obtain out-of-beam source levels.

Table I-4. Correction factors for out-of-beam source levels.

Description		In-beam		Correction (dB)	Out-of-beam	
Equipment	System	Source level (dB re 1 µPa m)	Peak source level (dB re 1 µPa m)		Source level (dB re 1 µPa m)	Peak source level (dB re 1 µPa m)
Deep seismic profilers	Applied Acoustics AA251 Boomer	205	212	0.0	205.0	212.0
	GeoMarine Geo Spark 2000 (400 tip)	203	213	0.0	203.0	213.0

I.4. Distances

Table I-5 lists the geophysical survey sources and the horizontal impact distances to the Level A and B criteria that were obtained by applying the methods from Appendix I with the source parameters in Appendix I.3.

Table I-5.Horizontal distance to Level A and Level B impact threshold.

Equipment	System	Level A horizontal impact distance (m) to PK threshold					Level A horizontal impact distance (m) to SEL threshold					Level B horizontal impact distance (m)
		LFC	MFC	HFC	PPW	OPW	LFC	MFC	HFC	PPW	OPW	
Deep seismic profilers	Applied Acoustics AA251 Boomer	—	—	3	—	—	<1	<1	53	<1	<1	178
	GeoMarine Geo Spark 2000 (400 tip)	—	—	4	—	—	<1	<1	4	<1	<1	141

A dash (—) indicates that a source level is less than threshold level.

The methods used here are approximate, and a rigorous propagation loss model coupled with a full beam pattern and spectral source model would result in more accurate impact distances.

I.5. Equipment Specification Reference Sheets

I.5.1. GeoMarine Geo Spark 2000 (400 tip)

Geo-Source 200 - 400
Marine Multi-Tip Sparker System

Operational Features

- Powerful hi-resolution seismic source
- Primary pulse < 1ms, no ringing
- Proven operation in 1000 m water depth
- Penetration to 400 ms below seabed, depending on geology and survey conditions
- Vertical resolution < 30 cm

Ideal seismic profiling system for small and large vessels

- Site & route surveys
- Offshore engineering
- Mineral exploration
- Oceanographic research

INNOVATIVE Preserving Electrode Mode

The innovative Geo-Source 200 has been designed for operation with the Geo-Spark 1000 pulsed power supply (PPS) using the patented **Preserving Electrode Mode.** This mode uses a NEGATIVE electric discharge pulse instead of a positive pulse.

(Please note that this negative pulse is NOT the same as the simple reversal of the positive polarity of a 'standard' power supply.)

Maintenance free electrodes 5 year guarantee

The Preserving Electrode Mode **reduces the tip wear to practically zero**. You can shoot day after day, week after week, month after month with practically **NO tip maintenance.**

Always a stable acoustic pulse

Zero tip wear is essential for the **acoustic repeatability** of the pulse, which depends largely on a constant, unaltered electrode surface and tip insulation.

Efficient & Cost Effective

With the Geo-Spark HV power supplies you will save a lot of time and money, since the electrodes do NOT burn off like in all other systems.

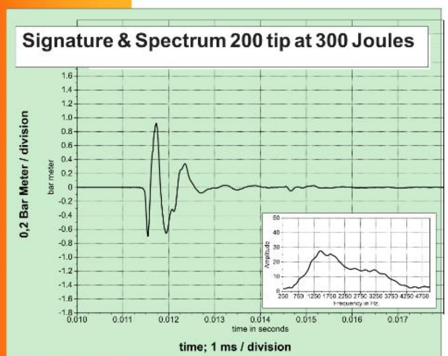
You don't need to trim tips during the survey. There is no need to have any stock of consumables.

Examples of Records

To see examples of our sparker records, please visit the 'Downloads' page on our website: ***www.geo-spark.com***

Geo-Source 200-400

Technical Specifications



Maintenance free electrodes, no trimming, stable signature

GEO Marine Survey Systems b.v.
Sheffieldstraat 8, 3047 AP Rotterdam
The Netherlands
Phone: + 31 10 41 55 755
Fax: +31 10 41 55 351
info@geomarinesurveysystems.com
Website: www.geo-spark.com

Electrodes Geometry

The electrode modules are evenly spaced in a planar array of 0.75 m x 1.00 m. This geometry not only enhances the downward projection of the acoustic energy, it also reduces the primary pulse length, since all tips are perfectly in phase.

Control of Source Parameters 200 - 400 tips

The advanced Geo-Source 200-400 design gives you total control of the source depth and the energy (Joules) per tip

Source depth

Two floats provide a stable towing configuration and insure the proper depth of the electrode tips. This is critical to achieve constructive interference between the primary pulse and its own sea-surface reflection (surface ghost)

Number of tips in use and Energy per tip

Four individually powered electrode modules of 50 or 100 tips each allow you to distribute the energy from the Geo-Spark power supply over 50, 100......, up to 400 tips. (Each tip has an exposed surface area of 1.4 mm^2.)

200 tips, the classic 200 tip configuration is normally used with the Geo-Spark 1000 PPS and consists of four 50-tip electrode modules. This configuration gives an excellent hi-res pulse over the 100 to 500 J power range.

400 tips, for higher energies above 1000 J, and in particular with the Geo-Spark 2000X, we recommend a 400 tip configuration with 4 x 100-tip electrode modules

Coaxial High Voltage (HV) Power/Tow Cable

The Geo-Source 200 is towed by a very high quality, Kevlar-reinforced, coaxial power/tow cable with stainless steel kellum grip. This dedicated high voltage (HV) cable contains **4 x 10 mm^2** inner cores (negative) plus a **40 mm^2** braiding (ground-referenced). It is designed to have a very low self-inductance to preserve the high dI/dt pulse output of the Geo-Spark 1000 PPS.

The coaxial structure of the HV cable reduces the electromagnetic interference to the absolute minimum.

The wet end of the cable is terminated with four special HV connectors to the electrode modules and a ground connector to the frame. Connecting or disconnecting the cable to the Geo-Source 200 takes only 10 minutes; so you can handle the sparker sled and the HV cable as independent units.

The dry end of the cable is terminated at the Geo-Source 200 patch panel, which allows you to select the number of electrode arrays in use

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Appendix J. Unexploded Ordnance Exposure Analysis

Memo

DATE: 23 June 2022

Version: 3.0

FROM: David Hannay, Madison Clapsaddle, and David Zeddies
(JASCO Applied Sciences [USA] Inc.)

TO: Park City Wind LLC

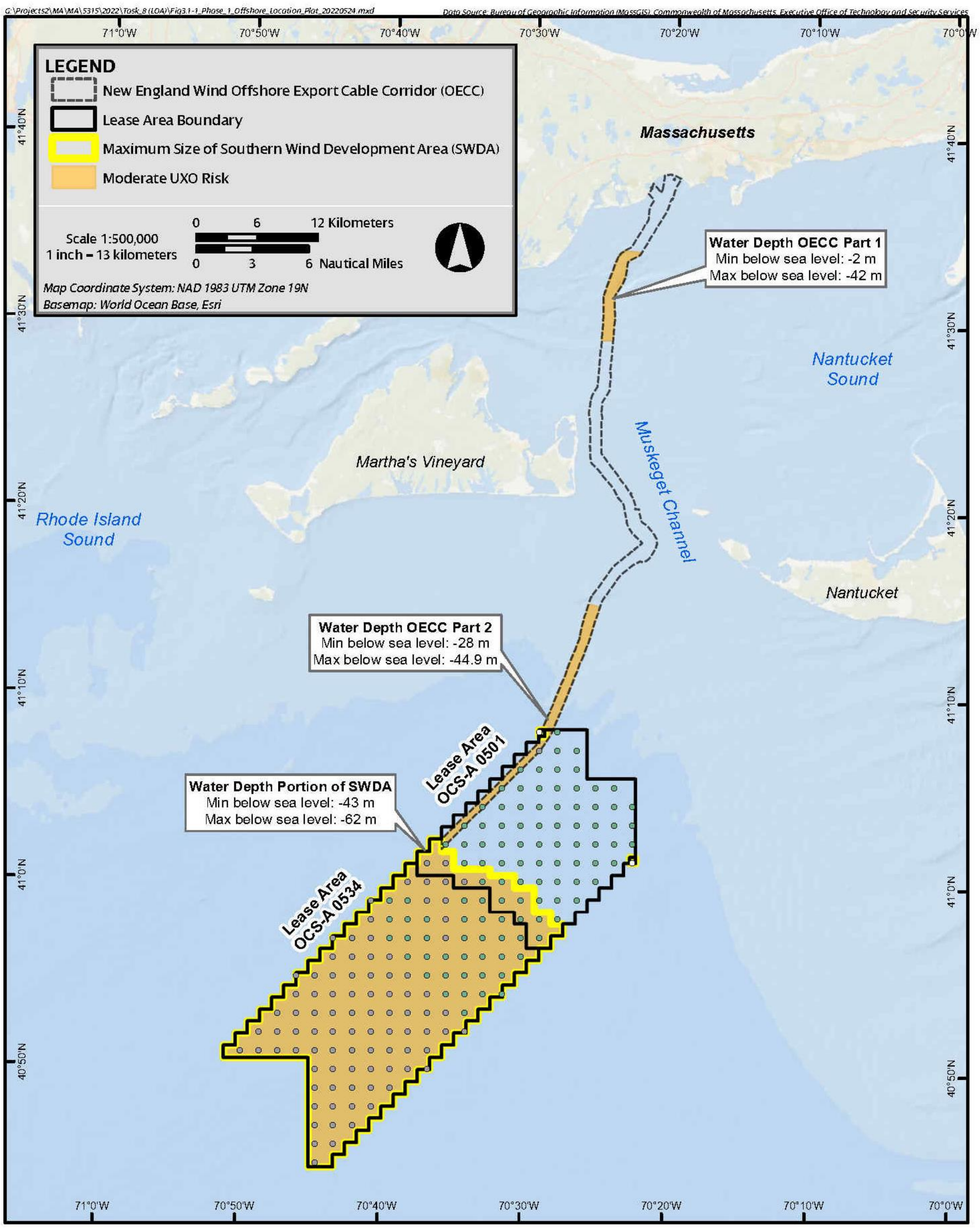
Subject: Marine Mammal Level A and Level B Exposure Estimates for Potential Unexploded Ordinance Detonation During New England Wind Construction

CONTAINS CONFIDENTIAL BUSINESS INFORMATION

Park City Wind LLC (Park City Wind) is currently assessing the risk of encountering unexploded ordnance (UXO) within the New England Wind southern wind development area (SWDA) and offshore export cable corridors (OECCs). In instances where avoidance, physical UXO removal, or alternative combustive removal technique (e.g., deflagration) is not feasible due to layout restrictions or considered safe for project personnel, UXOs may need to be detonated in situ to conduct seabed-disturbing activities such as foundation installation and cable laying during construction of New England Wind. The selection of the disposal method will be determined by the size, location, and condition of each individual UXO that the project may encounter.

The project team is continuing to evaluate the risk of encountering potential UXO. Geophysical surveys to identify the amount and magnitude of potential UXO within the SWDA and OECC are ongoing. As these surveys and analysis of survey data are still in progress, the number, location, and type of UXO in the project area is not known at this time. Initial survey data, however, suggests that there are potential areas of moderate risk for UXO presence (Figure 1). Water depth at these locations range from approximately 2 to 62 m (Mills 2021).

Geophysical survey operations and the development of UXO risk analysis and mitigation strategy for New England Wind are currently in line with requirements for COP development and will be further matured as the project timeline progresses towards construction.



New England Wind

Figure 1
Areas of Moderate UXO Risk

J.1. Baseline Threat Assessment

Park City Wind has commissioned a UXO desktop study in which a comprehensive historic analysis of all activities which may have contributed to potential UXO-related contamination have been considered and are summarized. The conclusion of this historical research is presented in Table J-1 and Table J-2. The probability of encounter of UXOs within the entire New England Wind project area is classified as possible to improbable for all but one classification of UXO.

Table J-1. Probability levels.

Probability Assessment Levels		
Grade	**Probability level**	**Rationale**
A	Highly Probable	Clear evidence that this type of munition would be encountered.
B	Probable	Significant evidence to indicate that this type of munition would be encountered.
C	Possible	Evidence suggests that this type of munition could be encountered.
D	Remote	Evidence suggest that these munitions have been found in the wider area but not specifically on the site.
E	Improbable	Not considered likely to encounter this type of munition on site, but not possible to discount completely.
F	Highly Improbable	No evidence that this type of munition would be encountered on site or the immediate vicinity.

Source: Mills (2021)

Table J-2. Probability of encounter for each ordnance type.

UXO		Probability	
Small Arms Ammunition		E	Improbable
Land Service Ammunition		E	Improbable
≤155 mm Projectiles		D	Remote
≥155 mm Projectiles		D	Remote
HE Bombs	Allied Origin	B	Probable
	Axis Origin	E	Improbable
Sea Mines	Allied Origin	E	Improbable
	Axis Origin	D	Remote
	Axis Origin (Non-Ferrous)	E	Improbable
Torpedoes		C	Possible
Depth Charges		C	Possible
Dumped Conventional Munitions		C	Possible
Dumped Chemical Munitions		E	Improbable
Missiles/Rockets		D	Remote

Source: Mills (2021)

J.2. Acoustic Modeling Methodology and Assumptions

An acoustic modeling study of peak pressure, acoustic impulse and sound exposure level from UXO detonation was performed recently for the Revolution Wind project, an Orsted and Eversource Investment joint venture (Hannay and Zykov 2022), which is geographically adjacent to the New England Wind project area. Although this study was targeted for the Revolution Wind project, the results are being applied to Orsted's Ocean Wind 1 and Sunrise Wind projects due to site similarities such as water depth and seabed sediment properties. This modeling study is currently available as Appendix B in the *Revolution Wind Petition for Incidental Take Regulations for the Construction and Operation of the Revolution Wind Offshore Wind Farm* starting at Page 329 of that application (available at https://media.fisheries.noaa.gov/2022-03/RevWind_ITR_App_OPR1.pdf; LGL Ecological Research Associates, Inc. 2022) and Appendix C in the *Ocean Wind Offshore Wind Farm Application for Marine Mammal Protection Act (MMPA) Rulemaking and Letter of Authorization (LOA)* (available at https://media.fisheries.noaa.gov/2022-03/OceanWind1OWF_2022_508APP_OPR1.pdf; HDR 2022).

The modeling study employed an approach adopted from the US Navy of 'binning' items of UXO which may be encountered on the site and may need to be mitigated through detonation. The study included acoustic ranges for potential UXO detonations for four different water depths (12, 20, 30, and 45 m) within the Revolution Wind project area and for five different UXO charge weight bins (E4 [2.3 kg], E6 [9.1 kg], E8 [45.5 kg], E1b0 [227 kg], and E12 [454 kg]; Table J-3) (Hannay and Zykov 2022). The modeling locations were chosen at two sites along the Revolution Wind subsea export cable route in Narragansett Bay in water depths of 12 m and 20 m, and two sites within the Revolution Wind lease area at depths of 30 m and 45 m.

Table J-3. Navy "bins" and corresponding maximum UXO charge weights (Maximum equivalent weight trinitrotoluene [TNT]) to be modeled.

Navy Bin	Maximum equivalent weight TNT	
	(kg)	(lbs)
E4	2.3	5
E6	9.1	20
E8	45.5	100
E10	227	500
E12	454	1000

Source: Hannay and Zykov (2022)

The acoustic modeling considered injurious effects to lung and gastrointestinal tracts of marine mammals using peak pressure and acoustic impulse metrics. Auditory system injury zones were assessed using Sound Exposure Level (SEL) based on Permanent Threshold Shift (PTS) onset. Disturbance to marine mammals was based on Temporary Threshold Shift (TTS) onset. Injury to fish zones were assessed using peak pressure and SEL thresholds. This modeling also considered the use of sound reduction/mitigation technologies that would reduce the produced pressures by 10 dB across all acoustic frequencies. This amount of reduction is expected to be possible using noise mitigation systems (NMS) such as modern air curtains.

The peak pressure and acoustic impulse levels and effects threshold exceedance zones depend only on charge weight, water depth, animal mass and submersion depth. They depend only slightly on local bathymetry that could affect the maximum submersion depth of nearby animals. These results do not depend on seabed composition or acoustic reflectivity. Therefore, the peak pressure and impulse results are expected to be directly relevant for use with New England Wind activities, as long as those activities are performed similarly (i.e., by detonating the same UXO charge sizes, performing only one charge detonation per 24 hours, and using an NMS capable of reducing pressures by at least 10 dB).

The water depths considered in the acoustic modeling study (i.e., 12, 20, 30, and 45 m) are relevant to the New England Wind project areas that may require UXO detonation, although the export cable route for New England Wind comes to shore northeast of Cape Cod Island and not into Narragansett Bay, as was considered in the modeling study. The modeled SEL from Revolution Wind are mostly transferable to similar depth sites over New England Wind's project area, with the possible exception of the shallowest site (12 m) that is located in a constrained channel in Narragansett Bay with nearby islands blocking sound propagation in some directions. The area of possible effects threshold exceedances could be larger for other sites with similar water depths when islands or shoals are not nearby to block sound propagation. The SEL results from the other Revolution Wind model sites will be approximately transferable to New England Wind sites of the same depth. Those results, however, depend on the sound propagation loss that is specific to the bathymetric variations along multiple radials leading away from each model site. In general, the bathymetry near the Revolution Wind model sites was gently sloping, but there were some non-uniform bathymetry features included. This could lead to slight differences in the sizes of the effects threshold exceedance zones. Nevertheless, differences of charge sizes within each UXO weight range bin and the unknown fraction of contained explosive that will detonate are likely to produce much more variability in noise level for each bin size than location-dependent effects.

The maximum equivalent weight of the UXO types indicated as possible to be encountered by the New England Wind project fall within or below bin E12, and possible UXO types expected within the footprint of New England Wind generally fall in bin E10 and below (Mills 2021). Park City Wind will employ avoidance through microrouting/micrositing of project infrastructure. Due to this avoidance measure, the low likelihood of encounter, and the similarity in bathymetry between the Revolution Wind and New England Wind project areas, the modeling study (Hannay and Zykov 2022) is proposed to be sufficient for New England Wind.

J.3. Acoustic Ranges

New England Wind construction operations may encounter UXO along the OECC and within the SWDA. UXO encountered during New England Wind construction activities are expected to be of the same type and sizes considered for the Ocean Wind 1 project (Mills 2021; HDR 2022). For the purposes of the New England Wind LOA application, the same UXO risk assumptions as the Ocean Wind application (HDR 2022) have been made for the New England Wind project, whereby up to 10 E12-bin UXOs were assumed between the various depths expected to be encountered in the project area, estimating 2 UXOs at 12 m, 3 UXOs at 20 m, 3 UXOs at 30 m, and 2 UXOs at 40 m. Based on the results of the UXO desktop study (Mills 2021), Park City Wind does not expect that 10 E12-size UXOs will be present, but a combination of up to 10 UXOs may be encountered. As a conservative measure the larger E12 bin will be used to analyze potential effects.

Table J-4 presents SEL-based $R_{95\%}$ PTS (Level A) and TTS (Level B) isopleths and their equivalent areas, which include both no attenuation results and results with an assumed 10 dB of attenuation due to the use of NMS (Bellmann and Betke 2021). New England Wind will use NMS with an expected 10 dB of attenuation (Bellmann and Betke 2021).

Table J-4. SEL-based criteria ranges (m) and equivalent areas (km^2) to PTS- and TTS-onset ($R_{95\%}$) for various depths assuming no attenuation and 10 dB attenuation.

Hearing Group	Threshold (dB re 1 µPa^{2}s)	No Attenuation				10 dB of Attenuation			
		12 m	20 m	30 m	45 m	12 m	20 m	30 m	45 m
Radii									
Level A (PTS-onset)									
LF	183	7,640	8,800	8,440	8,540	3,220	3,780	3,610	3,610
MF	185	1,540	1,450	1,480	1,410	461	386	412	412
HF	155	11,300	11,000	10,700	10,900	6,200	6,190	6,190	6,160
PW	185	4,340	4,500	4,450	4,520	1,600	1,430	1,480	1,350
Level B (TTS-onset)									
LF	168	18,300	19,200	19,300	19,000	11,000	11,900	11,500	11,800
MF	170	5,860	5,850	5,840	5,810	2,550	2,430	2,480	2,480
HF	140	20,200	20,200	20,200	20,000	14,100	13,800	13,300	13,700
PW	170	13,300	13,200	12,800	13,300	6,750	6,990	6,900	7,020
Area									
Level A (PTS-onset)									
LF	183	183.37	243.28	223.79	229.12	32.57	44.89	40.94	40.94
MF	185	7.45	6.61	6.88	6.25	0.67	0.47	0.53	0.53
HF	155	401.15	380.13	359.68	373.25	120.76	120.37	120.37	119.21
PW	185	59.17	63.62	62.21	64.18	8.04	6.42	6.88	5.73
Level B (TTS-onset)									
LF	168	1,052.09	1,158.12	1,170.21	1,134.11	380.13	444.88	415.48	437.44
MF	170	107.88	107.51	107.15	106.05	20.43	18.55	19.32	19.32
HF	140	1,281.90	1,281.90	1,281.90	1,256.64	624.58	598.28	555.72	589.65
PW	170	555.72	547.39	514.72	555.72	143.14	153.50	149.57	154.82

Source: Hannay and Zykov (2022)

LF = low-frequency cetaceans; MF = mid-frequency cetaceans; HF = high-frequency cetaceans; PW = phocid pinnipeds in water

J.4. Density Calculations

Marine mammal densities in the project area were estimated using the Marine Geospatial Ecology Laboratory (MGEL)/Duke University Habitat-based Marine Mammal Density Models for the U.S. Atlantic (Roberts et al. 2016a, 2016b, 2017, 2018, 2021a, 2021b). Densities in the MGEL/Duke models are provided as the number of animals per 100 square kilometers (animals/100 km^2) and given for each 10 × 10 km cell in the U.S. Atlantic for most species, with a cell size of 5 × 5 km for the North Atlantic right whale (NARW).

The UXO desktop study (Mills 2021) identified three areas as moderate UXO risk within the project area (Figure 1):

1. The shallow water segment of the OECC (OECC Part 1);
2. The deepwater segment of the OECC (OECC Part 2); and
3. The SWDA.

To calculate marine mammal densities for the 10 potential UXO detonations, whereby 2 UXOs would be assumed at the 12 m depth location, 3 UXOs at 20 m, 3 UXOs at 30 m, and 2 UXOs at 40 m, monthly density was calculated for each species at the shallow portion of the OECC (representing the 12 m depth location) and the combined deepwater segment of the OECC and SWDA (20 m – 62 m depths). As a conservative measure, the month with the highest density among the areas of interest for each species was carried forward to the exposure calculations.

Because the MGEL/Duke model for pilot whales considers long- and short-finned pilot whales together as the pilot whale guild, densities for these two species were scaled by their relative abundances using the following example equation:

$$d_{short-finned} = d_{both}\left(\frac{a_{short-finned}}{a_{short-finned}+a_{long-finned}}\right), \quad \text{(J-1)}$$

where d is density and a is abundance. Also note that the MGEL/Duke model for the pilot whale guild (Roberts et al. 2016a, 2016b, 2017) provides only an annual density, not monthly, so the densities for these two species are predicted annual densities.

Harbor and gray seals were similarly scaled by their relative abundances using the MGEL/Duke model for the seals guild (Roberts et al. 2016a, 2016b, 2018). The seals guild model is based primarily on harbor and gray seals and harp seals are considered uncommon in the area so lack sufficient data to provide a density estimate. As a conservative approach, the gray seal density (i.e., lesser of gray and harbor seal density) was used as a surrogate for harp seal density.

The monthly densities for each species used to estimate exposures above the Level A and Level B acoustic thresholds during potential UXO detonations for New England Wind are shown in Table J-5.

Table J-5. Maximum monthly density (animals/100 km^2) at the moderate UXO risk areas used to estimate exposures above the Level A and Level B acoustic thresholds during potential detonations for New England Wind.

Species		Maximum monthly density (animals/100 km^2)	
		Shallow OECC Segment	Deep OECC Segment and SWDA
LF	Fin whale[a]	0.000305	0.003792
	Minke whale	0.000478	0.002696
	Humpback whale	0.001510	0.004146
	North Atlantic right whale[a,]	0.000288	0.009282
	Sei whale[a]	0.000011	0.000497
MF	Atlantic white-sided dolphin	0.001318	0.066818
	Atlantic spotted dolphin	0.000005	0.001325
	Short-beaked common dolphin	0.000846	0.308527
	Bottlenose dolphin	0.370979	0.099623
	Risso's dolphin	0.000001	0.000487
	Long-finned pilot whale[b]	0.000009	0.006294
	Short-finned pilot whale[b]	0.000007	0.004642
	Sperm whale[a]	0.000003	0.000332
HF	Harbor porpoise	0.027993	0.165059
PPW	Gray seal[c]	0.321642	0.072733
	Harbor seal[c]	0.722646	0.163411
	Harp seal[c]	0.321642	0.072733

[a] Listed as Endangered under the Endangered Species Act.
[b] Long- and short-finned pilot whale densities are the annual pilot whale guild density scaled by their relative abundances.
[c] Gray and harbor seal densities are the seals guild density scaled by their relative abundances; gray seals are used as a surrogate for harp seals.

J.5. Exposure Calculations

To calculate potential marine mammal exposures, the area distances in Table J-5 were multiplied by the highest monthly species density in the deepwater OECC segment and the SWDA for the 20–45 m depths, and by the highest monthly species density in the shallow water OECC segment for the 12 m depth. The result of the areas multiplied by the densities were then multiplied by the number of UXOs estimated at each of the depths to calculate total estimated exposures. The UXO removal processes for New England Wind are expected to be similar as the Ocean Wind 1 project, with the same commitment for a single detonation removal per 24-hour period to reduce accumulated sound exposures and to limit behavioral response.

J.6. Estimated Level A Exposures

SEL-based PTS exposures for potential UXO detonations are listed in Table J-6 as Level A exposures, below. Level A exposures are unlikely during UXO detonation, but possible. Table J-6 presents unmitigated and mitigated Level A exposure estimates for comparison. To reduce potential exposures, the use of NMS (e.g., bubble curtain system or other system) to achieve broadband noise attenuation is planned to be used during UXO detonations. NMS-use is expected to achieve a broadband attenuation level of 10 dB (Bellman et al. 2020; Bellmann and Betke 2021) and will minimize the size of the ensonified zones, thereby reducing the number of potential marine mammal PTS exposures.

Table J-6. Estimated potential maximum Level A exposures of marine mammals resulting from the possible detonations of up to 10 UXOs assuming both no attenuation and 10 dB of attenuation.

Species		Estimated Level A Exposures (PTS SEL)	
		No Attenuation	10 dB Attenuation
LF	Fin whale[a]	7.16	1.31
	Minke whale	5.19	0.95
	Humpback whale	8.26	1.51
	North Atlantic right whale[a,b]	17.37	3.17
	Sei whale[a]	0.93	0.17
MF	Atlantic white-sided dolphin	3.56	0.27
	Atlantic spotted dolphin	0.07	0.01
	Short-beaked common dolphin	16.36	1.25
	Bottlenose dolphin	10.80	0.90
	Risso’s dolphin	0.03	0.00
	Long-finned pilot whale	0.33	0.03
	Short-finned pilot whale	0.25	0.02
	Sperm whale[a]	0.02	0.00
HF	Harbor porpoise[c]	1,120.62	165.32
PPW	Gray seal	74.86	8.91
	Harbor seal	168.18	20.01
	Harp seal	74.86	8.91

a Listed as Endangered under the Endangered Species Act.
b Level A exposures were estimated for this species, but due to mitigation measures (described in the New England Wind Letter of Authorization Request, Section 11), no Level A takes are expected.
c Potential Level A exposures for harbor porpoise with no attenuation were estimated using the distance to PK threshold (PTS = 16,098 m), which is larger than the distance to their PTS SEL threshold.

J.7. Estimated Level B Exposures

SEL-based TTS exposures for potential UXO detonations and are listed in Table J-7 as Level B exposures, below. The use of NMS and mitigation measures described in Section 11 of the New England Wind Letter of Authorization Request will reduce received sound levels and the size of the ensonified zones, thereby reducing the number of potential marine mammal TTS exposures.

Table J-7. Estimated potential maximum Level B exposures of marine mammals resulting from the possible detonations of up to 10 UXOs assuming both no attenuation and 10 dB of attenuation.

Species		Estimated Level B Exposures (TTS SEL)	
		No Attenuation	10 dB Attenuation
LF	Fin whale[a]	35.73	13.34
	Minke whale	25.95	9.68
	Humpback whale	41.54	15.48
	North Atlantic right whale[a]	86.49	32.30
	Sei whale[a]	4.62	1.73
MF	Atlantic white-sided dolphin	57.49	10.23
	Atlantic spotted dolphin	1.14	0.20
	Short-beaked common dolphin	264.31	47.01
	Bottlenose dolphin	165.33	30.33
	Risso's dolphin	0.42	0.07
	Long-finned pilot whale	5.39	0.96
	Short-finned pilot whale	3.98	0.71
	Sperm whale[a]	0.28	0.05
HF	Harbor porpoise[b]	4,209.95	801.06
PPW	Gray seal	670.08	180.73
	Harbor seal	1,505.48	406.05
	Harp seal	670.08	180.73

[a] Listed as Endangered under the Endangered Species Act.

[b] Potential Level B exposures for harbor porpoise with no attenuation were estimated using the distance to PK threshold (TTS = 31,202 m), which is larger than the distance to their TTS SEL threshold.

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Appendix K. Vibratory Pile Setting Exposure Analysis

Memo

DATE: 13 July 2022

Version: 4.0

FROM: Susan Dufault, Karlee Zammit, Madison Clapsaddle, and David Zeddies (JASCO Applied Sciences [USA] Inc.

TO: Park City Wind, LLC

Subject: Marine Mammal Exposure Estimates for Vibratory Setting of Piles During New England Wind Construction

During construction of the New England Wind project, it may be necessary to start pile installation using a vibratory hammer rather than using an impact hammer, a technique known as vibratory setting of piles. The vibratory method is particularly useful when soft seabed sediments are not sufficiently stiff to support the weight of the pile during the initial installation, increasing the risk of ‘pile run’ where a pile sinks rapidly through seabed sediments. In foundation positions where sediment information indicates risk of pile run, vibratory pile driving may be used to support the pile, thus reducing the safety risk of this event. The vibratory hammer installation method can continue until the pile is inserted to a depth that is sufficient to fully support the structure, and then the impact hammer can be positioned and operated to complete the pile installation. The average expected duration of vibratory setting is approximately 30 minutes per pile for the New England Wind project.

New England Wind conducted a seabed drivability analysis to estimate the number of foundation positions that could potentially require vibratory setting of piles. The analysis suggested that up to 50% of foundations (~66 foundations) could require vibratory setting. Adding 20% conservatism to this estimate (20% of 66 is ~13 additional foundations) results in approximately 79 foundations that may require vibratory setting. This information was used to estimate the number of days of vibratory setting shown in the pile installation schedules provided in this memo.

K.1. Acoustic Ranges

The Proponent is not aware of publicly available acoustic measurements of vibratory pile driving of large (>2 m) monopiles. Vibratory driving of smaller 72-inch steel pipe piles has an apparent source level of SPL ~167-180 dB re 1 μPa at 10 m (Molnar et al. 2020). Recognizing that the maximum pile size of this Project is larger than 72 inches, it is assumed that these source levels may not be indicative of what would be measured during construction of the Project, so a method to estimate expected levels by extrapolation from smaller piles was used. Extrapolation of piling sound levels for larger piles has previously been conducted in Europe for impact pile driving (Bellmann et al. 2020). A similar approach has been used here, which is consistent with extrapolation work undertaken on other Avangrid Renewables projects in non-US jurisdictions.

Data for smaller piles are compiled in the GARFO Acoustics Tool (https://s3.amazonaws.com/media.fisheries.noaa.gov/2020-09/GARFO-Sect7-PileDriving-AcousticsTool-09142020.xlsx?.Egxagq5Dh4dpIwJQsmN1gV0nggnk5qX). Received SEL levels at 10 m for round steel pile driven with vibratory hammers was plotted as a function of pile diameter and fitted with a power function (method previously accepted by European authorities for impact piling extrapolation for Avangrid Renewables) (Figure 1). As seen in Figure 1, the power function represents the SEL trend as a function of pile diameter with an R^2 value of 0.6465 for piles 12 inches to 72 inches in diameter. Extrapolating to 13 m piles, with a diameter of 512 inches, results in a received level at 10 m of SEL ~198 dB re 1 µPa2·s (~188 dB re 1 µPa2·s assuming a noise attenuation system [NAS] and 10 dB of attenuation).

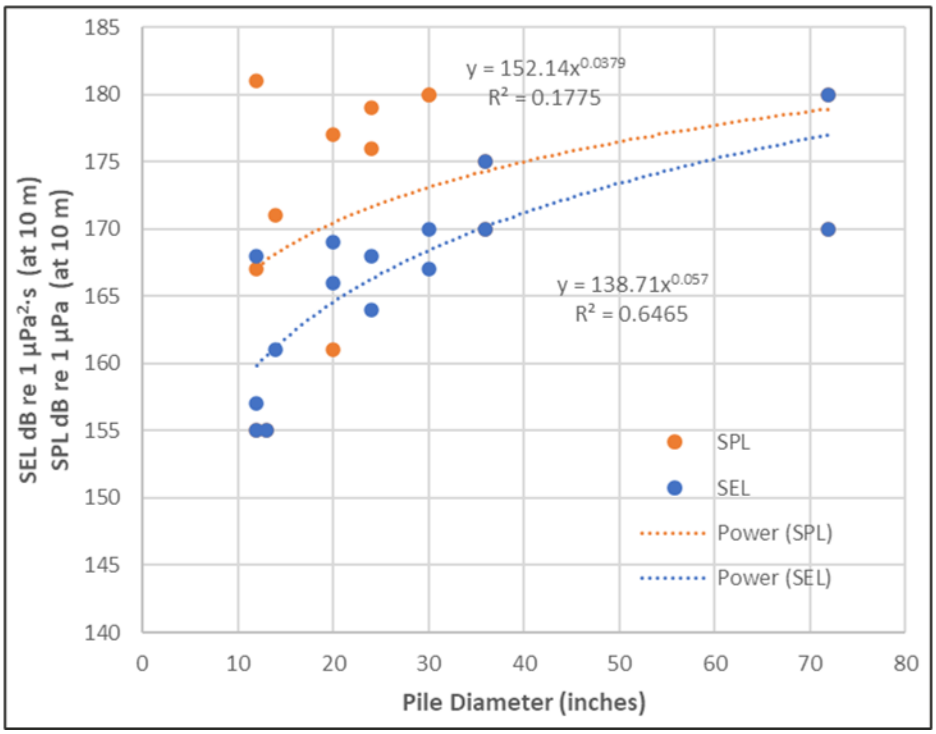

Figure 1. SEL (blue) and SPL (orange) received levels as a function of pile diameter, in inches, from the GARFO Acoustics Tool.

Assuming (1) a received SEL ~188 dB re 1 µPa2·s at 10 m for 13 m monopiles using NAS, (2) sound propagation by the practical spreading loss model (15 Log(range)), and (3) an average vibratory setting duration of 30 minutes per pile (1 hour per day assuming 2 monopiles), the PTS ranges calculated using the NMFS online User Spreadsheet Tool (NMFS 2020, https://view.officeapps.live.com/op/view.aspx?src=https%3A%2F%2Fmedia.fisheries.noaa.gov%2F2021-02%2F2020_BLANK_USER_SPREADSHEET_508_DEC.xlsx&wdOrigin=BROWSELINK) are as follows:

- LF cetaceans = 430.9 m
- MF cetaceans = 38.2 m
- HF cetaceans = 637.1 m

- Phocid pinnipeds = 261.9 m

Due to the small size of the PTS ranges and the mitigation that will be applied during construction, no Level A exposures are expected, nor have they been calculated for this activity.

The threshold criterion for Level B harassment for vibratory hammering, a non-impulsive sound, is 120 dB re 1µPa root mean square (rms) unweighted sound pressure level (SPL). The power function fit described above for the received SPL at 10 m is poor, so an alternative approach is needed. Noting that animals are not expected to experience a behavioral response at distances greater than 50 km (Dunlop et al. 2017a; Dunlop et al. 2017b), the source level necessary to produce a received level of 120 dB at 50 km was found. Assuming practical spreading loss (15 Log(range)), a source level of 190.5 dB will result in received levels of 120 dB at 50 km. Because vibratory driving of smaller 72-inch steel pipe piles has an apparent source level of SPL ~167-180 dB re 1 µPa at 10 m (Molnar et al. 2020), it is assumed that the sound levels for a 13 m pile could exceed the behavioral threshold to 50 km. All animals within a 50-km radius around a given foundation location would be exposed above the 120 dB SPL threshold for any given day on which vibratory setting was used for pile installation. Therefore, the acoustic range to the Level B threshold is 50 km, and the daily impact area is a circle with radius of 50 km (7,854 km^2).

K.2. Density Calculations

Monthly marine mammal densities in the potential impact area used the Marine Geospatial Ecology Laboratory (MGEL)/Duke University Habitat-based Marine Mammal Density Models for the U.S. Atlantic (Roberts et al. 2016a, 2016b, 2017, 2018, 2021a, 2021b). Densities in the MGEL/Duke models are provided as the number of animals per 100 square kilometers (animals/100 km^2) and given for each 10 × 10 km cell in the U.S. Atlantic for most species, with a cell size of 5 × 5 km for the North Atlantic right whale (NARW).

The monthly density of each species within the impact area was calculated as the average of all MGEL/Duke density cells overlapping partially or completely with a 50-km buffer around the Southern Wind Development Area (SWDA) (cells entirely on land were not included, but cells that overlap only partially with land were included).

Because the MGEL/Duke model for pilot whales considers long- and short-finned pilot whales together as the pilot whale guild, densities for these two species were scaled by their relative abundances using the following example equation:

$$d_{short-finned} = d_{both}\left(\frac{a_{short-finned}}{a_{short-finned}+a_{long-finned}}\right), \tag{K-1}$$

where *d* is density and *a* is abundance. Also note that the MGEL/Duke model for the pilot whale guild (Roberts et al. 2016a, 2016b, 2017) provides only an annual density, not monthly, so the densities for these two species are predicted annual densities.

Harbor and gray seals were similarly scaled by their relative abundances using the MGEL/Duke model for the seals guild (Roberts et al. 2016a, 2016b, 2018). The seals guild model is based primarily on harbor and gray seals and harp seals are considered uncommon in the area so lack sufficient data to provide a density estimate. As a conservative approach, the gray seal density (i.e., lesser of gray and harbor seal density) was used as a surrogate for harp seal density.

The monthly densities for each species used to estimate exposures above Level B acoustic thresholds during vibratory setting of piles for New England Wind are shown in Table K-1.

Table K-1. Mean monthly marine mammal density estimates for all modeled species in a 50-km buffer around the SWDA, used to calculate exposures above the 120 dB behavioral threshold for vibratory hammering sounds.

Species	Monthly density (animals/100 km^2)												Annual mean	May to Dec mean
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec		
Fin whale[a]	0.173	0.169	0.193	0.331	0.327	0.334	0.348	0.316	0.276	0.183	0.148	0.151	0.246	0.260
Minke whale	0.055	0.068	0.070	0.166	0.268	0.240	0.095	0.062	0.064	0.080	0.029	0.040	0.103	0.110
Humpback whale	0.035	0.023	0.045	0.153	0.179	0.183	0.108	0.066	0.190	0.148	0.083	0.055	0.106	0.126
North Atlantic right whale[a]	0.517	0.607	0.640	0.694	0.276	0.020	0.003	0.002	0.003	0.008	0.045	0.247	0.255	0.076
Sei whale[a]	0.002	0.002	0.001	0.041	0.035	0.021	0.008	0.004	0.007	0.002	0.002	0.002	0.011	0.010
Atlantic white-sided dolphin	2.985	1.726	1.800	3.748	6.753	6.195	3.828	2.010	2.356	3.322	3.657	4.271	3.554	4.049
Atlantic spotted dolphin	0.002	0.001	0.003	0.013	0.027	0.050	0.092	0.127	0.127	0.179	0.066	0.008	0.058	0.084
Short-beaked common dolphin	15.796	4.541	2.212	4.236	6.703	8.475	7.293	10.472	14.493	17.788	13.446	20.900	10.530	12.446
Bottlenose dolphin, offshore	0.641	0.175	0.073	1.215	1.417	3.748	7.478	6.064	6.925	5.759	2.911	1.395	3.150	4.462
Risso's dolphin	0.044	0.025	0.013	0.016	0.036	0.052	0.116	0.213	0.136	0.052	0.051	0.086	0.070	0.093
Long-finned pilot whale[b]	0.434	0.434	0.434	0.434	0.434	0.434	0.434	0.434	0.434	0.434	0.434	0.434	0.434	0.434
Short-finned pilot whale[b]	0.320	0.320	0.320	0.320	0.320	0.320	0.320	0.320	0.320	0.320	0.320	0.320	0.320	0.320
Sperm whale[a]	0.005	0.006	0.005	0.008	0.012	0.014	0.032	0.030	0.012	0.011	0.009	0.004	0.012	0.015
Harbor porpoise	3.609	5.809	9.848	7.146	3.811	1.136	0.836	0.853	0.625	0.544	1.913	2.099	3.186	1.477
Gray seal[c]	3.446	2.735	2.749	5.640	5.551	1.733	0.386	0.199	0.228	0.474	1.138	3.669	2.329	1.672
Harbor seal[c]	7.743	6.145	6.176	12.672	12.471	3.893	0.866	0.447	0.513	1.065	2.556	8.244	5.233	3.757
Harp seal[c]	3.446	2.735	2.749	5.640	5.551	1.733	0.386	0.199	0.228	0.474	1.138	3.669	2.329	1.672

[a] Listed as Endangered under the ESA.

[b] Long- and short-finned pilot whale densities are the annual pilot whale guild density scaled by their relative abundances.

[c] Gray and harbor seal densities are the seals guild density scaled by their relative abundances; gray seals are used as a surrogate for harp seals.

K.3. Estimated Level B Exposures

The following were used to estimate potential Level B exposures for vibratory setting of piles:

- All animals within a 50-km radius around a given foundation location would be exposed above the 120 dB SPL threshold for any given day on which vibratory setting was used for pile installation.
- The daily impact area is a circle with radius of 50 km (7,854 km^2).
- Because of the long-expected ranges to the 120 dB behavioral threshold for continuous sound from vibratory hammering, it was assumed that all animals within a 50-km radius (7,854 km^2) around a given foundation location would be exposed above the 120 dB SPL threshold for any given day on which vibratory setting of piles was used.
- Each monthly density value was multiplied by the 7,854 km^2 impact area to estimate the number of exposures that could occur on a given day during each month in the May through December proposed pile installation period.
- Soil sediment data gathered during geotechnical coring campaigns in the SWDA were analyzed to estimate the number of project foundation positions that might be at risk for pile run. Approximately 50% of positions (~66 foundations) were determined to have the sediment conditions that might indicate a risk of pile run. A 20% contingency on this percentage was added to account for additional sediment data analysis or installation contractor-provided information (20% of 66 foundations, or 13 additional foundations). This brought the total number of positions to approximately 79.
- The daily Level B exposure estimates based on 79 foundation positions were multiplied by the number of days with vibratory setting of piles each month from the two construction schedules. The monthly exposures were then summed to get yearly exposure estimates as well as species-specific exposure estimates for the complete project buildout.

Daily exposure estimates above the 120 dB threshold criterion calculated using these assumptions and methods are shown in Table K-2 for each day of vibratory hammering depending on the month in which it occurs.

Table K-2. Density-based estimates of the number of marine mammals of each species that could be exposed to sound above the 120 dB behavioral threshold criterion per day of vibratory hammering based on their average monthly density within a 50 km buffer of the SWDA and assuming a range to threshold of 50 km.

Species	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Fin whale	25.64	26.24	27.33	24.79	21.68	14.41	11.66	11.83
Minke whale	21.05	18.86	7.42	4.88	5.05	6.26	2.26	3.17
Humpback whale	14.06	14.41	8.47	5.20	14.94	11.60	6.49	4.29
North Atlantic right whale	21.64	1.59	0.26	0.18	0.23	0.60	3.55	19.41
Sei whale	2.72	1.63	0.59	0.30	0.54	0.13	0.17	0.17
Atlantic white-sided dolphin	530.39	486.55	300.64	157.90	185.06	260.91	287.23	335.47
Atlantic spotted dolphin	2.09	3.90	7.21	9.95	10.00	14.03	5.16	0.66
Short-beaked common dolphin	526.47	665.63	572.78	822.43	1138.26	1397.04	1056.03	1641.49
Bottlenose dolphin, offshore	111.26	294.39	587.33	476.27	543.86	452.33	228.60	109.54
Risso's dolphin	2.81	4.07	9.10	16.73	10.72	4.12	4.03	6.75
Long-finned pilot whale	34.11	34.11	34.11	34.11	34.11	34.11	34.11	34.11
Short-finned pilot whale	25.16	25.16	25.16	25.16	25.16	25.16	25.16	25.16
Sperm whale	0.91	1.10	2.49	2.35	0.96	0.86	0.72	0.31
Harbor porpoise	299.33	89.23	65.69	67.01	49.05	42.75	150.25	164.88
Gray seal	435.96	136.09	30.29	15.64	17.93	37.23	89.34	288.18
Harbor seal	979.49	305.75	68.05	35.14	40.28	83.64	200.72	647.47
Harp seal	435.96	136.09	30.29	15.64	17.93	37.23	89.34	288.18

The number of pile driving days during which vibratory setting could be used per month and per schedule as well as the total days per year and for the full project buildout are shown in Table K-3 and Table K-4. These were multiplied by the monthly exposure estimates to obtain exposures by year and for the full buildout of New England Wind.

Table K-3. Schedule A: Number of pile driving days during which vibratory setting may be required, used in exposure estimation.

Month	Schedule A		
	Year 1	Year 2	2-Year total
May	2	1	3
Jun	4	2	6
Jul	5	3	8
Aug	9	4	13
Sep	7	4	11
Oct	2	3	5
Nov	2	2	4
Dec	0	0	0
Total	31	19	50

Table K-4. Schedule B: Number of pile driving days during which vibratory setting may be required, used in exposure estimation.

Month	Schedule B			
	Year 1	Year 2	Year 3	3-Year total
May	2	1	1	4
Jun	4	4	1	9
Jul	7	8	3	18
Aug	7	8	3	18
Sep	4	7	3	14
Oct	3	3	1	7
Nov	1	1	1	3
Dec	0	0	0	0
Total	28	32	13	73

Table K-5 and Table K-6 show the number of animals that could be exposed above the Level B threshold during a single construction year and for the full buildout of the project using Construction Schedule A and Schedule B, respectively.

Table K-5. Construction Schedule A: Number of Level B exposures calculated for vibratory setting of piles, assuming vibratory hammering is required for 79 foundations and using a 50-km impact radius.

Species	Level B harassment exposure estimate		
	Year 1	Year 2	2-Year total
Fin whale	719.90	412.53	1,132.44
Minke whale	250.97	144.07	395.04
Humpback whale	315.64	196.61	512.25
North Atlantic right whale	62.48	36.14	98.62
Sei whale	22.00	11.85	33.85
Atlantic white-sided dolphin	8,322.95	5,134.42	13,457.37
Atlantic spotted dolphin	253.69	163.69	417.37
Short-beaked common dolphin	26,855.21	17,722.03	44,577.24
Bottlenose dolphin, offshore	13,792.05	8,356.74	22,148.79
Risso's dolphin	309.34	168.48	477.82
Long-finned pilot whale	1,057.36	648.06	1,705.43
Short-finned pilot whale	779.89	477.99	1,257.88
Sperm whale	49.68	27.82	77.51
Harbor porpoise	2,616.51	1,567.87	4,184.38
Gray seal	2,087.12	1,223.64	3,310.76
Harbor seal	4,689.21	2,749.21	7,438.42
Harp seal	2,087.12	1,223.64	3,310.76

Table K-6. Construction Schedule B: Number of Level B exposures calculated for vibratory setting of piles, assuming vibratory hammering is required for 79 foundations and using a 50-km impact radius.

Species	Level B harassment exposure estimate			
	Year 1	Year 2	Year 3	3-Year total
Fin whale	662.70	754.21	299.36	1,716.27
Minke whale	244.92	251.31	100.49	596.72
Humpback whale	282.46	326.89	132.38	741.73
North Atlantic right whale	58.98	38.47	29.39	126.85
Sei whale	20.93	20.72	8.95	50.60
Atlantic white-sided dolphin	8,026.92	8,510.24	3,495.86	20,033.03
Atlantic spotted dolphin	227.09	272.15	106.63	605.86
Short-beaked common dolphin	23,282.16	27,565.68	11,245.59	62,093.43
Bottlenose dolphin, offshore	12,606.33	15,190.23	5,908.96	33,705.52
Risso's dolphin	262.00	317.18	124.69	703.87
Long-finned pilot whale	955.04	1,091.47	443.41	2,489.92
Short-finned pilot whale	704.41	805.04	327.05	1,836.50
Sperm whale	47.21	54.02	20.97	122.20
Harbor porpoise	2,359.21	2,339.74	1,126.83	5,825.78
Gray seal	2,010.52	1,674.27	890.19	4,574.98
Harbor seal	4,517.11	3,761.66	2,000.03	10,278.79
Harp seal	2,010.52	1,674.27	890.19	4,574.98

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Appendix L. Drilling Exposure Analysis

Memo

DATE: 13 July 2022

Version: 4.0

FROM: Susan Dufault, Karlee Zammit, Madison Clapsaddle, and David Zeddies (JASCO Applied Sciences [USA] Inc.

TO: Park City Wind LLC

Subject: Marine Mammal Exposure Estimates for Drilling Activities During Pile Installation for New England Wind

There may be instances during construction of New England Wind where large sub-surface boulders or hard sediment layers are encountered, requiring drilling to pass through these barriers. New England Wind conducted a seabed drivability analysis to estimate the number of foundation positions that could potentially require drilling during pile installation. The analysis suggested that up to 30% of foundations (~40 foundations) could require drilling. Adding 20% conservatism to this estimate (20% of 40 is ~8 foundations) results in approximately 48 foundations that may requiring drilling. This information was used to estimate the number of days of drilling shown in the pile installation schedules provided in this memo.

L.1. Acoustic Ranges

The Proponent is not aware of acoustic measurements of very large rotational drills specifically for this purpose, but comprehensive measurements of large seabed drills are available from projects in the Alaskan Chukchi and Beaufort Seas. In particular, measurements were made during use of mudline cellar drilling with a 6 m diameter bit (Austin et al. 2018). The mudline cellar is a circular area centered on an oil or gas well on the seabed for the purpose of placing well heads and blow-out preventers below the seafloor elevation. Mudline cellars are important in shallow arctic waters, where deep ice keels can destroy equipment that sits above the seafloor grade. Austin et al. (2018) measured SPL of ~140 dB re µPa at 1000 m and estimated the broadband source level for this device as 191 dB re µPa^{2}m^2 at 1 m. The source level that Austin et al. (2018) estimated did not assume practical spreading loss, so this source level is not used. When assuming practical spreading loss, the source level back-propagated to 1 m is 185 dB re µPa^{2}m^2.

The mudline cellar drilling in the Chukchi Sea was measured at a site with water depth 46 m, which is similar to depths at the deeper sections of the New England Wind project area. Seabed sediment geoacoustic properties differ: the Chukchi Sea drilling site had softer surface sediments with a 14.5 m thick top layer of constant sound speed 1630 m/s and density 1.45 g/cm^3, overlying more consolidated sediments with sound speed 2384 m/s and density 2.32 g/cm^3. In comparison, the New England Wind sediments are believed to consist of a top layer of about 15 m thickness with sound speed gradient 1650–

1830 m/s and density 1.87 g/cm^3, overlying more consolidated sands with a sound speed gradient from 1830–2140 m/s through the next 100 m and having density 1.87-2.04 g/cm^3. Overall, the Chukchi Sea surface sediments have a slightly lower sound speed and lower density than the New England Wind site, but the reverse is true for the deeper sediments. Overall, the acoustic reflectivity at lower frequencies is expected to be similar between these sites. The ocean sound speed profiles at both sites are slightly downward refracting in summer, when the activities were measured in the Chukchi and when most pile installations are planned to occur for New England Wind.

A separate modeling study that included mudline cellar drilling was performed to predict noise footprints of that operation in the Chukchi Sea (Quijano et al. 2019). This modeling study found the 120 dB re µPa SPL threshold occurred at a distance of 16 km, which included noise from several vessels near the drillsite on dynamic positioning. We assume that pile installation drilling produces similar sound levels as mudline cellar drilling, and, as a conservative measure, we will use the SPL of 140 dB re µPa at 1000 m (as measured by Austin et al. 2018) along with practical spreading loss to obtain an estimate of 21.5 km to the 120 dB re µPa threshold. If assuming the back-propagated SPL of 185 dB re µPa at 1 m described above, the range to the 120 dB re µPa threshold is the same.

Assuming (1) a sound source level of 185 dB re 1 µPa2·s at 1 m for drilling (2) sound propagation by the practical spreading loss model (15 Log(range)), and (3) 12 hours of drilling per pile (24 hours per day assuming 2 monopiles), the PTS ranges calculated using the NMFS online User Spreadsheet Tool (NMFS 2020, https://view.officeapps.live.com/op/view.aspx?src=https%3A%2F%2Fmedia.fisheries.noaa.gov%2F2021-02%2F2020_BLANK_USER_SPREADSHEET_508_DEC.xlsx&wdOrigin=BROWSELINK) are as follows:

- LF cetaceans = 226.2 m
- MF cetaceans = 20.1 m
- HF cetaceans = 334.5 m
- Phocid pinnipeds = 137.5 m

Due to the small size of the PTS ranges and the mitigation that will be applied during construction, no Level A exposures are expected, nor have they been calculated for this activity.

The threshold criterion for Level B harassment for drilling, a non-impulsive sound, is 120 dB re 1µPa root mean square (rms) unweighted sound pressure level (SPL). Assuming practical spreading loss (15 Log(range)), a measured SPL of ~140 dB re µPa at 1000 m (Austin et al. 2018) will result in received levels of 120 at 21.5 km. All animals within a 21.5-km radius around a given foundation location would be exposed above the 120 dB SPL threshold for any given day during which drilling is used for pile installation. Therefore, the acoustic range to the Level B threshold is 50 km, and the daily impact area is a circle with radius of 21.5 km (1,452 km^2).

L.2. Density Calculations

Monthly marine mammal densities in the potential impact area used the Marine Geospatial Ecology Laboratory (MGEL)/Duke University Habitat-based Marine Mammal Density Models for the U.S. Atlantic (Roberts et al. 2016a, 2016b, 2017, 2018, 2021a, 2021b). Densities in the MGEL/Duke models are provided as the number of animals per 100 square kilometers (animals/100 km^2) and given for each 10 × 10 km cell in the U.S. Atlantic for most species, with a cell size of 5 × 5 km for the North Atlantic right whale (NARW).

The monthly density of each species within the impact area was calculated as the average of all MGEL/Duke density cells overlapping partially or completely with a 21.5-km buffer around the Southern Wind Development Area (SWDA) (cells entirely on land were not included, but cells that overlap only partially with land were included).

Because the MGEL/Duke model for pilot whales considers long- and short-finned pilot whales together as the pilot whale guild, densities for these two species were scaled by their relative abundances using the following example equation:

$$d_{short-finned} = d_{both}\left(\frac{a_{short-finned}}{a_{short-finned}+a_{long-finned}}\right), \quad \text{(L-1)}$$

where *d* is density and *a* is abundance. Also note that the MGEL/Duke model for the pilot whale guild (Roberts et al. 2016a, 2016b, 2017) provides only an annual density, not monthly, so the densities for these two species are predicted annual densities.

Harbor and gray seals were similarly scaled by their relative abundances using the MGEL/Duke model for the seals guild (Roberts et al. 2016a, 2016b, 2018). The seals guild model is based primarily on harbor and gray seals and harp seals are considered uncommon in the area so lack sufficient data to provide a density estimate. As a conservative approach, the gray seal density (i.e., lesser of gray and harbor seal density) was used as a surrogate for harp seal density.

The monthly densities for each species used to estimate exposures above Level B acoustic thresholds for drilling during pile installation for New England Wind are shown in Table L-1.

Table L-1. Mean monthly marine mammal density estimates for all modeled species in a 21.5-km buffer around the SWDA, used to calculate exposures above the 120 dB SPL behavioral threshold for drilling sounds.

Species	Monthly density (animals/100 km^2)												Annual mean	May to Dec mean
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec		
Fin whale[a]	0.187	0.169	0.169	0.310	0.325	0.322	0.351	0.325	0.263	0.157	0.140	0.145	0.239	0.254
Minke whale	0.063	0.079	0.081	0.172	0.258	0.236	0.085	0.059	0.061	0.073	0.033	0.046	0.104	0.106
Humpback whale	0.030	0.018	0.031	0.177	0.157	0.153	0.132	0.076	0.255	0.174	0.062	0.032	0.108	0.130
North Atlantic right whale[a]	0.618	0.725	0.755	0.827	0.329	0.021	0.004	0.003	0.003	0.009	0.048	0.262	0.300	0.085
Sei whale[a]	0.002	0.002	0.001	0.043	0.040	0.021	0.006	0.003	0.007	0.001	0.002	0.002	0.011	0.010
Atlantic white-sided dolphin	3.422	1.941	2.083	4.272	7.876	7.453	4.888	2.677	2.895	3.786	4.011	5.182	4.207	4.846
Atlantic spotted dolphin	0.002	0.002	0.003	0.013	0.024	0.045	0.081	0.140	0.136	0.131	0.068	0.009	0.054	0.079
Short-beaked common dolphin	13.980	2.789	1.142	2.777	5.146	5.524	5.748	10.010	16.618	18.872	13.322	23.055	9.915	12.287
Bottlenose dolphin, offshore	0.576	0.058	0.019	0.551	0.598	0.869	1.812	1.605	2.860	3.145	1.485	0.812	1.199	1.648
Risso's dolphin	0.019	0.009	0.004	0.004	0.013	0.015	0.039	0.076	0.056	0.020	0.025	0.044	0.027	0.036
Long-finned pilot whale[b]	0.502	0.502	0.502	0.502	0.502	0.502	0.502	0.502	0.502	0.502	0.502	0.502	0.502	0.502
Short-finned pilot whale[b]	0.370	0.370	0.370	0.370	0.370	0.370	0.370	0.370	0.370	0.370	0.370	0.370	0.370	0.370
Sperm whale[a]	0.002	0.003	0.002	0.003	0.004	0.009	0.034	0.034	0.011	0.010	0.008	0.002	0.010	0.014
Harbor porpoise	4.624	7.291	13.845	9.142	4.362	1.022	0.725	0.670	0.550	0.523	1.304	2.214	3.856	1.421
Gray seal[c]	1.180	2.327	2.411	2.834	3.529	0.452	0.095	0.055	0.088	0.130	0.091	0.511	1.142	0.619
Harbor seal[c]	2.650	5.228	5.417	6.368	7.928	1.015	0.214	0.124	0.198	0.293	0.204	1.149	2.566	1.391
Harp seal[c]	1.180	2.327	2.411	2.834	3.529	0.452	0.095	0.055	0.088	0.130	0.091	0.511	1.142	0.619

[a] Listed as Endangered under the ESA.
[b] Long- and short-finned pilot whale densities are the annual pilot whale guild density scaled by their relative abundances.
[c] Gray and harbor seal densities are the seals guild density scaled by their relative abundances; gray seals are used as a surrogate for harp seals.

L.3. Estimated Level B Exposures

The following were used to estimate potential Level B exposures for drilling that may be required during pile installation:

- All animals within a 21.5-km radius around a given foundation location were assumed to be exposed above the 120 dB SPL threshold for any given day on which drilling was used during pile installation.
- The daily impact area is a circle with radius of 21.5 km (1,452 km^2).
- Because of the long-expected ranges to the 120 dB behavioral threshold for non-impulsive sound from drilling, it was assumed that all animals within a 21.5-km radius (1,452 km^2) around a given foundation location would be exposed above the 120 dB SPL threshold for any given day on which drilling was used during pile installation.
- Each monthly density value was multiplied by the 1,452 km^2 impact area to estimate the number of exposures that could occur on a given day during each month in the May through December proposed pile driving period.
- Soil sediment data gathered during geotechnical coring campaigns in the SWDA were analyzed to estimate the number of project foundation positions that might be at risk for encountering boulders or hard sediments causing pile refusal. Approximately 30% of positions (~40 foundations) were determined to have the sediment conditions that might indicate a risk of boulder encounter or pile refusal. A 20% contingency on this percentage was added to account for additional sediment data analysis or installation contractor-provided information (20% of 40 foundations, or 8 additional foundations). This brought the total number of positions to approximately 48.
- The daily Level B exposure estimates based on 48 foundation positions were multiplied by the number of piling days each month from the two construction schedules where drilling might be used during installation. The monthly exposures were then summed to get yearly exposure estimates as well as species-specific exposure estimates for the complete project buildout.

Daily exposure estimates above the 120 dB threshold criterion calculated based on these methods are shown in Table L-2 for each day of drilling depending on the month in which it occurs.

Table L-2. Density-based estimates of the number of marine mammals of each species that could be exposed to sound above the 120 dB behavioral threshold criterion per day of drilling based on their average monthly density within a 21.5 km buffer of the SWDA and assuming a range to threshold of 21.5 km.

Species	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Fin whale	4.72	4.67	5.10	4.72	3.81	2.29	2.04	2.11
Minke whale	3.74	3.43	1.23	0.86	0.89	1.06	0.47	0.67
Humpback whale	2.28	2.22	1.92	1.10	3.70	2.53	0.90	0.47
North Atlantic right whale	4.78	0.31	0.05	0.04	0.05	0.13	0.69	3.80
Sei whale	0.58	0.31	0.08	0.05	0.09	0.02	0.03	0.02
Atlantic white-sided dolphin	114.37	108.21	70.97	38.88	42.03	54.97	58.25	75.25
Atlantic spotted dolphin	0.35	0.66	1.17	2.03	1.97	1.90	0.99	0.13
Short-beaked common dolphin	74.72	80.21	83.46	145.35	241.30	274.02	193.43	334.76
Bottlenose dolphin, offshore	8.69	12.61	26.32	23.31	41.53	45.66	21.56	11.79
Risso's dolphin	0.19	0.22	0.57	1.11	0.82	0.28	0.37	0.64
Long-finned pilot whale	7.29	7.29	7.29	7.29	7.29	7.29	7.29	7.29
Short-finned pilot whale	5.37	5.37	5.37	5.37	5.37	5.37	5.37	5.37
Sperm whale	0.06	0.13	0.49	0.49	0.15	0.15	0.12	0.03
Harbor porpoise	63.34	14.85	10.52	9.72	7.99	7.59	18.93	32.15
Gray seal	51.24	6.56	1.38	0.80	1.28	1.89	1.32	7.42
Harbor seal	115.11	14.74	3.11	1.80	2.88	4.25	2.97	16.68
Harp seal	51.24	6.56	1.38	0.80	1.28	1.89	1.32	7.42

The number of days per month and year during which drilling may be required during pile installation are shown in Table L-3 and Table L-4, respectively.

Table L-3. Schedule A: Number of pile driving days during which drilling may be required, used in exposure estimation.

Month	Schedule A		
	Year 1	Year 2	2-Year total
May	2	1	3
Jun	4	2	6
Jul	7	2	9
Aug	7	4	11
Sep	8	2	10
Oct	3	2	5
Nov	2	2	4
Dec	0	0	0
Total	33	15	48

Table L-4. Schedule B: Number of pile driving days during which drilling may be required, used in exposure estimation.

Month	Schedule B			
	Year 1	Year 2	Year 3	3-Year total
May	2	1	1	4
Jun	4	4	2	10
Jul	3	4	2	9
Aug	4	4	1	9
Sep	4	4	1	9
Oct	2	1	1	4
Nov	1	1	1	3
Dec	0	0	0	0
Total	20	19	9	48

Table L-5 and Table L-6 show the number of animals that could be exposed above the Level B threshold during a single construction year and for the full buildout of the project using Construction Schedule A and Schedule B, respectively, and assuming drilling is required during pile driving for 48 foundations.

Table L-5. Construction Schedule A: Number of Level B exposures calculated for drilling during pile installation, using a 21.5-km impact radius.

Species		Year 1	Year 2	All Years Combined
LF	Fin whale[a]	138.31	59.42	197.73
	Minke whale	47.08	21.35	68.43
	Humpback whale	73.61	29.24	102.86
	North Atlantic right whale[a]	13.55	7.38	20.93
	Sei whale[a]	4.15	1.82	5.97
MF	Atlantic white-sided dolphin	2,048.15	938.73	2,986.88
	Atlantic spotted dolphin	49.17	21.84	71.01
	Short-beaked common dolphin	5,211.25	2,400.95	7,612.20
	Bottlenose dolphin, offshore	927.56	397.29	1,324.85
	Risso's dolphin	21.18	9.16	30.33
	Long-finned pilot whale	240.45	109.29	349.74
	Short-finned pilot whale	177.35	80.61	257.96
	Sperm whale[a]	9.39	4.09	13.49
HF	Harbor porpoise	452.36	222.00	674.36
PPW	Gray seal	162.58	79.32	241.90
	Harbor seal	365.27	178.21	543.48
	Harp seal	162.58	79.32	241.90

[a] Listed as Endangered under the Endangered Species Act.

Table L-6. Construction Schedule B: Number of Level B exposures calculated for drilling during pile installation, using a 21.5-km impact radius.

Species		Year 1	Year 2	Year 3	All Years Combined
LF	Fin whale[a]	84.17	82.27	37.12	203.56
	Minke whale	34.49	30.92	16.35	81.75
	Humpback whale	44.39	41.49	18.79	104.67
	North Atlantic right whale[a]	12.22	7.37	6.40	25.99
	Sei whale[a]	3.26	2.75	1.55	7.56
MF	Atlantic white-sided dolphin	1,366.30	1,267.93	666.85	3,301.08
	Atlantic spotted dolphin	27.63	26.56	10.90	65.08
	Short-beaked common dolphin	3,008.71	2,743.43	1,256.15	7,008.30
	Bottlenose dolphin, offshore	519.02	490.99	218.61	1,228.61
	Risso's dolphin	11.62	11.72	4.35	27.70
	Long-finned pilot whale	145.73	138.44	65.58	349.74
	Short-finned pilot whale	107.48	102.11	48.37	257.96
	Sperm whale[a]	5.09	5.37	2.20	12.66
HF	Harbor porpoise	322.60	262.20	158.32	743.11
PPW	Gray seal	146.30	94.56	72.42	313.27
	Harbor seal	328.70	212.44	162.70	703.84
	Harp seal	146.30	94.56	72.42	313.27

[a] Listed as Endangered under the Endangered Species Act.

L.4. Literature Cited

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